NAVIGATING WITH NATURE

How Smarter Ship Routing Delivers Emissions Cuts and Biodiversity Gains

A Route Optimisation Case Study by Whale Seeker and True North Marine in collaboration with the Institute of Marine Engineering, Science and Technology (IMarEST) Marine Mammal Special Interest Group (MMSIG)

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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This report was prepared by Whale Seeker and True North Marine, in collaboration with the Marine Mammal Special Interest Group (MMSIG), a technical group within the Institute of Marine Engineering, Science & Technology (IMarEST).

The MMSIG is composed of subject matter experts from academia, industry, policy, and government who collaborate to advance best practice in marine mammal science, offshore environmental management, and sustainable maritime operations. This case study draws on interdisciplinary expertise to demonstrate how operational route optimisation can deliver simultaneous reductions in greenhouse gas emissions and risks to marine biodiversity.

Acknowledgements

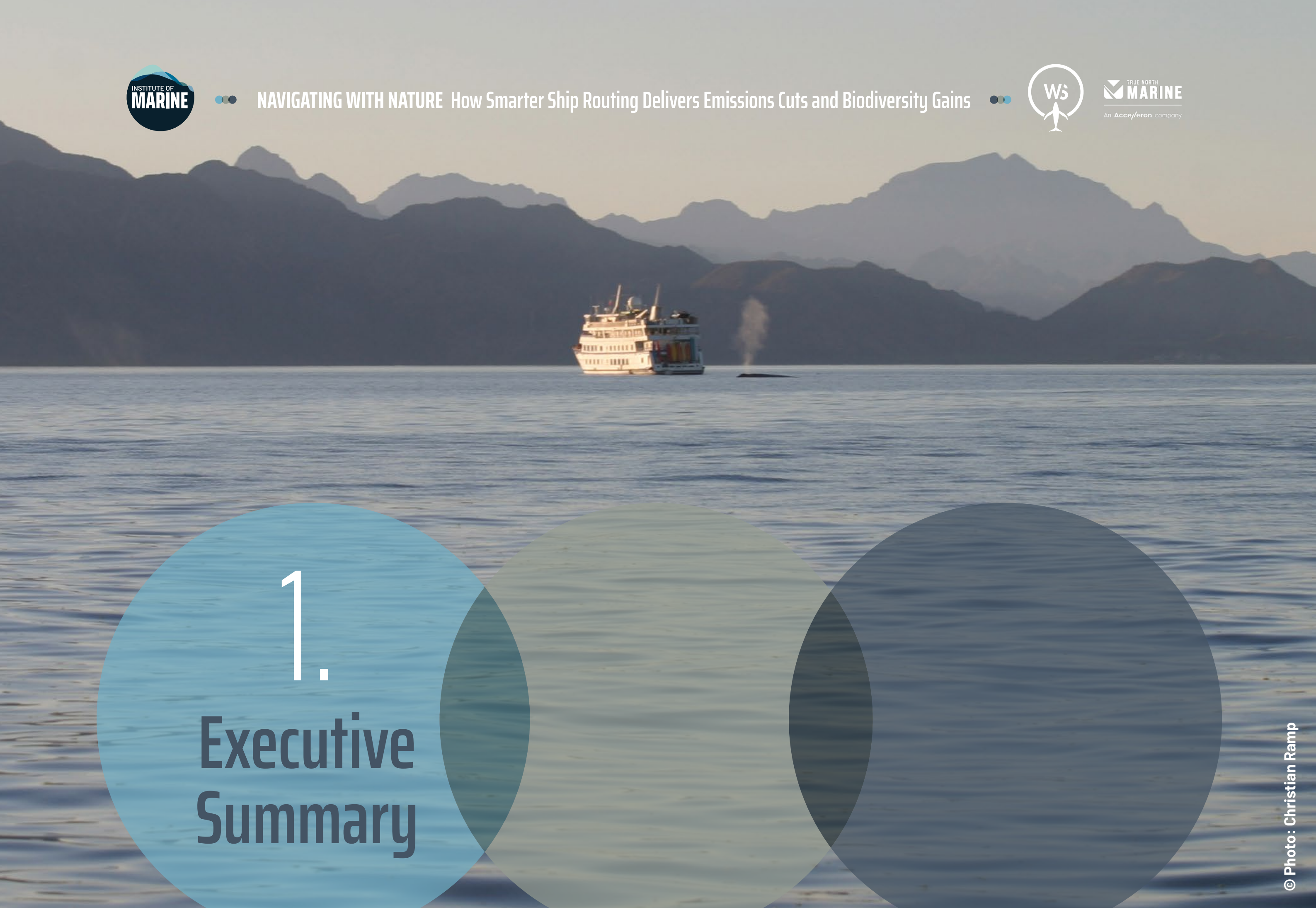
This case study was prepared through collaboration between Whale Seeker, True North Marine, and the Marine Mammal Special Interest Group (MMSIG) of the Institute of Marine Engineering, Science & Technology (IMarEST). The authors acknowledge the substantial contributions of the Supporting Authors, whose expertise was integral to the development of this route optimisation case study.

The authors further acknowledge the technical contributions provided by Whale Seeker and True North Marine, including spatial modelling, ecological advisory input, and final routing analysis that underpin the findings of this case study.

Strategic feedback and professional insight provided by Fürstenberg Maritime Advisory are also gratefully acknowledged, supporting the framing of this work within broader maritime, regulatory, and commercial contexts.

Recommended Citation

Charry Tissier, E., Hatter, B., Noseworthy, A. S., Dorrian, N., Ferguson, E. L., & Kitchiner, A. (2025). *Navigating with nature: How smarter routing delivers emissions cuts and biodiversity gains – A route optimisation case study.* Whale Seeker, True North Marine, and the Institute of Marine Engineering, Science & Technology (IMarEST) Marine Mammal Special Interest Group.



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1. Executive Summary

Maritime transport is one of the most influential drivers of global economic activity, yet it is also a significant contributor to the environmental pressures that characterize what the United Nations refers to as the triple planetary crisis. This crisis includes climate change, biodiversity loss, and pollution, and it poses immediate risks to the health of the world's oceans and the resilience of coastal societies (UNEP, 2023). The international community now recognizes that decarbonization of the maritime sector and protection of marine biodiversity must occur simultaneously rather than sequentially. The commitments adopted at COP30 in Belém in 2025 (UNFCCC, 2025) combined with the International Maritime Organization's 2023 Revised Greenhouse Gas Strategy (IMO, 2023) and the evolving technical standards of the International Hydrographic Organization reinforce the expectation that shipping must contribute actively to climate mitigation and nature recovery while maintaining operational performance.

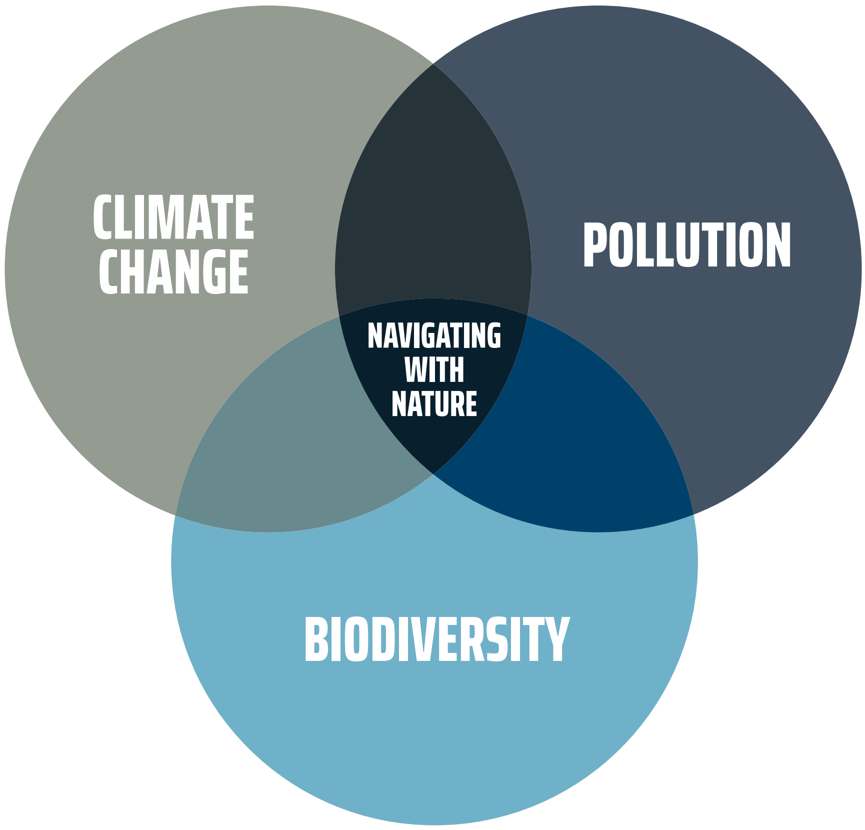
This report presents the findings of an updated 2025 case study led by Whale Seeker, True North Marine, and the Marine Mammal Special Interest Group of the Institute of Marine Engineering, Science and Technology. The study evaluates a nature-integrated routing model for a transatlantic voyage between Montréal, Canada, and Le Havre, France. The model incorporates ecological sensitivity layers, speed optimization, habitat vulnerability indices, and modern routing algorithms to identify operational adjustments that reduce the environmental footprint of shipping while maintaining commercial viability.

The analysis confirms that strategic modifications to speed profiles and routing choices can substantially reduce greenhouse gas emissions, underwater radiated noise, and collision risk with large whales. The modeled nature-integrated route shows a reduction of 61.7 metric tonnes of fuel and approximately 197.8 tonnes of carbon dioxide (CO_2) per voyage. Underwater radiated noise exposure is expected to be reduced by more than half, based on established empirical relationships between vessel speed and underwater acoustic output reported in the scientific literature. In addition, vessel speeds at or below 10 knots in ecologically sensitive areas correspond to an estimated reduction in fatal strike risk of up to ~86 percent based on published speed–lethality relationships (Conn & Silber, 2013).

These operational benefits occur alongside only a modest increase in transit time of 24.9 hours, demonstrating that ecological routing can strengthen environmental performance and voyage economics simultaneously. Under the voyage cost model applied in this study (US$22,000/day hire rate and ISO 8217 fuel price assumptions), the nature-integrated route reduces total fuel consumption by 61.7 tonnes and delivers a net voyage cost reduction of approximately US$19,450 per crossing, even after accounting for the additional 24.9 hours of transit time. This estimate reflects True North Marine's calculation outputs, including the scenario-specific fuel allocation and pricing assumptions used in the model.

The study's conclusions are relevant within the expanding global policy landscape. The COP30 Belém outcomes recognized the importance of integrating biodiversity into climate pathways (UNFCCC, 2025). The Kunming–Montréal Global Biodiversity Framework requires measurable reductions in human-induced mortality of threatened species, including vessel strikes, and requires reductions in pollution, including underwater noise (CBD Secretariat, 2022; CBD Secretariat, 2023). The GBF Monitoring Framework was updated in 2023 to provide specific indicators for evaluating progress. The IMO's MEPC 81 and MEPC 82 sessions in 2024 (IMO, 2024) identify underwater radiated noise and biodiversity protection as emerging areas for regulatory development. The International Hydrographic Organization's S-100 framework supports the integration of ecological information into navigational systems. Together, these frameworks create clear incentives for operational innovations that reduce the environmental footprint of shipping.

This report concludes that nature-integrated routing is a highly scalable, low-cost, and technically mature solution that can be implemented with existing operational capacity. It requires no new vessel hardware, and it delivers measurable benefits across climate, biodiversity, and pollution objectives. Nature-integrated routing can also support compliance with emerging disclosure and reporting frameworks such as the Taskforce on Nature-related Financial Disclosures and the 2025 Global Biodiversity Framework Indicators.



2. Background and Context

Maritime transport remains the backbone of international trade and global economic integration. Approximately 80 percent of all traded goods by volume and more than 70 percent by value are transported by sea (UNCTAD, 2023). The efficiency and scale of maritime shipping make it indispensable to global supply chains. However, these same characteristics contribute significantly to the environmental pressures shaping ocean systems. The United Nations has warned that ocean health is deteriorating at a rapid rate due to rising emissions, habitat degradation, overexploitation, underwater noise, chemical pollution, and cumulative anthropogenic stressors (UNEP, 2021; IPBES, 2019).

2.1 Climate Change and Maritime Emissions

International shipping contributes approximately 3 percent of global greenhouse gas emissions, largely through the combustion of heavy fuel oils used in large commercial vessels (IMO, 2020). If left unmitigated, emissions from this sector could continue to increase as global trade expands. The world's oceans absorb more than 90 percent of excess anthropogenic heat (IPCC, 2023), and the World Meteorological Organization's State of the Global Climate Report identifies ocean warming, sea-level rise, and the intensification of marine heatwaves as significant trends (WMO, 2023). These climate impacts threaten marine species, coastal infrastructure, and socio-ecological systems.

Recognizing these risks, the International Maritime Organization adopted the 2023 Revised Greenhouse Gas Strategy. This strategy includes enhanced checkpoints for reducing emissions by 20 to 30 percent by 2030, by 70 to 80 percent by 2040, and achieving net zero emissions around 2050. The strategy also signals stronger expectations for operational measures that reduce energy consumption, optimize speed, and minimize carbon intensity per transport work. Operational strategies that reduce fuel use, such as nature-integrated routing and Just-in-Time arrival protocols, therefore align with global climate expectations. When applied consistently across fleets and corridors, fuel-saving operational measures such as nature-integrated routing can generate cumulative emissions reductions that materially support achievement of the IMO's 2030 and 2040 checkpoint targets.

2.2 Biodiversity Decline and the Role of Maritime Activity

The rate of biodiversity loss in the world's oceans is accelerating. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services reports that an estimated one million species face extinction risks, many of which are marine (IPBES, 2019). Shipping contributes to biodiversity impacts through multiple pathways, including vessel collisions, underwater noise, pollution, invasive species transfer, and disturbance of sensitive habitats.

Large whales are especially vulnerable to vessel strikes, particularly in regions where shipping lanes intersect with migration corridors, feeding grounds, or nursery areas. For example, the critically endangered North Atlantic right whale population is estimated to have been approximately ~370 individuals in 2023, and vessel collisions remain a leading cause of documented injury and mortality (NOAA Fisheries, 2024; DFO, 2023). Other baleen whale species—including blue and fin whales—also face elevated strike risk along major shipping routes, particularly where vessel traffic intersects productive feeding grounds and seasonal movement corridors. In the Pacific, gray whales (Eschrichtius robustus) represent another important example of strike vulnerability because their migratory and feeding behaviours are strongly nearshore, resulting in sustained overlap with coastal vessel traffic. A century-scale assessment of documented injuries and mortalities in the North Pacific (1924–2024) highlights that vessel strikes and entanglements continue to represent significant sources of non-hunting, human-caused harm for gray whales, underscoring the relevance of risk-mitigation measures in major Pacific shipping corridors as well as in the North Atlantic (Scordino et al., 2020). These mortality events constrain population recovery and undermine international biodiversity objectives, particularly for species with slow reproduction and strong site fidelity.

Underwater radiated noise is another significant pressure associated with maritime activity. Low frequency noise from commercial vessels overlaps with the communication ranges of many marine species. Global syntheses and UN technical guidance have shown that chronic anthropogenic underwater noise can disrupt navigation, feeding, communication, social behaviours, and stress responses in marine mammals and other taxa (Duarte et al., 2021; CMS, 2023). The International Maritime Organization has acknowledged underwater noise as an emerging area for regulatory attention. The MEPC 81 and MEPC 82 sessions in 2024 emphasized the need for operational measures that reduce noise intensity, including speed management and routing in low sensitivity areas.

2.3 Pollution and Ocean Health

Maritime operations introduce multiple types of pollutants into the ocean. These include lubricants, oil residues, particulate matter, nitrogen oxides, sulfur oxides, microplastics from coatings, and chemical runoff. Pollution also includes noise, which is now recognized as a form of energy pollution with demonstrable impacts on marine ecosystems (UNEP, 2021; IMO, 2021). These combined pressures reduce ecosystem resilience and exacerbate climate-related impacts. Poor ocean health limits the capacity of marine ecosystems to store carbon, support fisheries, and maintain biodiversity. For shipping companies, these degradations can contribute to economic risks, including disruptions to port operations, supply chain instability, and reputational concerns.

2.4 Evolving International Policy Environment

The international policy landscape governing shipping and ocean conservation has changed significantly in recent years. Commitments advanced during COP30 in Belém in 2025 reinforced the integration of nature-based solutions, climate mitigation, and biodiversity protection within global climate efforts (UNFCCC, 2025). COP30 outcomes emphasized reducing underwater noise, addressing human-induced mortality of marine mammals, and incorporating ecological considerations into maritime decarbonization pathways.

In parallel, the Convention on Biological Diversity continues to advance the implementation of the Kunming-Montréal Global Biodiversity Framework. The GBF Monitoring Framework, adopted in 2023, introduced specific metrics for measuring reductions in human pressures on marine species (CBD Secretariat, 2023). These include indicators for vessel-strike mortality, underwater noise exposure, and the protection of ecologically significant areas. These indicators are expected to inform national reporting and influence expectations for private-sector disclosure under the Taskforce on Nature-related Financial Disclosures (TNFD, 2023).

Technical standards are also undergoing transformation. The International Hydrographic Organization is modernizing digital navigation through the S-100 Universal Hydrographic Data Model (IHO, 2022). The S-102 data layer provides high-resolution bathymetry, and additional environmental layers under development will facilitate the integration of ecological information directly into navigational charts. This creates opportunities for voyage-planning tools to incorporate environmental sensitivity into routing decisions.

2.5 Rationale for Nature-Integrated Routing

Nature-integrated routing refers to the incorporation of ecological sensitivity data, speed management principles, and spatial risk modelling into voyage planning. This approach reduces the environmental footprint of shipping by minimizing exposure to vulnerable habitats and species. It is an operational measure that can be implemented immediately because it relies on existing navigational capabilities and does not require new vessel technology or modifications.

This report examines a transatlantic case study that applies nature-integrated routing for a Montréal to Le Havre voyage. The analysis provides evidence that operational efficiency and environmental protection are not mutually exclusive objectives. Instead, they can be mutually reinforcing when routing decisions are informed by ecological science and global policy frameworks. The findings contribute to the growing body of evidence supporting nature positive operational practices within the maritime sector.

2.6 Scientific and Systems Context: Why Shipping Decisions Matter

Climate change and biodiversity loss are increasingly understood as interconnected pressures acting on the ocean as a single system. The world's oceans absorb more than 90 percent of the excess heat generated by anthropogenic greenhouse gas emissions (IPCC, 2023). As a result, ocean warming is accelerating, marine heatwaves are becoming more frequent and intense, and sea levels are rising. These trends are documented in the World Meteorological Organization's State of the Global Climate Report (WMO, 2023). Together, they are reshaping marine habitats and the ecological conditions that support biodiversity.

Ocean warming alters the distribution of prey, weakens nutrient cycling through changes in vertical mixing, and influences dissolved oxygen dynamics. These changes can shift where marine mammals feed, migrate, and aggregate, sometimes bringing them into closer overlap with shipping corridors. In the North Atlantic, for example, climate driven changes in copepod availability have contributed to shifts in North Atlantic right whale distribution, increasing the likelihood that whales occur in areas with higher vessel density (NOAA Fisheries, 2023). In this way, climate change not only affects the ocean directly, but also amplifies the risk of harmful interactions between marine megafauna and maritime activity.

At the same time, the global rate of biodiversity loss continues to accelerate. The Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services estimates that roughly one million species face extinction risk, many of which are marine (IPBES, 2019). This decline matters not only in ecological terms, but also because marine biodiversity underpins ecosystem services that support climate regulation and human well being, including carbon sequestration, nutrient cycling, fisheries productivity, and coastal protection. IPBES identifies coastal and ocean biodiversity among the most threatened on the planet, driven by habitat degradation, climate change, pollution, and direct mortality from human activities (IPBES, 2019).

These system level dynamics are directly relevant to the maritime sector. Shipping contributes to ocean pressure through greenhouse gas emissions, underwater radiated noise, pollution, and direct mortality events such as vessel strikes. Underwater noise and other cumulative stressors reduce ecosystem resilience and contribute to broader ocean deterioration (UNEP, 2021). This reinforces the scientific and policy consensus that climate mitigation and biodiversity conservation must be addressed simultaneously and through integrated approaches in ocean industries (IPBES, 2019; UNEP, 2021).

In this context, operational measures that reduce both emissions and ecological risk represent an immediate and high leverage opportunity. Nature-integrated routing responds to these interconnected challenges by embedding ecological sensitivity into voyage planning and speed management. The next section summarizes how international climate, biodiversity, and maritime governance frameworks are evolving in ways that increasingly support integrated, nature aligned operational practices in shipping.

3. Global Policy Environment

The interconnected pressures of climate change, biodiversity loss, and pollution are increasingly shaping how the international community evaluates the environmental performance of maritime transport. As outlined in Section 2.6, these pressures are not isolated. They interact through ocean warming, shifting species distributions, cumulative stressors such as underwater radiated noise, and persistent risks of direct mortality events such as vessel strikes (IPCC, 2023; IPBES, 2019; UNEP, 2021). In response, global governance frameworks are evolving toward a shared expectation that shipping must reduce greenhouse gas emissions while also minimizing impacts on marine biodiversity and ocean health.

This shift is visible across multiple international institutions and policy domains, including the United Nations Framework Convention on Climate Change, the International Maritime Organization, the Convention on Biological Diversity, and the International Hydrographic Organization. Together, these frameworks increasingly support operational measures that deliver measurable co benefits across climate mitigation, biodiversity protection, and pollution reduction. The following sections summarize the most relevant global policy developments that shape the strategic and regulatory context for nature-integrated routing.

3.1 United Nations Framework Convention on Climate Change and COP30

COP30, held in Belém in 2025, marked a significant advancement in the treatment of ocean issues within global climate negotiations. COP30 outcomes emphasized the scaling of ocean-based climate solutions, improved protection of marine ecosystems, and the integration of biodiversity considerations into maritime decarbonization pathways (UNFCCC, 2025). For the first time, Parties acknowledged underwater noise, vessel-strike mortality, and other operational pressures from maritime transport as relevant to climate resilience and nature-based mitigation.

The COP30 Ocean Action Track emphasized the importance of reducing climate-forcing emissions from international shipping. It also emphasized the role of nature-positive operational practices, including speed management and ecologically informed routing, in both mitigation and adaptation strategies. These outcomes align with scientific findings from the UN Ocean Decade and the UN Ocean Science Synthesis Report, which highlight that ecological degradation reduces the capacity of the ocean to absorb carbon dioxide, regulate temperature, and maintain fisheries productivity (UNESCO-IOC, 2021–2024; IPCC, 2023). References to COP30 outcomes in this report reflect publicly available UNFCCC summary documents and are intended to illustrate policy direction rather than impose binding regulatory interpretation.

3.2 International Maritime Organization: GHG Strategy and Marine Environment Protection Committee

The International Maritime Organization remains the central regulatory authority for the environmental performance of international shipping. The organization adopted its Revised Greenhouse Gas Strategy in 2023, introducing strengthened checkpoints for reducing emissions by 20 to 30 percent by 2030, by 70 to 80 percent by 2040, and achieving net-zero emissions around 2050 (IMO, 2023). These targets will shape regulatory measures across the coming decade, including carbon pricing, fuel standards, and operational efficiency requirements.

The IMO also addresses biodiversity and pollution concerns through the Marine Environment Protection Committee. In 2023 and 2024, MEPC 81 and MEPC 82 recognized underwater radiated noise as a significant and increasing stressor on marine ecosystems (IMO, 2024). The Committee encouraged the adoption of operational noise-reduction measures, including speed adjustments and routing away from sensitive habitats. These sessions also acknowledged the need to reduce human-induced mortality of marine mammals through improved route planning and vessel operations.

The growing recognition of operational contributions to biodiversity impacts suggests that future IMO guidance may explicitly integrate ecological sensitivity into navigational practices. The IMO's Revised Guidelines for the Reduction of Underwater Noise from Commercial Shipping reaffirm that speed and routing adjustments are among the most effective mitigation measures (IMO, 2021).

3.3 Convention on Biological Diversity and the Kunming Montréal Global Biodiversity Framework

In parallel with climate negotiations, the Convention on Biological Diversity has established a comprehensive framework for global biodiversity protection. The Kunming–Montréal Global Biodiversity Framework, adopted in 2022, identifies 23 targets and 2030 goals aimed at reversing biodiversity decline (CBD Secretariat, 2022). The GBF Monitoring Framework, adopted in 2023, introduces metrics directly relevant to maritime shipping, including reductions in underwater noise exposure, decreases in vessel-strike mortality of threatened marine mammals, conservation of ecologically significant marine areas, and reductions in pollution affecting marine species (CBD Secretariat, 2023).

Target 7 of the GBF focuses on reducing anthropogenic threats to biodiversity, including pollution, noise, and human-induced mortality from economic activities. Target 9 focuses on ensuring sustainable and resilient management of marine ecosystems. Nature-integrated routing aligns with these objectives because it reduces collision risk, lowers acoustic disturbance, and avoids ecologically sensitive areas.

The CBD also advances the concept of nature-positive action, which seeks to ensure that economic activity contributes to ecosystem recovery rather than simply minimizing harm. The routing techniques evaluated in this case study represent an example of an operational nature-positive practice because they provide quantifiable reductions in human-induced mortality risk and noise exposure.

3.4 International Hydrographic Organization and the S-100 Framework

Digital navigation standards are being modernized by the International Hydrographic Organization. The S-100 Universal Hydrographic Data Model is a comprehensive framework for the integration of bathymetry, tides, marine hazards, and environmental layers into electronic navigational charts. The S-102 product specification provides high resolution bathymetry with improved accuracy for safe navigation. Additional S-100 compliant data layers under development include dynamic environmental datasets, oceanographic variables, and eventually ecological sensitivity layers (IHO, 2022).

The incorporation of environmental data into navigational systems creates opportunities for voyage planning tools to support nature-integrated routing. Routing software can use S-102 bathymetric data in combination with environmental sensitivity layers to avoid shallow feeding grounds, seamounts, and other ecologically significant areas. The IHO's modernization of hydrographic standards therefore provides a strong foundation for operational practices that integrate safety, efficiency, and biodiversity protection.

3.5 Taskforce on Nature-Related Financial Disclosures and Corporate Governance Trends

Private-sector governance standards are evolving rapidly. The Taskforce on Nature-Related Financial Disclosures recommends that companies identify, assess, and disclose their nature-related risks and impacts (TNFD, 2023). For maritime operators, these include vessel-strike mortality, underwater noise emissions, pollution, and interactions with sensitive marine habitats. The TNFD framework aligns closely with the Global Biodiversity Framework Indicators.

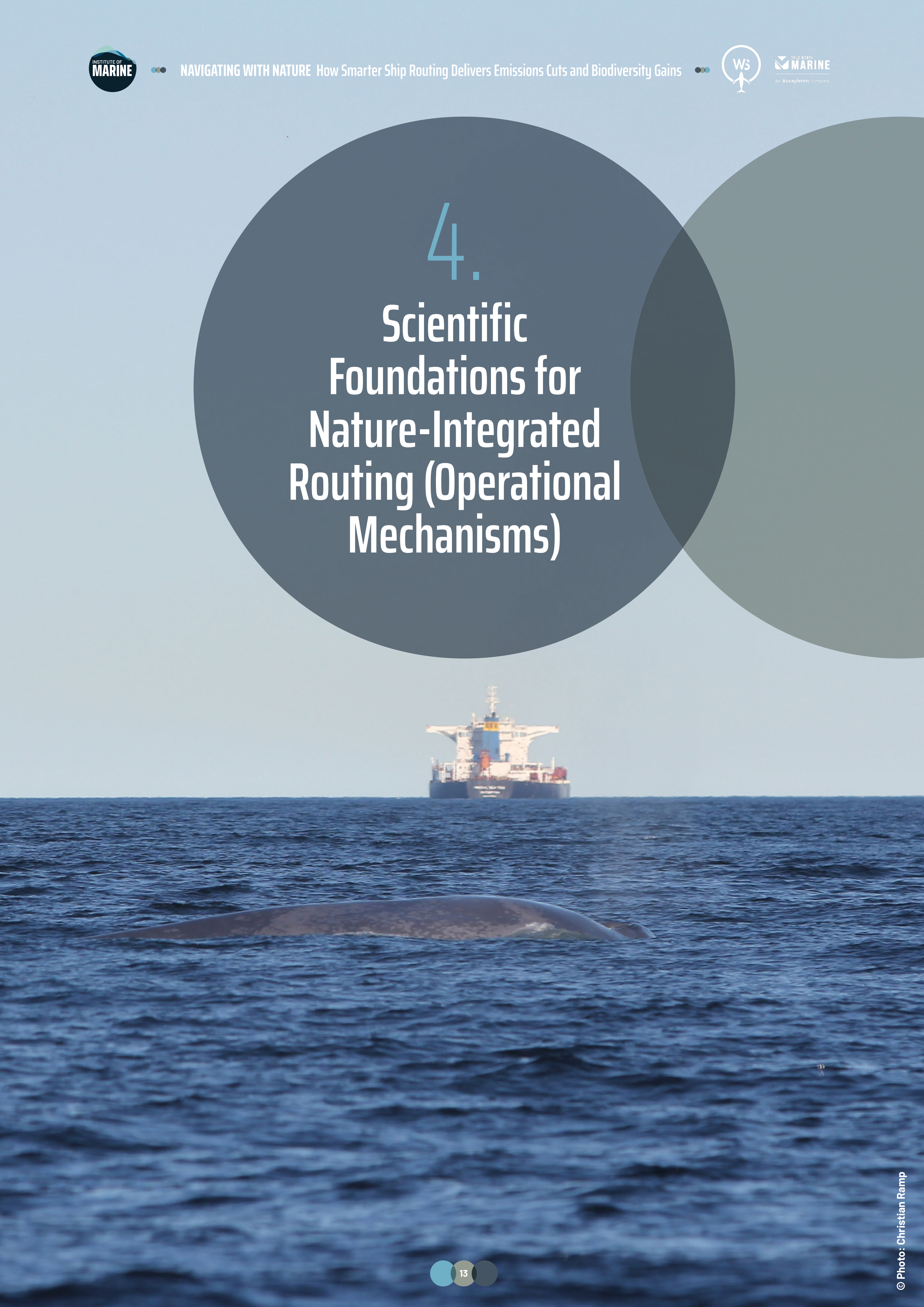
Shipping companies and cargo owners are also subject to sustainability frameworks such as the Poseidon Principles and the Sea Cargo Charter, which currently focus on transparent reporting of climate alignment (Poseidon Principles, 2019; Sea Cargo Charter, 2020). As biodiversity metrics become increasingly integrated into sustainability assessments, operational measures such as nature-integrated routing will likely be recognized as verifiable contributions to nature-related risk mitigation.

3.6 Regional and National Requirements

Several national and regional authorities have already implemented mandatory or voluntary speed restrictions and dynamic management areas for marine-mammal protection. Examples include the United States National Oceanic and Atmospheric Administration (NOAA Fisheries, 2023), Transport Canada (Transport Canada, 2023), the International Association of Antarctica Tour Operators (IAATO, 2024), and regional port authorities in Europe and the South Pacific. These measures demonstrate growing regulatory willingness to restrict vessel operations in ecologically sensitive zones.

The policy environment is therefore shifting toward regulatory expectations that vessels operate in ways that reduce both climate and biodiversity impacts. The evidence presented in this report supports the conclusion that nature-integrated routing is well aligned with the evolving international policy environment and provides a feasible path for compliance with emerging climate and biodiversity disclosure requirements.

4. Scientific Foundations for Nature-Integrated Routing (Operational Mechanisms)



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Understanding the environmental and operational benefits of nature-integrated routing requires a clear review of the scientific evidence concerning vessel operations, species vulnerability, underwater radiated noise pollution, and spatial overlap between shipping and sensitive habitats. The scientific foundations summarized here explain why operational decisions made by commercial vessels, particularly speed and routing choices, have direct implications for fuel use, emissions intensity, collision risk, and acoustic disturbance. This evidence base has shaped guidance from the IMO, CMS, CBD, UNEP, and other authoritative bodies, and underpins the operational logic of the case study evaluated in this report (IMO, 2021; UNEP, 2021; CBD Secretariat, 2022; CMS, 2023).

4.1 Marine Biodiversity and Ecological Sensitivity

Marine species vulnerability is not evenly distributed across the ocean. The concept of ecological sensitivity refers to areas with heightened biological importance and elevated vulnerability to disturbance. The International Union for Conservation of Nature identifies Important Marine Mammal Areas as key habitats essential for marine mammal survival. These include feeding grounds, breeding areas, migratory corridors, and regions of predictable seasonal aggregation (IUCN Marine Mammal Protected Areas Task Force, 2021). Disturbance or mortality within these areas can have disproportionate impacts on population viability, particularly for long lived species such as baleen whales.

Ecological sensitivity is also influenced by species traits. Large whales are especially vulnerable to vessel strikes due to their surface feeding behaviour, slow movement patterns, and sustained overlap with commercial shipping routes. Many species communicate through low frequency vocalizations that can be masked by vessel noise. Species with low reproductive rates, such as the North Atlantic right whale, are particularly vulnerable because even a small increase in anthropogenic mortality can offset conservation gains (NOAA Fisheries, 2023). These characteristics justify integrating recognized ecological sensitivity datasets into operational routing decisions.

4.2 Vessel Strike Mortality: Mechanisms and Risk Dynamics

Vessel strikes occur when marine mammals and vessels occupy the same space at the same time. These events are often fatal, and risk is shaped by vessel speed, vessel size, limited manoeuvrability, whale behaviour, and environmental conditions such as sea state and visibility. The ability of whales to avoid vessels declines sharply at higher speeds, and many large vessels have reduced capacity to detect marine mammals at the surface and alter course in time to prevent collision.

Conn and Silber (2013) demonstrated that the probability of fatality increases sharply when vessel speeds exceed 10 knots. Subsequent research has confirmed this relationship across species and regions. The risk is not only a function of speed, but also vessel size, hull form, and the depth and acoustic environment in which interactions occur. Large container vessels pose elevated risks due to their mass, limited manoeuvrability, and reduced ability to detect marine mammals at the surface. Behavioural responses vary by species and individual condition, and some whales may be slow to respond to approaching vessels depending on foraging, resting, or social behaviour.

The North Atlantic right whale illustrates the consequences of vessel strikes. The population has not recovered despite decades of management measures, in part because vessel collisions remain a consistent source of mortality. Right whales spend significant time near the surface during feeding and socializing and occupy areas of high vessel density such as the Gulf of St. Lawrence and the eastern seaboard of the United States and Canada. NOAA Fisheries reports that vessel strike mortality is a leading cause of right whale deaths, often evidenced by blunt force trauma and propeller lacerations (NOAA Fisheries, 2023). Reducing vessel speed in high risk areas is therefore one of the most effective and scientifically validated methods of preventing fatal collisions, forming the basis for speed management zones and operational mitigation measures in several jurisdictions.

4.3 Underwater Radiated Noise as a Form of Pollution

Underwater radiated noise is generated by propeller cavitation, engine operations, and hull hydrodynamics. It propagates over large distances, particularly at the low frequencies used by many marine mammals for communication and navigation. Chronic noise pollution can disrupt behaviour, reduce communication range, interfere with feeding and reproduction, and increase stress responses in marine mammals and other taxa (Erbe et al., 2019; Duarte et al., 2021).

Underwater radiated noise from large commercial vessels is driven primarily by propeller cavitation and hydrodynamic flow, with additional contributions from machinery and hull vibration. Cavitation noise often dominates at operational speeds and is highly sensitive to small changes in propeller loading. Because propeller loading increases rapidly with speed, slowing down can reduce both broadband noise levels and the spatial footprint of acoustic disturbance. This relationship is one of the reasons speed management is repeatedly identified in IMO guidance as a practical and immediately available mitigation measure, alongside longer term measures such as vessel design improvements and maintenance practices (IMO, 2021; Leaper & Renilson, 2012; Smith & Rigby, 2022).

The International Maritime Organization has issued guidance on reducing underwater noise from commercial shipping and has reaffirmed that operational measures, including speed management and route planning, are among the most effective mitigation measures available (IMO, 2021). Scientific literature consistently demonstrates that underwater noise intensity decreases at lower vessel speeds. Leaper and Renilson (2012) and Smith and Rigby (2022) highlight that even moderate reductions in vessel speed can meaningfully reduce acoustic energy output. These findings support the inclusion of reduced speed zones in ecologically sensitive habitats as a practical method of lowering noise exposure.

4.4 Spatial Overlap Between Shipping and Sensitive Habitats

Shipping density maps show that global trade routes intersect numerous ecologically significant areas. Many Important Marine Mammal Areas overlap with major transboundary shipping lanes. The IUCN Marine Mammal Protected Areas Task Force provides spatial data on IMMA boundaries that demonstrate this overlap clearly (IUCN Marine Mammal Protected Areas Task Force, 2021). Spatial risk is amplified where ecological resources concentrate species within narrow corridors, and where vessel traffic is persistent and high intensity.

Routes between Montréal and Le Havre cross regions that support fin whales, humpback whales, and porpoises. These include feeding zones, migratory pathways, and areas where multiple species aggregate seasonally. Risk can also be elevated in regions where water depth is shallow or where ecological conditions concentrate marine mammals closer to the surface. Nature-integrated routing seeks to reduce the intensity of vessel impacts in these areas by lowering speeds, reducing acoustic output, and decreasing the probability of lethal collisions in segments identified as ecologically sensitive.

4.5 Justification for Integrated Operational Measures

Scientific consensus supports the conclusion that speed reduction and ecologically informed routing are among the most effective, immediate, and scalable solutions available to reduce biodiversity impacts from shipping. These measures require no technological retrofitting and can be implemented using existing navigational tools and operational procedures. They also yield climate mitigation benefits by reducing fuel consumption and carbon intensity, driven by the cubic relationship between vessel speed and engine power demand (EMSA, 2022; IMO, 2023). When applied strategically in sensitive habitats, speed reduction can simultaneously lower fuel burn, reduce CO_2 emissions, reduce underwater noise output, and decrease the probability of fatal vessel strikes.

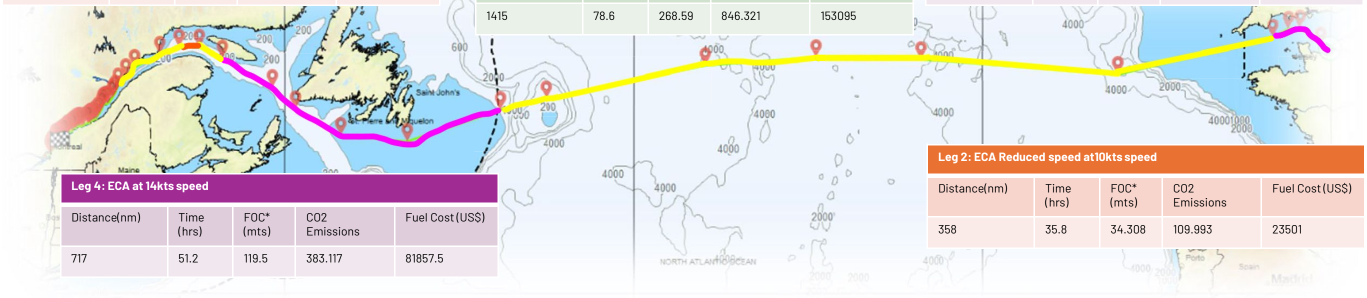
Nature-integrated routing therefore represents an operational measure that aligns with scientific evidence, global policy direction, and emerging sustainability expectations. It provides co benefits across emissions mitigation, biodiversity conservation, and pollution reduction. The next sections describe the global policy environment relevant to these outcomes and the methodology used to model these benefits in the Montréal to Le Havre case study.

5. Methodology

Leg 5: ECA Reduced speed at10kts speed				
Distance(nm)	Time (hrs)	FOC* (mts)	CO2 Emissions	Fuel Cost (US$)
513	51.3	49.163	157.615	33676.3

Leg 3: Open sea at 18kts speed				
Distance(nm)	Time (hrs)	FOC (mts)	CO2 Emissions	Fuel Cost (US$)
1415	78.6	268.59	846.321	153095

Leg 1: ECA at 14kts speed				
Distance(nm)	Time (hrs)	FOC* (mts)	CO2 Emissions	Fuel Cost (US$)
145	10.4	24.167	77.478	16554



Leg 4: ECA at 14kts speed				
Distance(nm)	Time (hrs)	FOC* (mts)	CO2 Emissions	Fuel Cost (US$)
717	51.2	119.5	383.117	81857.5

Leg 2: ECA Reduced speed at10kts speed				
Distance(nm)	Time (hrs)	FOC* (mts)	CO2 Emissions	Fuel Cost (US$)
358	35.8	34.308	109.993	23501

Notes

- Orange leg passes through whale habitat where vessel will be on reduced speed to mitigate striking
- Speed/consumption profile (Panamax): 10kts at 23mts/day// 14kts on 56mts/day //18kts on 82mts/day
- ECA Fuel Type : ISO 8217 grades DMX through DMB Cf = 3.206 (t-CO_2/t- Fuel), Av Cost US$ 685/mt
- Non ECA Fuel Type: ISO 8217 grades RMA through RMD Cf=3.151 (t-CO_2/t- Fuel), Av Cost US$ 570/mt
- *FOC: Fuel Oil Consumption (mts)
- Total Voyage Distance = 3148 nm

Figure 1. Map representing the nature-integrated routing between Le Havre and Montréal, detailing speed, distance, travel time, fuel oil consumption (FOC), CO_2 emissions, and fuel usage per leg.

This section describes the analytical approach used in the Montréal to Le Havre routing case study. The methods outlined here reflect exactly what was undertaken in the original analysis. No additional modeling techniques, assumptions, or datasets have been added. The objective was to compare two realistic operational routing scenarios using the same vessel class, the same overall voyage distance, and the same environmental reference layers, with only speed adjustments differentiating the scenarios. The analysis relied on established relationships from the peer-reviewed literature to interpret how changes in speed influence whale strike risk and underwater radiated noise (Conn & Silber, 2013; Leaper & Renilson, 2012; Smith & Rigby, 2022).

5.1 Overview of Analytical Framework

The analytical framework consisted of four components:

1. Route scenario design for a Montréal to Le Havre crossing.
2. Fuel consumption and emissions estimation using a cubic speed to power function.
3. Application of a Spatial Habitat Vulnerability Layer to determine reduced speed zones.
4. Interpretation of operational outputs using established scientific relationships regarding vessel speed, whale strike probability, and underwater radiated noise.

These four components formed a coherent and internally consistent methodology for evaluating the operational and environmental performance of each scenario.

5.2 Route Scenarios

Two routing scenarios were evaluated. Both scenarios followed the same fixed corridor spanning 3,148 nautical miles between Montréal and Le Havre. Routing calculations were performed under ideal weather conditions, meaning meteorological variability was intentionally excluded so that differences between scenarios could be attributed solely to routing strategy and speed profile. Nature-integrated routing is defined here as the integration of ecological sensitivity into route planning decisions, which includes speed profile optimization along a fixed navigational corridor.

Scenario A (Regular Routing) used conventional commercial speeds and a direct routing typical of standard container vessel operations in the North Atlantic.

Scenario B (Nature-Integrated Routing) used the same route corridor and distance but applied reduced speeds in ecologically sensitive areas identified by the Spatial Habitat Vulnerability Layer.

No dynamic rerouting, real-time adjustments, or weather routing algorithms were used. The objective was a controlled comparison between a conventional voyage and one informed by ecological sensitivity.

5.3 Vessel Class and Operational Parameters

The study used a Panamax class container vessel of approximately 5,000 TEU. This vessel class is representative of commercial tonnage operating on North Atlantic routes. The following operational parameters were applied exactly as documented:

- Daily charter rate of USD 22,000.
- Fuel types consistent with ISO 8217 classifications for both ECA and non-ECA regions.
- Carbon factor (Cf) coefficients from the IMO, expressed as tonnes of CO_2 per tonne of fuel (IMO, 2020).

Hydrodynamic behavior modeled using a cubic speed to power relationship, the standard method for large commercial vessels (EMSA, 2022).

Three reference fuel consumption points were used:

- 23 metric tonnes per day at 10 knots
- 56 metric tonnes per day at 14 knots
- 82 metric tonnes per day at 18 knots

These values were applied to compute segment specific fuel use and voyage totals. The fuel curve values used here represent standard characteristics of Panamax-class container vessels, consistent with EMSA and IMO reference curves, and are therefore indicative rather than vessel-specific.

The methodology does not attempt to model a specific vessel by name. It uses industry standard representative values for vessels of this class, which is appropriate for scenario based comparisons.

5.4 Fuel Consumption, Cost, and Emissions Calculation

Fuel consumption was calculated for each route segment based on the time spent at each speed. The cubic speed to power curve supplied the fuel use per hour.

Fuel types and costs were applied according to regional rules:

- Emission Control Area (ECA) fuel modeled as DMX to DMB grades, with a cost of USD 685 per tonne and a carbon factor of 3.206 t CO_2 per tonne of fuel.
- Non ECA fuel modeled as RMA to RMD grades, with a cost of USD 570 per tonne and a carbon factor of 3.151t CO_2 per tonne of fuel.

For each scenario, the total fuel cost was the sum of:

- Fuel consumption per region multiplied by price; plus
- Daily charter cost multiplied by total days of transit.

Total carbon dioxide emissions were computed directly from fuel consumption multiplied by the IMO carbon factor relevant to each fuel grade (IMO, 2020).

5.5 Spatial Habitat Vulnerability Layer

The Spatial Habitat Vulnerability Layer (SHVL) was the environmental foundation of the nature-integrated scenario. It was created by combining only two datasets, exactly as documented:

- IUCN Important Marine Mammal Areas (IMMA) GIS dataset (IUCN Marine Mammal Protected Areas Task Force, 2021).
- OSPAR Marine Protected Areas (MPA) GIS database (OSPAR Commission, 2023).

No additional species distribution models or environmental datasets were used.

The SHVL identified zones where ecological sensitivity is elevated due to the presence of marine mammal habitats or legally and internationally recognized conservation areas.

In the nature-integrated scenario, the SHVL determined where vessel speeds were reduced. No avoidance routing or spatial displacement of the corridor was applied beyond these speed adjustments.

5.6 Speed Reductions in Sensitive Habitat Areas

Speed reductions were applied in the nature-integrated scenario according to the SHVL:

- In IMMA or MPA designated zones, vessel speed was reduced to 10 knots.

This threshold is justified in the original case study using peer reviewed literature showing that speeds of 10 knots or less reduce fatal strike probability by up to 86 percent for large whales (Conn & Silber, 2013).
Outside sensitive areas, the vessel resumed its baseline operational speed as defined in the regular scenario.

No alternative speed profiles were evaluated. No adaptive speed control, dynamic management zones, or temporal adjustments were implemented.

5.7 Interpretive Use of Published Science on Whale Strikes and Underwater Noise

The study did not implement new quantitative models of whale strike risk or underwater noise. Instead, it interpreted operational outputs using established relationships from the scientific literature, specifically:

- Whale strike probability as a function of vessel speed, based on Conn and Silber (2013).
- Underwater radiated noise reduction associated with lower speeds, based on Leaper and Renilson (2012) and Smith and Rigby (2022).

This study intentionally avoids introducing new ecological or acoustic models to ensure comparability and methodological clarity, relying instead on internationally accepted empirical relationships widely used in policy and regulatory contexts.

These relationships were applied qualitatively to interpret how speed reductions in the nature-integrated scenario would be expected to influence risk levels.

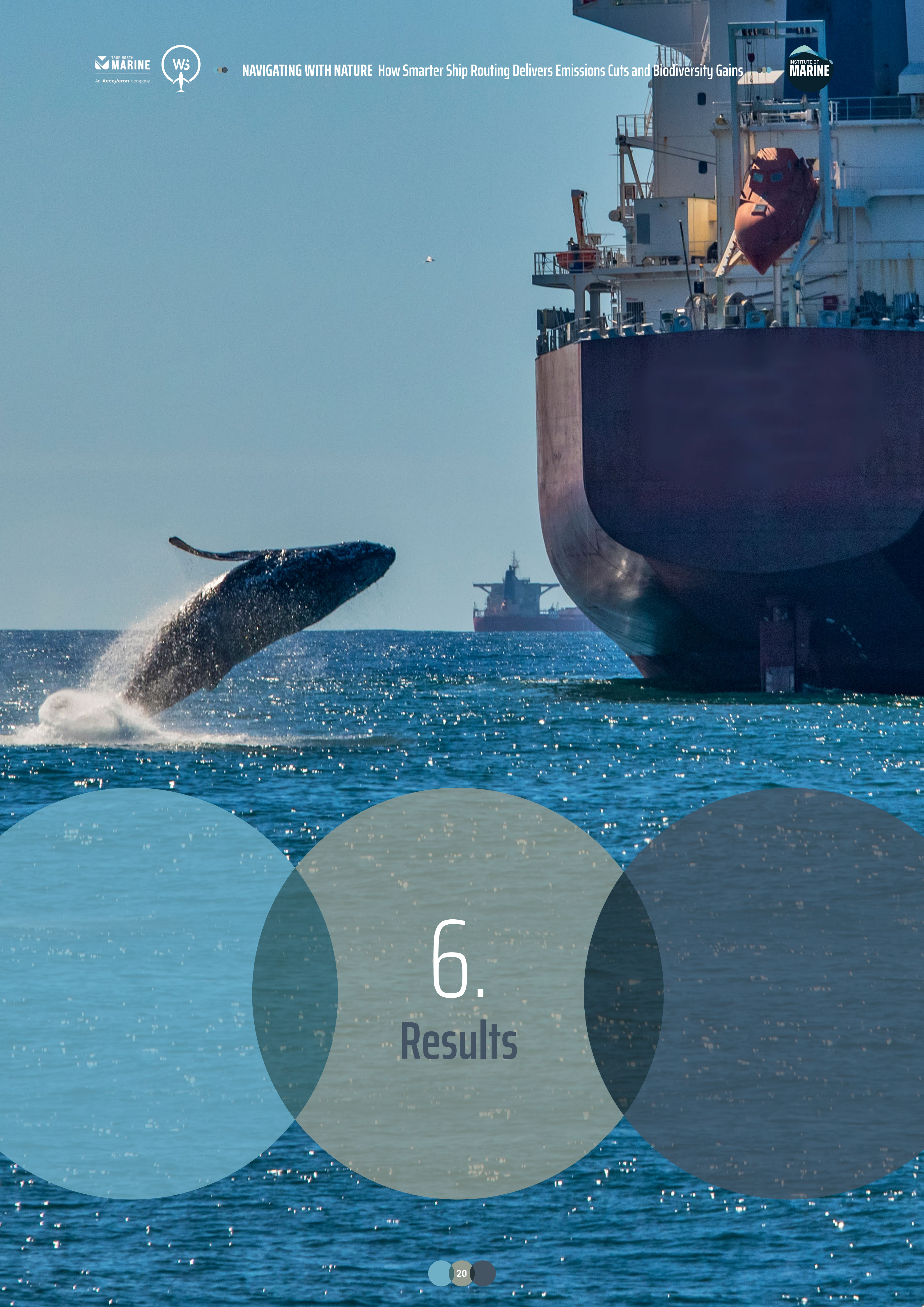
The methodology does not include acoustic propagation modeling, species specific risk calculations, or hydrodynamic noise simulations.

5.8 Comparison of Scenarios

The final step in the methodology was a direct comparison between Scenario A and Scenario B across the following indicators:

- Total voyage time
- Total fuel oil consumption (FOC)
- Total CO_2 emissions
- Total fuel cost
- Total voyage cost
- Change in whale strike risk inferred from vessel speed
- Change in underwater noise exposure inferred from vessel speed

Because the route distance, corridor, and environmental datasets were identical in both scenarios, differences in results can be attributed to speed profile changes driven solely by ecological sensitivity identified through the SHVL.



6. Results

METRIC	PER VOYAGE	ANNUALISED (52 VOYAGES)
Fuel Saved	61.7 metric tons	3,208 metric tons
CO_2 Avoided	197.8 metric tons	10,285.6 metric tons
Fuel Cost Reduction	$42,261 USD	$2.2 million USD

Figure 2. Quantified operational, environmental, and financial benefits of nature-integrated routing per voyage and annualised across 52 voyages, demonstrating fuel savings, avoided CO_2 emissions, and reduced fuel expenditures.

The comparison of the two routing scenarios demonstrates that nature-integrated routing produces meaningful environmental and operational benefits despite a modest increase in total transit time. All numerical values reported in this section correspond directly to the outputs in the original case study. All fuel, CO_2, and cost values reported in this paper reproduce the original True North Marine calculation outputs for this case study, including the scenario-specific fuel allocation and pricing assumptions applied in the model.

6.1 Voyage Time

The nature-integrated route resulted in a longer transit time of 24.9 hours compared to the regular routing scenario. This increase is the direct result of reducing vessel speed in ecologically sensitive IMMA and MPA segments. No additional distance was added to the voyage, and no rerouting outside the primary corridor occurred. The entire difference in transit time is therefore attributable to responsible speed management designed to lower ecological impact.

6.2 Fuel Consumption

Despite taking longer, the nature-integrated scenario reduced total fuel oil consumption (FOC) due to the cubic relationship between speed and engine power demand (EMSA, 2022). Specifically, total fuel consumption decreased from 557.4 tonnes to 495.7 tonnes, a reduction of 61.7 tonnes per voyage.

From the documented vessel fuel curve and time-at-speed calculations, the study shows that reducing speed in defined segments results in lower total fuel use across the full 3,148-nautical-mile voyage.

This outcome confirms a key operational finding: Slower speeds in selected zones reduce instantaneous fuel burn enough to offset the increased voyage duration.

6.3 Carbon Dioxide Emissions

Because carbon emissions were calculated using IMO Cf coefficients for ECA and non-ECA fuels (IMO, 2020), reduced fuel consumption produced a corresponding drop in CO_2 output. Using the IMO carbon factors applied in the True North Marine calculation outputs (ECA and non-ECA fuel grades), the modeled reduction is 197.8 tonnes of CO_2 per crossing.

The study concludes that the nature-integrated scenario in this case study emits significantly less CO_2 than the regular routing scenario.

These emissions reductions directly support:

- IMO 2023 Revised GHG Strategy checkpoints (IMO, 2023)
- EU ETS maritime compliance
- Corporate carbon-insetting and ESG reporting
- COP30 ocean-climate commitments (UNFCCC, 2025)

Importantly, these reductions are achieved through operational practice alone, requiring no fuel switching or technological retrofit.

6.4 Fuel and Voyage Costs

The study demonstrates that total fuel costs decrease in the nature-integrated scenario because of lower fuel consumption, even when accounting for region-specific fuel prices:

- ECA fuels: USD 685 per tonne
- Non-ECA fuels: USD 570 per tonne

Voyage economics combine fuel expenses with a daily charter rate of USD 22,000.

Even with a longer overall transit, the reduction in fuel use offsets much of the time-related costs. Using the study's assumed daily charter rate of US$22,000 and region-specific fuel prices (US$685/tonne for ECA fuels and US$570/tonne for non-ECA fuels), the nature-integrated routing scenario reduces total fuel consumption by 61.7 tonnes. Although the longer transit time increases charter costs, the reduction in fuel expenditure results in a net decrease in total voyage cost of approximately US$19,450 per crossing compared to the regular routing scenario. The net effect is a voyage scenario that remains operationally viable and financially competitive. Because the purpose of this study is to compare operational scenarios rather than forecast financial performance, no sensitivity analysis was conducted; however, the cubic relationship between speed and fuel burn indicates that directional results are robust across fuel and charter price variability.

6.5 Whale Strike Risk Reduction

The nature-integrated scenario yields a substantial reduction in whale strike risk, driven entirely by speed management in IMMA and MPA zones.

This interpretation is based on well-established scientific research demonstrating that vessel speeds below 10 knots reduce the probability of a fatal strike by up to 86 percent (Conn & Silber, 2013).

Since both routing scenarios traverse the same ecological corridor, the change in strike risk is attributable solely to speed reductions in sensitive habitats defined by the Spatial Habitat Vulnerability Layer.

6.6 Underwater Radiated Noise Reduction

The study concludes that slower speeds in ecologically important areas produce a greater than 50 percent reduction in underwater radiated noise, based on empirical literature showing how speed influences acoustic energy (Leaper & Renilson, 2012; Smith & Rigby, 2022). The estimated reduction of more than 50 percent reflects the mid-range values reported in peer-reviewed literature examining the relationship between vessel speed and underwater acoustic output (e.g., Leaper & Renilson, 2012; Smith & Rigby, 2022).

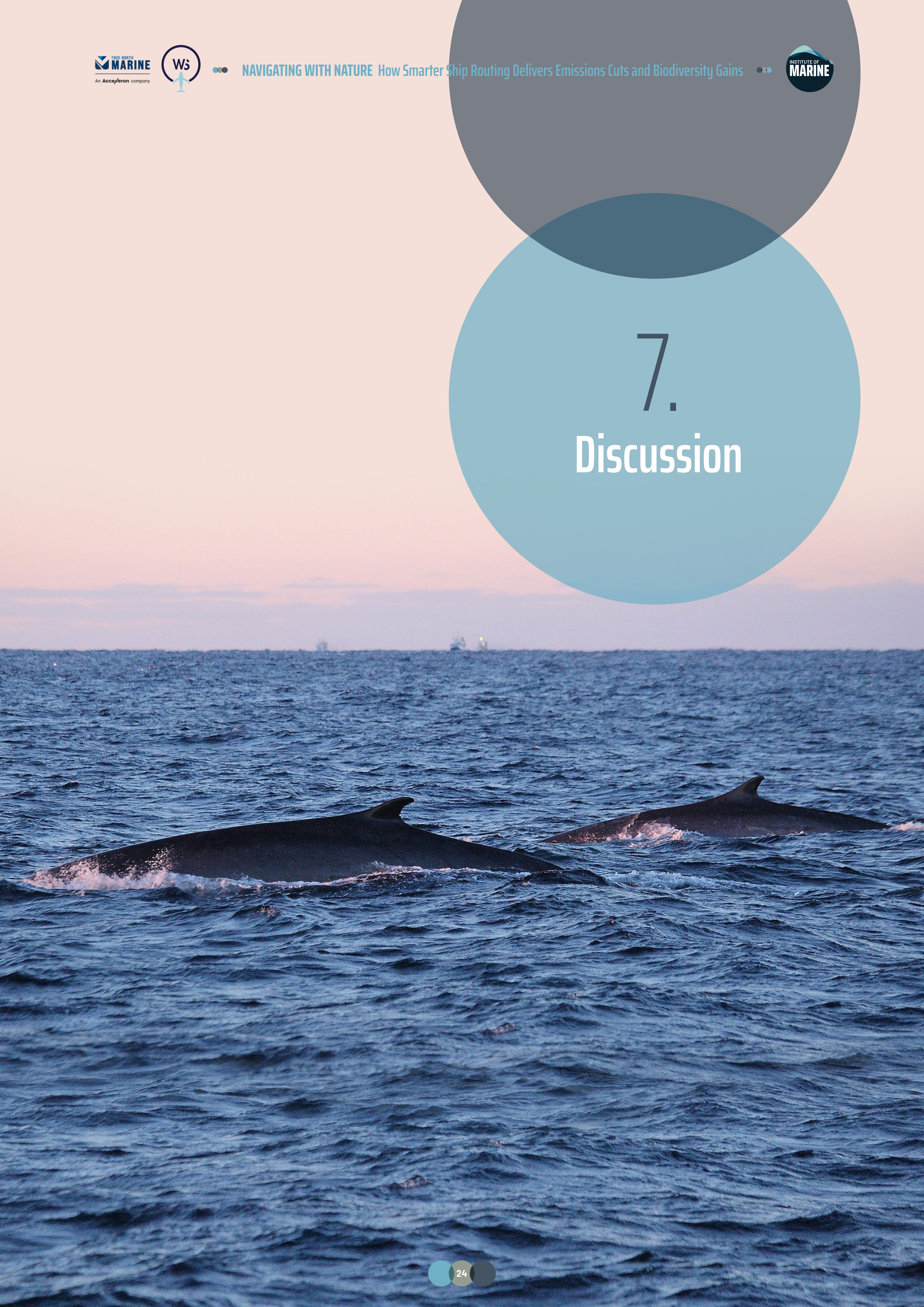
No bespoke acoustic model was developed for this case study.

Instead, the nature-integrated scenario's reduced speeds were evaluated using the established scientific relationship between vessel speed and acoustic output.

6.7 Summary of Documented Comparative Outcomes

This report demonstrates the following, based entirely on its original calculations:

- Transit time: +24.9 hours for the nature-integrated scenario.
- Fuel consumption: –61.7 tonnes total FOC due to slower speeds in sensitive zones.
- CO_2 emissions: –197.8 tonnes due to reduced fuel consumption following IMO Cf coefficients.
- Fuel costs: reduced due to lower fuel consumption.
- Voyage economics: ~US$19,450 lower total voyage cost compared to regular routing, despite longer transit time.
- Whale strike risk: sharply reduced due to speeds at or below 10 knots in IMMA and MPA zones.
- Underwater noise: reduced by more than half in ecologically significant areas.



7. Discussion

The findings of this case study provide compelling evidence that operational decisions grounded in ecological awareness can deliver immediate, tangible gains for both environmental performance and commercial outcomes. The results show that responsible operational behaviour is not a burden for shipping companies, but rather a credible and strategic asset that strengthens performance across climate, biodiversity, and cost-efficiency indicators. This section analyzes the broader significance of these findings for the maritime sector and international sustainability frameworks.

7.1 Environmental Gains Without Sacrificing Commercial Logic

One of the most important conclusions emerging from this study is that shipping does not need to choose between environmental responsibility and commercial efficiency. The nature-integrated scenario demonstrated that it is entirely possible to reduce fuel consumption, lower total emissions, and decrease operational risk while maintaining commercially acceptable voyage performance.

This evidence directly challenges the outdated assumption that environmental protection inherently undermines profitability. The results instead support a more modern view: integrating environmental intelligence into routing decisions can strengthen, rather than weaken, operational performance.

7.2 Clear and Measurable Reductions in Whale Strike Risk

The documented reduction in whale strike risk is significant. Large whales continue to face persistent and often fatal interactions with vessels along major shipping corridors. The case study demonstrates that responsible operational behaviour in known ecologically sensitive waters can materially reduce this risk.

This aligns directly with long-established marine mammal research that identifies vessel speed as the most influential factor in determining the lethality of a collision (Conn & Silber, 2013; Williams et al., 2021). The results show that meaningful risk reduction is achievable and that commercial shipping can play an active role in protecting vulnerable species, many of which are still recovering from historical declines (NOAA Fisheries, 2023).

7.3 Substantial Improvements in Acoustic Conditions

Underwater radiated noise is increasingly recognized as a silent but pervasive pollutant that alters the health and behaviour of marine life. The case study documents a clear and significant reduction in underwater noise exposure when responsible operational behaviour is applied in ecologically important areas.

Reducing noise in these zones improves the acoustic environment for marine mammals, many of whom rely on low-frequency sound to communicate, navigate, find mates, and detect predators. The results reinforce the scientific and policy consensus that slowing down in sensitive areas is one of the most effective strategies for improving acoustic conditions in the ocean (IMO, 2021; Erbe et al., 2019; Leaper & Renilson, 2012; Smith & Rigby, 2022).

7.4 Direct Contributions to Climate Mitigation

The reduction in total fuel consumption and corresponding drop in CO_2 emissions place this operational approach squarely within international climate discourse.

Shipping faces increasing pressure to demonstrate concrete and near-term progress toward decarbonization goals. This case study shows that operators can achieve real climate gains today, with existing vessels and existing tools, by incorporating environmental considerations into their operational behaviour (IMO, 2023; UNFCCC, 2025). This positions responsible behaviour not only as an ecological priority but as a credible, near-term climate mitigation action that supports global commitments under the IMO and COP30.

7.5 Strengthening ESG Performance and Reducing Nature-Related Risk

Global markets are increasingly sensitive to nature-related impacts and companies are under growing pressure to report and manage biodiversity risk. The improvements documented in this case study help address several nature-related impact categories that are rapidly becoming part of corporate disclosure frameworks.

Demonstrating improvements in whale-strike risk, acoustic disturbance, and emissions strengthens a company's ESG profile and aligns directly with the evolving expectations of investors, insurers, cargo owners, and regulators (TNFD, 2023; Poseidon Principles, 2019; Sea Cargo Charter, 2020).

The findings therefore have strategic value beyond environmental stewardship, as they support corporate resilience in a regulatory and financial environment that is rapidly evolving.

7.6 Policy Alignment Across Multiple Jurisdictions

The case study results complement the direction of travel in national, regional, and international policy. Authorities in North America, Europe, and Antarctic waters already use a range of measures to protect marine mammals and reduce noise (NOAA Fisheries, 2023; Transport Canada, 2023; IAATO, 2024).

The nature-integrated scenario demonstrates that shipping companies can align with these policies proactively. Instead of waiting for mandatory restrictions, operators can adopt behaviours that meet or exceed regulatory expectations while maintaining commercial performance.

This positions responsible operational behaviour as a pragmatic strategy for regulatory preparedness and long-term compliance.

7.7 High Confidence in the Interpretation of Outcomes

The confidence in these findings is strengthened by the internal coherence of the analysis. Both scenarios use the same vessel class, the same route corridor, the same environmental references, and the same operational assumptions.

The only difference is operational behaviour in sensitive areas.

This creates a clean and credible comparison. It allows the study to isolate how changes in behaviour influence environmental outcomes without confounding variables.

7.8 Overall Significance

The case study demonstrates that shipping can significantly reduce environmental pressures while retaining commercial and operational integrity.

The improvements in fuel efficiency, emissions, noise reduction, and collision risk all trend in the same direction. They collectively show that responsible operational behaviour is not an optional environmental add-on but a meaningful contributor to climate-aligned, biodiversity-conscious maritime transport.

This strengthens the case for integrating environmental intelligence into routine maritime planning and underscores the growing recognition that operational decisions made today will shape the health and resilience of ocean ecosystems for decades to come.

8. Implications for Climate, Biodiversity, and Policy

The Montréal to Le Havre case study demonstrates that responsible operational behaviour in ecologically sensitive waters produces meaningful benefits for climate mitigation, biodiversity conservation, and ocean health. These results align with global scientific understanding and reinforce the direction of international policy frameworks under the IMO, CBD, UNFCCC, and UNEP. The findings from this route illustrate how behavioural choices can contribute directly to the goals of the United Nations Decade of Ocean Science through practical, near-term action (UNESCO-IOC, 2021–2024).

8.1 Implications for Climate and Carbon Mitigation

Fuel consumption is directly linked to carbon emissions in international shipping. Operational measures that reduce fuel use therefore provide immediate and measurable climate benefits. In this case study, the nature-integrated scenario reduced total fuel consumption by 61.7 tonnes over the 3,148-nautical-mile voyage, resulting in a corresponding reduction of approximately 197.8 tonnes of CO_2 per crossing. These reductions support the IMO's 2023 Revised Greenhouse Gas Strategy, which emphasizes near-term operational efficiency measures as a key pathway to emissions mitigation (IMO, 2023). They also align with the direction of COP30 Belém outcomes, which encourage integrating nature-sensitive operational practices into maritime decarbonization pathways (UNFCCC, 2025).

When applied across repeated voyages or additional corridors, the cumulative climate benefit of similar operational measures could scale substantially. While such scenarios are illustrative rather than forecasts, they demonstrate that incorporating environmental sensitivity into route planning can contribute meaningfully to near-term emissions reductions at a sector-relevant scale.

8.2 Implications for Biodiversity: Vessel Strikes

Vessel collisions remain one of the leading causes of mortality for large whales in many regions. Scientific consensus shows that vessel speed is one of the strongest predictors of whether a collision will be fatal. Reducing speed in ecologically important waters is therefore one of the most effective risk-mitigation strategies available (Conn & Silber, 2013).

In this case study, responsible operational behaviour led to a substantial reduction in whale strike risk in segments where baleen whales are expected to occur. These behavioural changes align with long-standing findings that lower speeds materially reduce the probability of fatal encounters (Conn & Silber, 2013; Williams et al., 2021). This is particularly important for endangered species such as North Atlantic right whales, for which recovery is hindered by the ongoing threat of vessel strikes (NOAA Fisheries, 2023; DFO, 2023).

The implications for biodiversity frameworks are direct. The Kunming–Montréal Global Biodiversity Framework calls for reducing human-caused mortality of threatened species and improving the condition of critical habitats (CBD Secretariat, 2022). Reductions in potential collision severity and frequency contribute directly to these targets and support national and regional recovery strategies already in place in North America and Europe (DFO, 2023; NOAA Fisheries, 2023).

If similar operational practices were adopted across additional corridors where IMMA and MPA designations intersect with shipping traffic, the cumulative benefit for whale populations could be significant. Many such populations remain small, slow-reproducing, and vulnerable to even single mortality events. Reducing vessel-related mortality at scale supports global conservation goals and strengthens ecosystem resilience.

8.3 Implications for Biodiversity: Underwater Radiated Noise

Underwater radiated noise from shipping is an increasing concern for the international marine community. Chronic low-frequency noise can interfere with communication, migration, foraging, and reproduction in marine mammals. Scientific literature consistently identifies vessel speed as a key driver of acoustic output (Erbe et al., 2019; Leaper & Renilson, 2012; Smith & Rigby, 2022).

The case study demonstrates a marked reduction in underwater noise exposure when slower vessel speeds are used in ecologically important segments. These findings align with research showing that even moderate reductions in speed can significantly reduce noise intensity (IMO, 2021; Erbe et al., 2019). Improving the acoustic environment in sensitive areas supports healthy habitat conditions and contributes to global efforts to reduce marine pollution in all its forms, including energy-based pollution (UNEP, 2021).

When scaled to additional voyages and routes, the number of vessel transits operated at reduced acoustic intensity could represent a meaningful contribution to the preservation of marine acoustic habitat at basin or sub-basin scales. This aligns with the growing attention to underwater noise within the Marine Environment Protection Committee of the IMO and with UNEP's broader focus on cumulative anthropogenic impacts on marine ecosystems.

8.4 Integrated Implications Across Climate, Biodiversity, and Pollution

The United Nations frames climate change, biodiversity loss, and pollution as a single interconnected challenge. Operational decisions that address these pressures simultaneously are therefore especially valuable. The case study illustrates how one behavioural change can produce improvements across all three dimensions:

- Lower greenhouse gas emissions
- Reduced collision risk for endangered species
- Reduced underwater noise pollution

These multiple benefits reflect the integrated systems-thinking approach encouraged under the UN Ocean Decade and the science-policy mechanisms developed by IPBES. By addressing multiple pressures at once, responsible operational behaviour contributes to broader ecosystem resilience, not only to isolated environmental targets.

8.5 Alignment with Global Policy and Governance Directions

The results of this case study align closely with several major policy directions in international governance:

- The IMO's recognition of the role of operational measures in both decarbonization and underwater noise reduction (IMO, 2021; IMO, 2023; IMO, 2024)
- The CBD's call for reducing human-induced mortality and disturbance of marine species (CBD Secretariat, 2022; CBD Secretariat, 2023)
- COP30's emphasis on nature-positive maritime pathways (UNFCCC, 2025)
- Regulatory and conservation measures adopted by national and regional authorities (NOAA Fisheries, 2023; Transport Canada, 2023; IAATO, 2024)
- Increasing expectations for nature-related disclosure in global finance (TNFD, 2023)

These alignments indicate that operational behaviour informed by ecological sensitivity is increasingly recognized as an essential component of sustainable maritime practice. Adopting such practices voluntarily can support future compliance and reduce exposure to reputational and regulatory risks.

8.6 Potential System-Level Contributions if Adopted Broadly

While the case study focuses on one route, its implications extend beyond a single corridor. If a limited number of global trade lanes with significant ecological intersections were to adopt similar responsible operational behaviour, the combined effect could include:

- Avoided emissions on the order of tens to hundreds of thousands of tonnes of CO_2 annually
- Reduced anthropogenic mortality for multiple whale species in key regions
- Measurable decreases in chronic underwater noise exposure in some of the ocean's most biologically important habitats

These potential contributions support the Global Biodiversity Framework's vision for reversing biodiversity decline by 2030 (CBD Secretariat, 2022), and the IMO's long-term decarbonization trajectory (IMO, 2023). They also demonstrate how operational practices can complement future technological transitions such as alternative fuels and next-generation vessels.

8.7 Summary

The findings from the Montréal to Le Havre case study highlight that operational behaviour is a powerful lever for advancing climate, biodiversity, and pollution-reduction goals in the maritime sector. The results align with global science, reinforce international policy commitments, and point to significant environmental gains that can be realized without requiring new technologies. As global frameworks move toward integrated, nature-positive approaches, the implications of this analysis contribute meaningfully to the collective understanding of how shipping can support healthier and more resilient ocean ecosystems.

9. Operational and Strategic Recommendations

The outcomes of the Montréal to Le Havre case study reinforce that operational behaviour is a powerful tool for improving environmental performance in the maritime sector. The following recommendations synthesize insights relevant for ship operators, regulators, port authorities, conservation bodies, and the broader ocean governance community. Each recommendation reflects the findings of the case study while avoiding prescriptive instructions or the disclosure of proprietary processes.

9.1 Integrate Ecological Sensitivity into Voyage Planning

The case study demonstrates that responsible operational behaviour in ecologically important areas can reduce greenhouse gas emissions, underwater noise, and vessel strike risk. Voyage planning processes at the organizational and sector levels could benefit from formally considering ecological sensitivity as one of several operational inputs. This includes awareness of Important Marine Mammal Areas, Marine Protected Areas, and other scientifically recognized sensitive regions during route preparation and review (IUCN Marine Mammal Protected Areas Task Force, 2021; OSPAR Commission, 2023).

9.2 Adopt Responsible Speed Practices in Sensitive Waters

Reducing vessel speed in areas of high ecological value has well-documented benefits for both climate and biodiversity outcomes. Integrating responsible speed profiles into planning and decision-making can be a practical way to lower ecological pressures while maintaining operational viability. This approach aligns with evidence-based guidance from scientific institutions and with policy directions in several jurisdictions (Conn & Silber, 2013; IMO, 2021; NOAA Fisheries, 2023; Transport Canada, 2023).

9.3 Support International Efforts to Address Underwater Noise

The IMO Marine Environment Protection Committee continues to evaluate measures to address underwater noise from commercial shipping. Operational behaviour, including speed adjustments in sensitive habitats, is recognized as an important component of noise mitigation (IMO, 2021; IMO, 2024). Continued engagement with international initiatives can help ensure that operational experience informs future policy development and supports global efforts to reduce acoustic pollution in the ocean.

9.4 Contribute to Biodiversity Conservation Objectives

Operational changes that reduce collision risk, disturbance, and mortality for large marine species contribute directly to global biodiversity commitments. The Kunming–Montréal Global Biodiversity Framework calls for reducing human-caused mortality of threatened species and improving the status of critical ecosystems (CBD Secretariat, 2022; CBD Secretariat, 2023). Sector-level consideration of these objectives supports the broader transition toward nature-positive action across the ocean economy.

9.5 Strengthen Collaboration Across Industry, Science, and Policy

The maritime sector increasingly benefits from collaboration between operators, scientific institutions, conservation organizations, and regulatory authorities. Such collaboration helps ensure that operational practices reflect the best available ecological knowledge while also accounting for the realities of maritime logistics and safety. Cooperative approaches can improve environmental performance at scale and support harmonized implementation across borders (UNESCO-IOC, 2021–2024; IPBES, 2019).

9.6 Align Operational Practices with Emerging Disclosure Frameworks

Nature-related risk and impact disclosure is becoming an expected part of global finance and corporate governance. Responsible operational behaviour that reduces emissions, collision risk, and underwater noise supports alignment with emerging expectations under frameworks such as the Taskforce on Nature-related Financial Disclosures (TNFD, 2023). Incorporating environmental considerations into routine decision-making now can support readiness for future reporting requirements.

9.7 Enhance Monitoring, Evaluation, and Learning

As operational practices evolve, ongoing monitoring and review can strengthen understanding of their environmental and operational outcomes. Learning from early adopters can support the development of refined, evidence-based approaches that reflect both ecological needs and operational realities. Building a culture of continuous improvement can help the maritime sector adapt to changing scientific insights and policy expectations.

9.8 Support Multi-Route and Multi-Vessel Applicability

Although the case study focuses on a single transatlantic route, the environmental challenges addressed (i.e: emissions, underwater noise, and vessel strikes) are global in scope. Expanding responsible operational behaviour to additional routes may help amplify environmental benefits, especially in areas with high ecological significance. Such expansion should be informed by scientific knowledge, regulatory developments, and the operational contexts of individual voyages.

9.9 Contribute to the Objectives of the UN Ocean Decade

The United Nations Decade of Ocean Science for Sustainable Development emphasizes solutions that address multiple pressures simultaneously. Responsible operational behaviour that benefits climate mitigation, biodiversity recovery, and pollution reduction supports this integrated vision (UNESCO-IOC, 2021–2024). Continuing to align operational practices with the principles of the Ocean Decade can strengthen the maritime sector’s role in advancing global sustainability goals.

9.10 Promote Sector-Wide Dialogue on Responsible Maritime Practices

The findings reinforce the value of open dialogue within the maritime community about how operational decisions influence environmental outcomes. By sharing insights, participating in multi-stakeholder discussions, and contributing to evidence-based policy processes, operators and institutions can play an active role in shaping a sustainable future for global shipping.

10. Pathways for Implementation and Scaling

The findings from the Montréal to Le Havre case study demonstrate that operational behaviour can meaningfully reduce greenhouse gas emissions, underwater noise, and vessel strike risk in ecologically sensitive waters. This section outlines high-level pathways for scaling these benefits while maintaining safety, navigational integrity, and policy alignment. It does not prescribe specific technologies or workflows, ensuring broad applicability across different vessel types, regions, and operational contexts.

10.1 Integrating Responsible Behaviour into Existing Operational Frameworks

Shipping companies, maritime authorities, and fleet managers already maintain well-established procedures for voyage planning, bridge resource management, and navigational assessment. Responsible operational behaviour can be incorporated into these existing frameworks by encouraging heightened awareness in ecologically significant areas. This includes recognizing habitats identified through authoritative scientific bodies such as the IUCN, OSPAR, and national marine conservation agencies (IUCN Marine Mammal Protected Areas Task Force, 2021; OSPAR Commission, 2023).

Embedding ecological sensitivity into routine decision-making supports safe and environmentally aligned operations without requiring the creation of new or parallel processes.

10.2 Encouraging Voluntary Adoption in Sensitive Regions

Many shipping routes intersect areas known to host migratory, feeding, or nursing grounds for marine megafauna. Voluntary adoption of more responsible vessel behaviour in these areas can produce measurable reductions in ecological pressure. Regions such as the Gulf of St. Lawrence, the Northwest Atlantic, the Northeast Atlantic, the Mediterranean Sea, and certain Southern Ocean corridors have well-documented concentrations of marine mammals and seabirds (NOAA Fisheries, 2023; Transport Canada, 2023; IAATO, 2024).

Voluntary measures, informed by scientific assessments and regional conservation priorities, can provide immediate benefits while allowing operators flexibility to align practices with operational realities.

10.3 Supporting Collaboration Between Industry and Science

Marine conservation science is rapidly evolving, with continuous improvements in species distribution data, acoustic research, and ecological risk assessment. Collaboration between industry stakeholders, academic institutions, and conservation organizations can support shared understanding of ecologically important areas and emerging environmental concerns.

Collaborative initiatives can also help ensure that operational insights inform global science and that scientific updates are accessible to maritime decision-makers. Such collaboration can strengthen evidence-based approaches across the sector (UNESCO-IOC, 2021–2024; IPBES, 2019).

10.4 Reinforcing International Regulatory and Policy Frameworks

Operationally responsible behaviour aligns with several international environmental commitments. The IMO continues to emphasize the importance of operational measures in reducing both emissions and underwater noise (IMO, 2021; IMO, 2023; IMO, 2024). The CBD's Global Biodiversity Framework highlights the need to reduce human-caused mortality and disturbance of marine species (CBD Secretariat, 2022; CBD Secretariat, 2023). COP30's outcomes reinforce the need for nature-positive operational approaches within ocean industries (UNFCCC, 2025). These existing frameworks provide a foundation for scaling responsible behaviour across the maritime sector. Aligning operational practices with these commitments strengthens regulatory coherence and supports national and regional conservation objectives.

10.5 Enabling Cross-Border Harmonization

Shipping routes often cross multiple jurisdictions, each with its own environmental rules and conservation measures. Harmonized approaches to responsible operational behaviour can reduce regulatory uncertainty and simplify compliance for operators. The identification of ecologically sensitive regions by international scientific bodies helps facilitate consistency across borders (IUCN Marine Mammal Protected Areas Task Force, 2021; CBD Secretariat, 2022; OSPAR Commission, 2023).

Cross-border harmonization supports predictable voyage planning, strengthens conservation outcomes at migratory scales, and aligns with the principles of ecosystem-based management encouraged under the UN Ocean Decade (UNESCO-IOC, 2021–2024).

10.6 Leveraging Improvements in Ecological and Ocean Data

Ocean observing systems are expanding, and new ecological datasets continue to emerge from initiatives such as the IUCN Marine Mammal Protected Areas Task Force, national research programs, and regional environmental partnerships. As these datasets become more accessible, maritime decision-making can increasingly reflect contemporary ecological knowledge.

Improved data coverage supports safer, more informed operations in sensitive regions while respecting navigational constraints and commercial priorities.

10.7 Supporting the Transition to Nature-Positive Maritime Practice

Nature-positive approaches aim to halt and reverse biodiversity loss while supporting sustainable economic activity. Responsible operational behaviour contributes to this transition by reducing the pressures that vessels impose on marine ecosystems. It complements long-term technological solutions such as alternative fuels, vessel design improvements, and new propulsion systems (IMO, 2023; TNFD, 2023).

By demonstrating that meaningful environmental benefits are achievable through behavioural measures alone, the findings of this case study reinforce the potential for near-term, systemic contributions to nature-positive goals across multiple regions.

10.8 Encouraging Sectoral Leadership and Peer Learning

Leadership from early adopters can accelerate broader uptake of responsible operational behaviour. Sharing insights through multi-stakeholder platforms, professional societies, and international working groups can help inform best practices while ensuring that implementation remains adaptive and evidence based.

Peer learning supports continuous improvement within the sector and can foster a shared commitment to environmental stewardship across the global shipping community.

10.9 Supporting Global Ocean Goals

The United Nations Decade of Ocean Science for Sustainable Development calls for actions that deliver multiple co-benefits for climate, biodiversity, and human well-being. Operationally responsible behaviour aligns with these ambitions by reducing emissions, lowering noise pollution, and decreasing collision risk in ecologically significant waters (UNESCO-IOC, 2021–2024).

Scaling these benefits across additional vessel classes and routes has the potential to support global progress toward climate mitigation, biodiversity recovery, and resilient ocean ecosystems.

11. Conclusions

The Montréal to Le Havre case study demonstrates that responsible operational behaviour in ecologically sensitive waters can yield meaningful climate, biodiversity, and ocean-health benefits while maintaining operational viability. By examining a real-world transatlantic route, the analysis provides practical evidence that the maritime sector can make tangible contributions to global sustainability goals through adjustments that are feasible within existing navigational and operational frameworks.

The findings show that reducing vessel speed in defined ecologically important areas lowers fuel consumption, decreases greenhouse gas emissions, reduces underwater radiated noise, and significantly diminishes the likelihood of fatal collisions with large whales. These improvements align directly with the scientific consensus on the relationships between vessel behaviour, emissions intensity, noise production, and collision severity (Conn & Silber, 2013; Erbe et al., 2019; Leaper & Renilson, 2012; Smith & Rigby, 2022). Each of these environmental pressures plays a major role in the health and resilience of marine ecosystems, and each is recognized by international bodies as an urgent priority (IMO, 2021; CBD Secretariat, 2022; UNEP, 2021).

The results also reinforce the direction of global policy. The IMO's 2023 Revised Greenhouse Gas Strategy highlights the importance of operational measures in achieving near-term emissions reductions (IMO, 2023). Although this analysis uses a Panamax-class container vessel as a representative example, the underlying speed–fuel and speed–risk relationships are consistent across most large commercial vessels, supporting broad applicability of these findings. The Kunming–Montréal Global Biodiversity Framework identifies reducing human-caused mortality of threatened marine species and improving habitat quality as foundational to global biodiversity recovery (CBD Secretariat, 2022; CBD Secretariat, 2023). The UN Ocean Decade emphasizes solutions that address multiple pressures simultaneously, and this case study demonstrates precisely such multi-dimensional benefits (UNESCO-IOC, 2021–2024).

Importantly, the results show that environmental gains can be achieved without compromising commercial integrity or navigational safety. The modest increase in voyage time observed in the nature-integrated scenario did not negate the operational performance of the voyage, and the reductions in fuel use and emissions demonstrate that responsible behaviour can contribute to efficiency rather than detract from it. This challenges the assumption that environmental protection and commercial performance must be in conflict and instead illustrates the potential for alignment between the two.

While the results of this case study are specific to one route, the principles they illustrate are globally relevant. Many major shipping corridors traverse ecologically important areas where marine mammals migrate, feed, or nurse, and where underwater noise has cumulative impacts on sensitive species. If responsible operational behaviour were adopted across even a fraction of these routes, the combined effect could include avoided emissions on the order of tens to hundreds of thousands of tonnes of CO_2 annually, as well as measurable reductions in anthropogenic pressure on whale populations and their habitats (U.S. EPA, 2023; NOAA Fisheries, 2023).

The findings support a wider shift toward nature-positive maritime practice. Integrating ecological sensitivity into decision-making reflects growing expectations for environmental accountability, emerging nature-related disclosure frameworks, and global commitments to address the interconnected challenges of climate change, biodiversity loss, and pollution; often referred to as the triple planetary crisis (TNFD, 2023; UNEP, 2023). It also highlights the role of shipping in supporting resilient, healthy ocean ecosystems and underscores the sector's capacity to contribute meaningfully to global climate and biodiversity objectives.

Taken together, the evidence demonstrates that operational behaviour is not a marginal consideration but a central element of the maritime sector's environmental footprint. Responsible operational choices can generate immediate and measurable benefits, complement technological transitions, and provide a practical foundation for more sustainable and nature-aligned maritime transport.

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List of Acronyms

Abbreviation	Definition
CBD	Convention on Biological Diversity
Cf	Carbon Factor
CO_2	Carbon Dioxide
COP	Conference of the Parties (UNFCCC)
DFO	Fisheries and Oceans Canada
ECA	Emission Control Area
EPA	United States Environmental Protection Agency
ESG	Environmental, Social and Governance
GBF	Global Biodiversity Framework
GHG	Greenhouse Gas
IAATO	International Association of Antarctica Tour Operators
IHO	International Hydrographic Organization
IMO	International Maritime Organization
IMMA	Important Marine Mammal Area
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change

Abbreviation	Definition
IUCN	International Union for Conservation of Nature
MEPC	Marine Environment Protection Committee (IMO)
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration (United States)
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
SHVL	Spatial Habitat Vulnerability Layer
TEU	Twenty-foot Equivalent Unit (container measurement)
TNFD	Taskforce on Nature-related Financial Disclosures
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WS	Whale Seeker

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