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An Economic Analysis of Shipping Costs Related to Potential Measures to Manage the Co-Occurrence of Maritime Vessel Traffic and Whales in the Channel Islands Region

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National Centers for Coastal Ocean Science
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An Economic Analysis of Shipping Costs Related to Potential Measures to Manage the Co-Occurrence of Maritime Vessel Traffic and Whales in the Channel Islands Region

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September 2017

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Container vessel at sea. Credit: NOAA Photo Library.

LIST OF ACRONYMS

AIS	Automatic Identification System
ATBA	Area to Be Avoided
AVIS	Authoritative Vessel Identification Service
CINMS	Channel Islands National Marine Sanctuary
CO	Carbon Monoxide
CO2	Carbon Dioxide
DMA	Dynamic Management Area
DoD	Department of Defense
DWT	Deadweight Tons
ECA	Emissions Control Area
FCC	Federal Communications Commission
GDP	Gross Domestic Product
GT	Gross Ton
HS	Harmonized System
ICC	Inventory Carrying Cost
IMO	International Maritime Organization
IWR	Institute for Water Resources
LA	Los Angeles
LB	Long Beach
LMIU	Lloyd's Maritime Intelligence Unit
LRS	Lloyd's Register of Shipping
MARAD	Maritime Administration
MMSI	Maritime Mobile Service Identity
MSWG	Marine Shipping Working Group
MT	Metric Tonne
MT-NM	Metric Tonne-Nautical Mile
Mx SoCal	Marine Exchange of Southern California
NCCOS	National Centers for Coastal Ocean Science
NM	Nautical Mile
NMFS	National Marine Fisheries Service
NNOMPEAS	National Navigation Operation and Maintenance Performance Evaluation and Assessment System
NOAA	National Oceanic and Atmospheric Administration
NOVA	Notice of Violation and Assessment
NOx	Nitrogen Oxide
OGV	Ocean Going Vessel
PIERS	Port Import\Export Reporting Service
RWSSRR	North Atlantic Right Whale Ship Strike Reduction Rule
SAC	Sanctuary Advisory Council
SBCAPCD	Santa Barbara County Air Pollution Control District
SMA	Seasonal Management Area
SOLAS	Safety of Life at Sea
SOx	Sulfur Dioxide
TC	Total Cost
TEU	Twenty-Foot Equivalent Unit
TSS	Traffic Separation Scheme
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
VOC	Vessel Operating Cost
VSR	Vessel Speed Reduction
VTC	Vessel Transportation Cost
WCSC	Waterborne Commerce Statistics Center

Executive Summary

Fluke of blue whale just south of the shipping lanes. Credit: J. Calambokidis (Cascadia Research).

Executive Summary

This report provides findings from an analysis and evaluation of the economic effects of potential measures to manage the co-occurrence of shipping traffic and whales in the Channel Islands region off the coast of California.

These potential management measures are part of one of two different approaches developed by members of the Channel Islands National Marine Sanctuary (CINMS) Advisory Council Marine Shipping Working Group (MSWG) one technology-based and the other spatial-management-based (Figure 0.1[1]). Both approaches received partial support from MSWG members, although components exist within the approaches that were broadly supported, as well. The spatial management approach has multiple components that the MSWG contributors feel have merit individually as well as in combination with one another. The four components are:

1. a Traffic Separation Scheme (TSS) extension;
2. a new Western route (along the south side of the Channel Islands);
3. an Area to Be Avoided (ATBA) expansion; and
4. a seasonal Vessel Speed Reduction (VSR) to 12 knots from approximately April 1st to November 15th to overlap with whale visitation and ozone season.

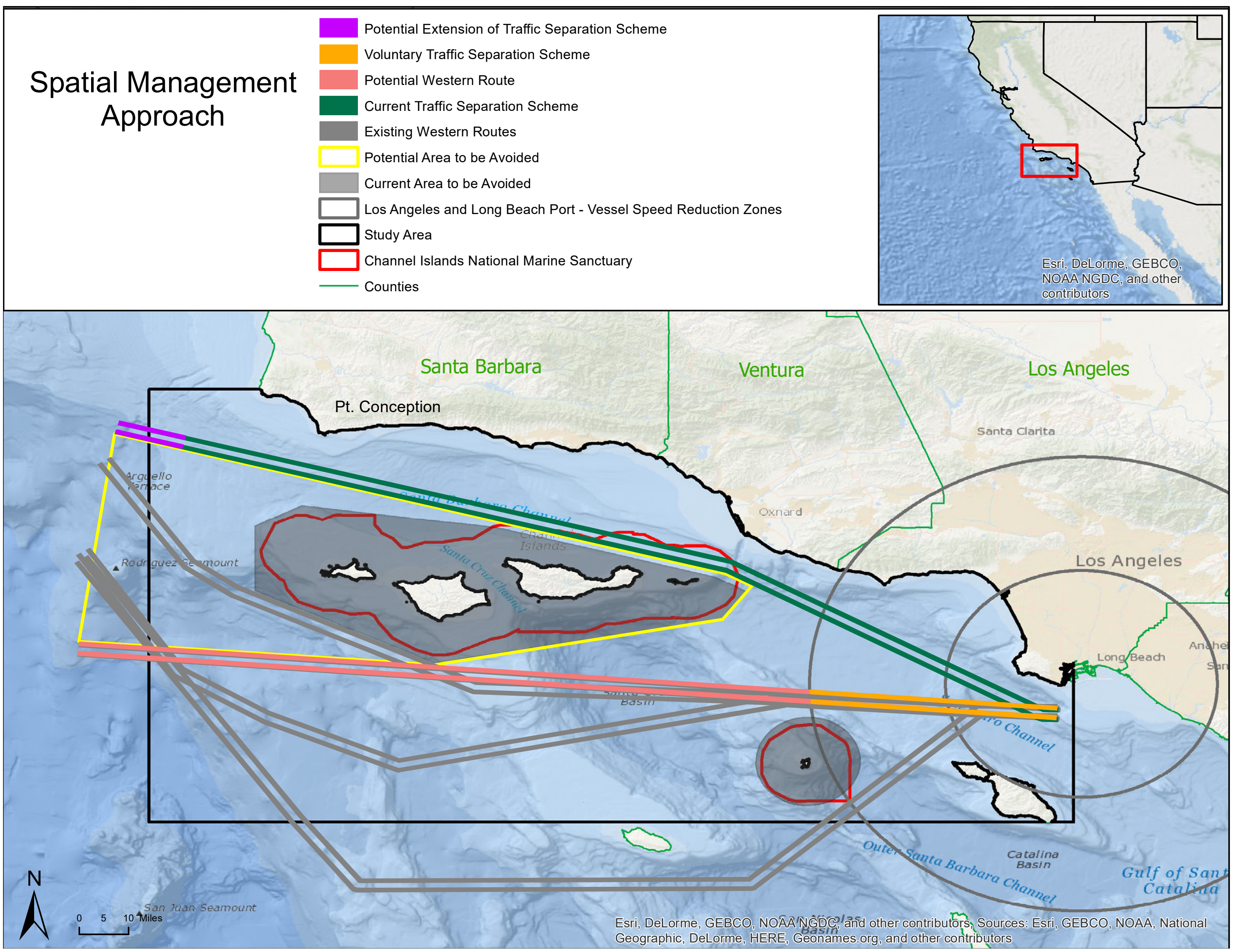

Figure 0.1. Spatial management approach.

[1] The study area extent is defined as North: 34.576; East: -118.250751; South: 33.302; West: -120.971. It should be noted that the study area is not a square, but an irregularly shaped polygon that follows the coastline. This includes the California coastline from Conception to the Port of Los Angeles/Long Beach.

Executive Summary

The Sanctuary Advisory Council (SAC) recommended that sanctuary staff carefully review the MSWG's 2016 final report (Channel Islands National Marine Sanctuary Advisory Council Marine Shipping Working Group, 2016) and work in collaboration with other agencies and interested parties to continue pursuing the feasibility of the various approaches listed within the report. In addition, CINMS staff requested analyses of four variations of the components above in order to expand the analysis. These variations were:

1. implementation of the spatial management approach with a 10-knot seasonal VSR, as opposed to a 12-knot seasonal VSR;
2. implementation of a 12-knot seasonal VSR only;
3. implementation of a 10-knot seasonal VSR only; and
4. implementation of the combined vessel re-routing components (TSS extension, new Western route, and ATBA expansion) only.

Thus, this evaluation analyzes for CINMS and other agencies the following potential management measures (hereafter termed potential management measures, Table 0.1) through a shipping cost analysis:

12-knot seasonal VSR with vessel re-routing (introduced above)

- TSS extension
- new Western route
- ATBA expansion
- seasonal 12-knot VSR

10-knot seasonal VSR with vessel re-routing

- TSS extension
- new Western route
- ATBA expansion
- seasonal 10-knot VSR

12-knot seasonal VSR only

- seasonal 12-knot VSR

10-knot seasonal VSR only

- seasonal 10-knot VSR

Vessel re-routing only

- TSS extension
- new Western route
- ATBA expansion

The methods used in this analysis include estimating vessel inventory carrying costs (ICCs) and vessel transportation costs (VTCs). To predict the effects of the potential management measures, baseline estimates

Table 0.1 Potential management measure components.

Potential Management Measures	TSS Extension	New Western Route	ATBA Expansion	Seasonal VSR
12-knot seasonal VSR with vessel re-routing	YES	YES	YES	YES – 12 Knots
10-knot seasonal VSR with vessel re-routing	YES	YES	YES	YES – 10 Knots
12-knot seasonal VSR only	NO	NO	NO	YES – 12 Knots
10-knot seasonal VSR only	NO	NO	NO	YES – 10 Knots
Vessel re-routing only	YES	YES	YES	NO

from 2015 are compared to estimates under the measures. While it is recognized that many types of costs may be impacted by alterations of current vessel operating characteristics, it was assumed that costs beyond ICCs and VTCs would be largely mitigated in the long-run owing to schedule revisions undertaken by shippers and ports that incorporate necessary changes. All monetary figures are expressed in 2015 dollars and t-tests at the 95% confidence interval were used to determine if differences are statistically significant[2] (hereafter termed significant). Differences in costs are measured both as total values across all vessels and in per 1,000 metric-ton nautical mile (MT-NM) units and differences in transit distance, speed, and time are measured per vessel transit.

KEY FINDINGS

A key finding (Table 0.2) of this evaluation is that the two costs to the shipping industry, as defined in this analysis, are predicted to decrease under the three potential management measures with vessel re-routing components:

1. 12-knot seasonal VSR with vessel re-routing (-2.2%);
2. 10-knot seasonal VSR with vessel re-routing (-1.6%); and
3. Vessel re-routing only (-3.4%).

The costs to the shipping industry are predicted to increase under the two seasonal VSR-only potential management measures:

1. 12-knot seasonal VSR only (+1.3%); and
2. 10-knot seasonal VSR only (+2.0%).

Table 0.2. Summary of expected total cost changes by potential management measure.

Potential Management Measure	Total Costs		
	Expected (2015$)	Change (2015$)	Change (%)
2015 Baseline	66,658,476	--	--
12-knot seasonal VSR with vessel re-routing	65,203,521	-1,454,959	-2.2
10-knot seasonal VSR with vessel re-routing	65,620,003	-1,038,458	-1.6
12-knot seasonal VSR only	67,539,241	880,766	1.3
10-knot seasonal VSR only	68,018,508	1,360,034	2.0
Vessel re-routing only	64,371,023	-2,287,472	-3.4

These results can be explained by the mechanisms through which the seasonal VSRs and vessel re-routing affect vessel costs. The seasonal VSRs affect ICCs through increased transit time and VTCs through both increased fuel efficiency and increased transit time. The vessel re-routing affects both ICCs and VTCs through decreased transit time[3]. Therefore, seasonal VSRs are predicted to increase ICCs and the increased fuel efficiency is predicted to outweigh the increased transit time for a net decrease in VTCs; vessel re-routing is predicted to decrease both ICCs and VTCs; and the predicted net effect of seasonal VSRs and vessel re-routing is an increase in ICCs and a decrease in VTCs.

[2] The term significance does not imply importance.

[3] Overall transit distance is predicted to decrease by 3.6% due to the removal of fanning along the Northern route and the consolidation to a single Western route. However, it is likely that this decrease in transit distance will be offset by an increase in transit distance outside of the study area. This is because the observed vessel track lines outside of the study area do not all line up with the vessel re-routing proposed in the potential management approach. As we assume vessels will comply with the re-routing measures, vessels will need to adjust their routes outside of the study area to close these gaps.

Executive Summary

The expected total costs (TCs) per 1,000 MT-NM, however, are not predicted to significantly change under any of the potential management measures. *Distance elasticity of TCs* can be used to explain how TCs change with transit distance as it is a measure that shows the responsiveness, or elasticity, of TCs to a change in transit distance. Mathematically, it is the ratio of the percentage change in TCs to the percentage change in transit distance. Under the measures with re-routing, the percentage change in transit distance (-3.6%) is predicted to be greater (in absolute value) than the percentage changes in TCs. That is, for every 1.0% change in distance, a 0.6% to 1.0% change in TCs is predicted to occur depending on the potential management measure, which suggests that TCs are not elastic with respect to transit distance.

To put these results into context, consider an individual vessel transit between Hong Kong and the Los Angeles (LA)/Long Beach (LB) Port Complex (6,300 NM). The total cost of vessel operation including fuel, crew, capital, insurance, and related administrative overhead costs on an individual vessel transit can easily range from approximately $0.6 to over $1.1 million depending on the type of vessel, fuel, and the degree to which the vessel was loaded. The estimated changes in costs from implementation of these potential management measures would therefore represent a 0.1% to 0.6% change in total vessel operating costs on this hypothetical transit. Additionally, the estimated changes in costs would represent 0.0003% to 0.001% of LA/LB Port Complex's total cargo value.

Near miss - whale dangerously close to getting hit by ship. Credit: NOAA Photo Library.

Channel Islands coastline. Credit: NOAA Photo Library.

FEASIBILITY

Each potential management measure has four distinct local management challenges, as well as effects on the shipping industry itself:

1. vessel strikes on endangered whales;
2. air pollution and greenhouse gas emissions;
3. navigational safety concerns; and
4. conflicts with naval operations.

When discussing the feasibility of potential management measures, their effects on these areas must be carefully considered. Additionally, the possible direct or indirect benefits derived from implementation of any of these measures should also be assessed. For instance, there is a growing literature on methods to measure the economic benefits of increased whale populations and decreased air pollution and greenhouse gas emissions.

Whales provide a wide array of ecosystem services which can, in part, be summarized by their ability to serve as ecosystem engineers in their roles as consumers, prey, detritus, and nutrient vectors throughout the water column and across the world's oceans (Nunes and Ghermandi, 2013; Roman et al., 2014; Onofri and Nunes, 2015). Several studies have demonstrated the non-consumptive value placed on whales, biodiversity, and favorable environmental conditions (Farr et al., 2013; Viana et al., 2017). Viana et al., 2017 discovered that private recreational boaters in the Channel Islands area display a higher willingness to pay for recreational sites which are higher in species richness and abundance. A healthy, thriving coastal ecosystem and non-consumptive activities, such as whale watching, not only provide opportunities for sustainable economic growth, but also provide a method of educating and engaging the public in local and global conservation initiatives.

Integrated assessment models (IAM) are used to quantify the marginal economic damages of emissions (Wang et al., 1994; Muller et al., 2011; Poycroft et al., 2011; Nordhaus, 2014; Jaramillo and Muller, 2016). IAMs include inputs such as emissions inventories and the valuation of the various damages caused by those emissions (Corbett and Koehler, 2003; Muller and Mendelsohn, 2007; Muller et al., 2011). Emissions inventories can be calculated using both bottom-up (i.e., spatially explicit/more localized) and/or top-down (i.e., aggregate/global) methodologies using ship fuel-based and activity-based datasets (Wang et al., 2007; Pokhrel and Lee, 2015; Zis et al., 2015).

Unfortunately, estimates derived from IAM are often limited by uncertainties in emission factors for certain engine types and the availability of fuel and activity data for some vessel types (Corbett and Koehler, 2003; Eyring et al., 2005). Likewise, finding reliable emission inventory data at finer scales and for specific industry sectors, such as marine transportation, can be challenging (Jaramillo and Muller, 2016). Also of concern is the transformation of gaseous pollutants (i.e., sulfur dioxide (SOx), nitrogen oxide (NOx), carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds) into sulfate, nitrate, and ozone, which contribute to processes, such as acidification, that negatively affect production in agriculture and forestry as well as changes in ocean chemistry (Pope et al., 2002; Laden et al., 2006; Muller et al., 2011; Bloor et al., 2014). Another limitation in IAM analyses revolves around uncertainties in the value of damages associated with specific emissions. For example, the values of statistical life (VSL) and injuries, the social cost of Carbon, and the dose-response relationship between pollutants and human mortality are all items which require further discussion and analyses (Muller et al., 2011; Pycroft et al., 2011; Nordhaus, 2014; Jaramillo and Muller, 2016).

In addition, some researchers postulate that, although reductions in emissions may be observed locally or regionally due to these regulations and VSRs, emissions may increase elsewhere due to the continued use of cheaper, low-quality fuels and increased speeds in international waters to compensate for lost time and money (Lack et al., 2011; Kotchenruther, 2015; Zis et al., 2015). However, the majority of these ship-based emissions are estimated to be concentrated within 400 km of land (Corbett et al., 1999) and along transit routes and ports (Richter et. al. 2004; Eyring et. al. 2007), while environmental factors such as local wind conditions transport those emissions hundreds of kilometers inland (Benkovitz et. al., 1994; Corbett et. al. 2007; Gonzalez et al., 2011; Pokhrel and Lee, 2015) into coastal regions where population densities are high and consistently growing (Neumann et al., 2015). Vutukuru and Dabdub (2008), for example, found that peak emissions of ozone and PM from ocean going vessels (OGVs) were concentrated in the coastal areas of the South Coast Air Basin of California.

APPLICATION CONSIDERATIONS

Two primary considerations to make when applying this framework to other study areas are current and expected vessel fleet behavior and current and expected vessel fleet composition.

Key drivers of vessel fleet behavior include current management measures, such as TSSs, VSRs, and fuel regulations. For example, in the Channel Islands study region, vessels have modified their routes in response to changes in fuel regulations that may not have the same effects in other regions. Additionally, while there are two voluntary VSR zones outside the LA/LB Port Complex, other areas, such as the San Francisco region, have implemented trial VSRs that may affect the baseline shipping costs. Finally, the vessel re-routing measure is predicted to decrease transit distances in the Channel Island study region by about 3.6%, which will not necessarily be the case in other regions and under different management measures and port capabilities. Additionally, the minimum engineering viability speeds used in this analysis may not be transferable to other regions or management measures depending on the length of the TSS under a VSR.

Vessel fleet composition, as well as cargo values, depends primarily on the cargo being transported in the region. For example, in the Channel Islands study region, the total value of cargo imported and exported is greater than any other port complex in the country and most of the value is carried in container vessels.

Vessel fleet behavior and composition are also important factors to consider in any future efforts aiming to estimate the marginal economic damages associated with shipping-based emissions. Emission inventory methodologies are highly sensitive to changes in fuel consumption, vessel and engine type, traffic patterns, cargo capacity, and vessel operator behavior and compliance to local regulations. Uncertainties surrounding the values applied to damages related to the environment and human health and mortality, such as the social cost of carbon, the value of statistical life (VSL), and dose-response relationships between pollutants and human mortality, require a standardized, yet localized application in estimating the total economic impact of the shipping industry within specific regions.

The effects of potential management measures in other regions necessitates a clear understanding of current and expected vessel fleet behavior and composition. This report provides a well detailed basis for conducting future analyses.

Whale tail. Credit: K. Balcomb (Center for Whale Research).

Section 1
Introduction

Channel Islands National Marine Sanctuary. Credit: NOAA Photo Library.

1.0. INTRODUCTION

The Channel Islands region (Figure 1.1) off the coast of southern California provides habitat to prominent populations of blue, fin, humpback, and gray whales. As ocean going vessels (OGV) have become more numerous, larger, and faster, the frequency of vessels striking whales (hereafter termed *vessel strikes*), as well as the force and severity with which vessels strike whales, has increased (Laist et al., 2001). Vessel strikes threaten the lives and the recovery of these populations from centuries of commercial whaling (Laist et al., 2014; Monnahan et al., 2014).

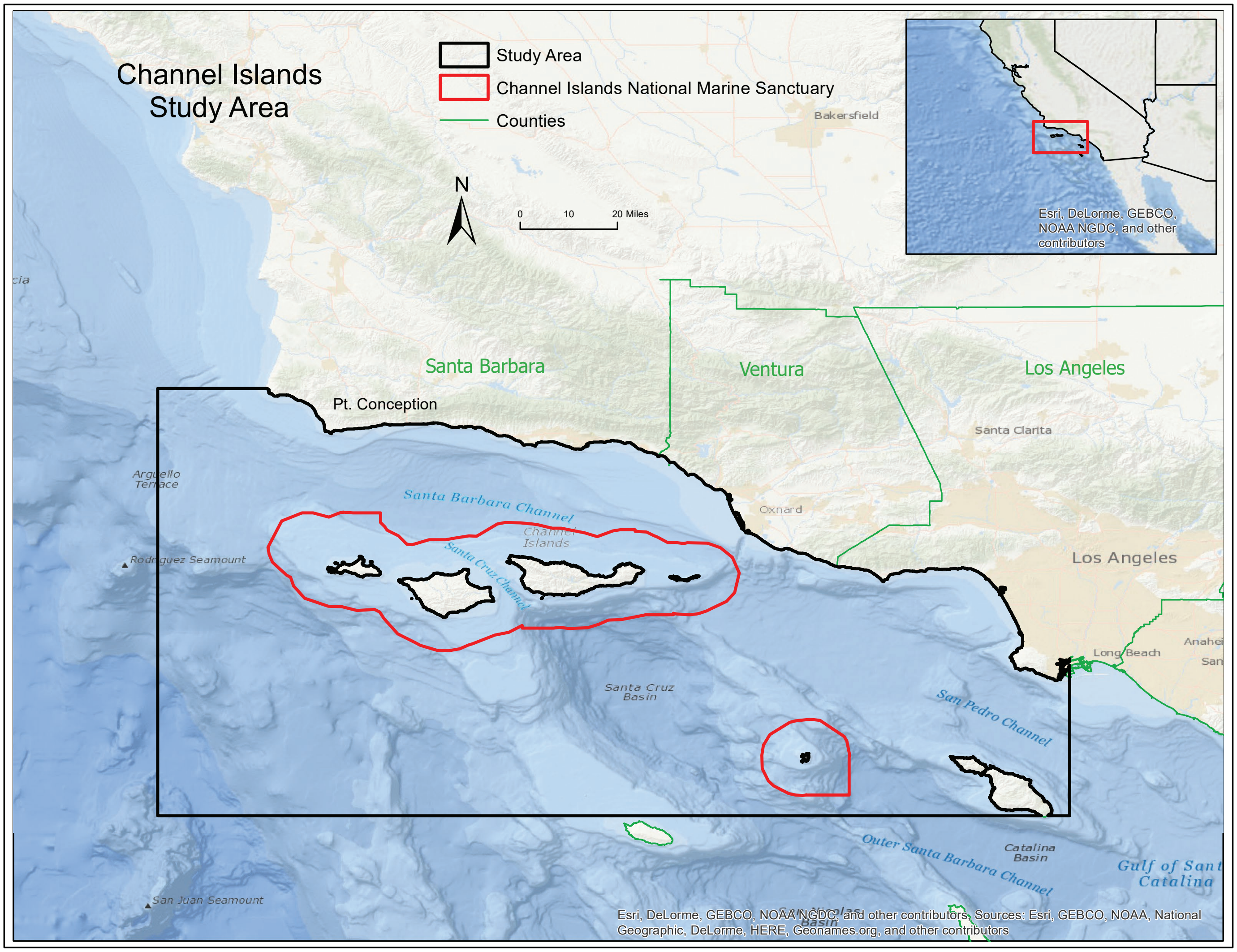

Figure 1.1. Channel Islands study area.

The marine shipping industry is a major contributor to the national economy and provides transportation for goods around the world. The Channel Islands region is home to the nation's two busiest ports: Long Beach and Los Angeles. The volume of trade through these two ports has grown substantially over the last 20 years (Le-Griffin and Murphy, 2006; The Tioga Group, 2009)[4]. Traditionally, thousands of cargo vessels transit through the Channel Islands region each year using an internationally approved Traffic Separation Scheme (TSS). Since 2009, many cargo vessels bypass the TSS and instead travel on the south side (backside) of the Channel Islands. The presence of vessels and changes in traffic patterns in the Channel Islands region presents four distinct local management challenges:

1. vessel strikes on endangered whales;

[4] In 2014, the Ports of Long Beach and Los Angeles accounted for 7% of all international waterborne gross tonnage and 16% of container gross tonnage. Source: Department of Transportation, Maritime Administration, 2014 Vessel Calls in US Ports, Selected terminals and Lightering Areas (Revised June 14, 2016); downloaded July 28, 2016.

2. air pollution and greenhouse gas emissions;
3. navigational safety concerns; and
4. conflicts with naval operations.

During September 2007, the National Oceanic and Atmospheric Administration (NOAA) received reports of five blue whale carcasses between Santa Cruz Island and San Diego, California that were determined to have been likely struck and killed by ships. NOAA's National Marine Fisheries Service (NMFS) designated the blue whale mortalities as an unusual mortality event[5] (Marine Mammal Commission, 2007). In response to that event, Channel Islands National Marine Sanctuary (CINMS) has collaborated with the shipping industry, governmental agencies, non-profit organizations, and other key stakeholders to reduce the risk of vessel strikes on endangered whales. For more than six years, the CINMS Advisory Council (SAC) has been the local forum for community and stakeholder deliberations on shipping issues.

In 2009, the SAC recommended to CINMS/NOAA a suite of research, outreach and management measures to reduce the risk of ship strikes on endangered whales. From 2009 to the present CINMS working with NMFS has implemented much of the advice, including seasonal, voluntary and incentive based vessel speed reduction zones, shifting the TSS in the Santa Barbara Channel and outreach to the shipping industry.

In 2014, CINMS, Santa Barbara County Air Pollution Control District (SBCAPCD), the National Marine Sanctuary Foundation, and the Environmental Defense Center launched a Vessel Speed Reduction (VSR) trial incentive program to slow ships down in the Santa Barbara Channel. The goals of this program were to reduce air pollution and protect endangered whales. Seven global shipping companies participated and twenty-seven cargo vessel transits were slowed to 12 knots or less (a 5.1 knot average reduction) from July through November. Participating vessels were paid an incentive of $2,500 per trip and were acknowledged in a positive public relations campaign locally and nationally. Reductions in vessel speed were estimated to result in three major benefits:

1. a 27% reduction in baseline nitrogen oxide (NOx) emissions from participating vessels;
2. a 33% reduction in baseline greenhouse gas (GHG) emissions from participating vessels; and,
3. no known occurrence of strikes on whales involving participating vessels (Birney et al., 2016).

The SAC formed the Marine Shipping Working Group (MSWG) in 2014 to develop additional recommendations to address regional shipping-related concerns. The working group consisted of a diverse group of stakeholders, including representatives from the: Department of Defense (DoD); United States Coast Guard (USCG); Channel Islands National Park; NMFS; Marine Exchange of Southern California (Mx SoCal); SBCAPCD; the shipping industry; and the tourism, research, and conservation communities.

The MSWG was tasked with developing a suite of management, education, outreach, and research recommendations that built upon CINMS and SAC's previous work to address the following goals:

1. reduce the risk of vessel strikes on endangered whales;
2. decrease air pollution and greenhouse gas emissions;
3. improve navigational safety and promote efficient maritime shipping throughout the region; and
4. manage ship traffic to minimize naval operation interruptions and reduce conflicts with other ocean users (e.g., fishing and whale watching concessionaires).

From February 2015 to January 2016, the MSWG convened four times in-person, eight times via webinar, and utilized SeaSketch, an interactive web-based mapping program to facilitate online collaboration. The early

[5] An unusual mortality event is defined under the Marine Mammal Protection Act as a stranding that is unexpected; involves significant die-off of any marine mammal population; and demands immediate response.

stages of the process focused on assembling relevant data and information-sharing so that working group members could begin to understand each other's perspectives.

By the fifth and final in-person meeting in January 2016, the group had proposed two management approaches: 1) a technology-based approach and 2) a spatial-management-based approach. Both approaches received partial support from MSWG members, although components exist within the approaches that were broadly supported, as well. The spatial approach is the focus of this analysis.

The technology-based approach focuses on monitoring the abundance and distribution of various whale species around the Channel Islands to inform mariners of whale locations with the goal of real-time ship responses to avoid vessel strikes. Evaluation of the economic impact of the technology-based approach proposed by the MSWG is not within the scope of this analysis as it is unclear how shipping behavior will be impacted.

The spatial management approach (Figure 1.2[6]) has multiple components that the MSWG contributors feel have merit individually as well as in combination with one another. The four components are:

1. a TSS extension;
2. a new Western route (along the south side of the Channel Islands);

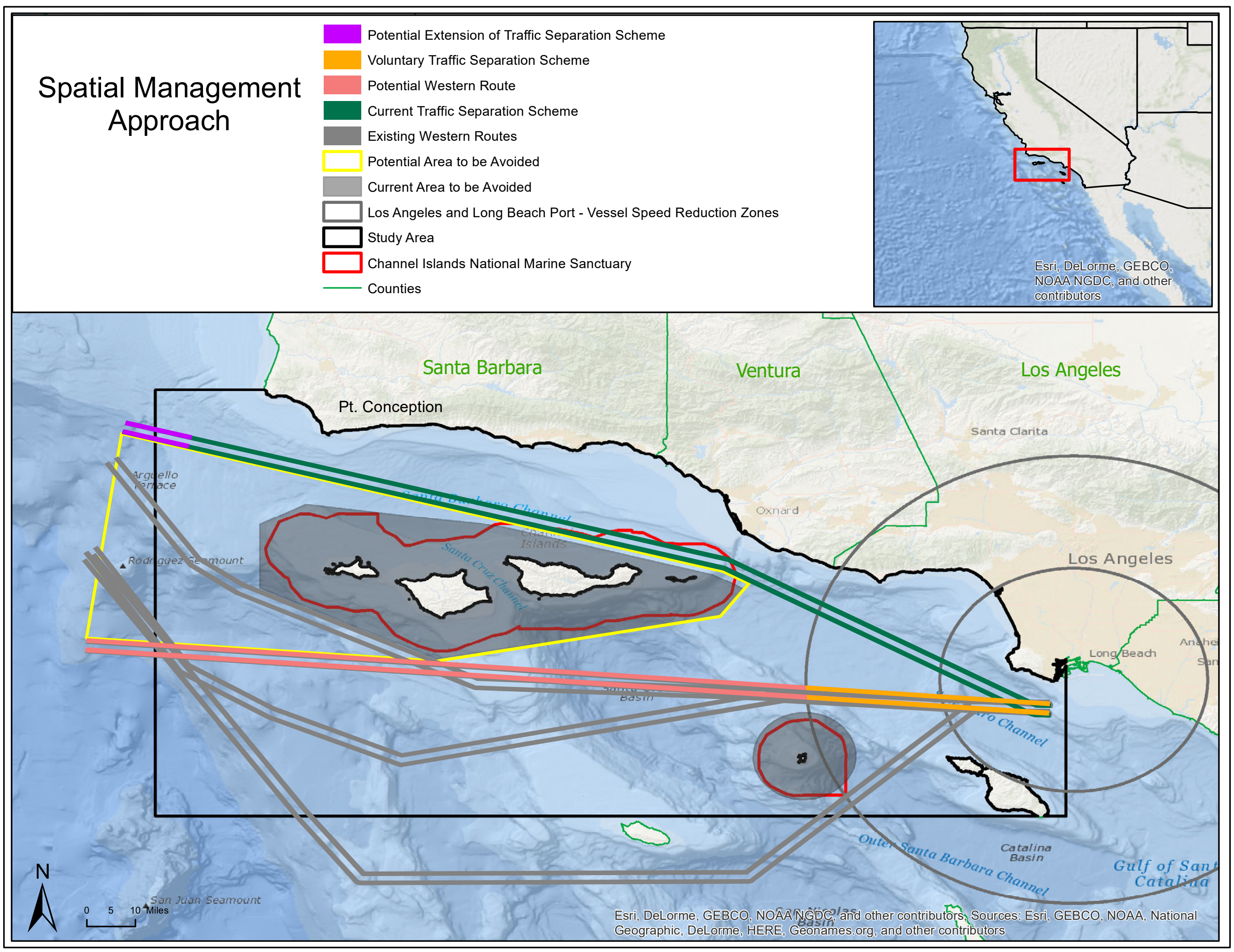

Figure 1.2. Spatial management approach.

[6] The study area extent is defined as North: 34.576; East: -118.250751; South: 33.302; West: -120.971. It should be noted that the study area is not a square, but an irregularly shaped polygon that follows the coastline. This includes the California coastline from Conception to the Port of Los Angeles/Long Beach.

3. an Area to Be Avoided (ATBA) expansion; and,
4. a seasonal VSR to 12 knots from approximately April 1st to November 15th to overlap with whale visitation and ozone season.

A comprehensive report with a range of solutions to address local impacts and solutions to explore ship routing options and incentives for a VSR was developed and presented to the SAC in March 2016.

The SAC recommended that CINMS staff carefully review the MSWG final report (Channel Islands National Marine Sanctuary Advisory Council Marine Shipping Working Group, 2016) and work in collaboration with other agencies and interested parties to continue pursuing the feasibility of the various approaches listed within the report. In addition, CINMS staff requested analyses of four variations of the components above in order to expand the analysis. These variations include:

1. the spatial management approach with a 10-knot seasonal VSR, as opposed to a 12-knot seasonal VSR;
2. a 12-knot seasonal VSR only;
3. a 12-knot seasonal VSR only; and
4. the combined vessel re-routing components only: TSS Extension, new Western Route, and ATBA expansion.

Thus, the objective of this report is to assess for CINMS and other agencies the economic effects of the following potential management measures (hereafter termed potential management measures, Table 1.1) through a shipping cost analysis:

12-knot seasonal VSR with vessel re-routing (introduced above)

- TSS extension
- new Western route
- ATBA expansion
- seasonal 12-knot VSR

10-knot seasonal VSR with vessel re-routing

- TSS extension
- new Western route
- ATBA expansion
- seasonal 10-knot VSR

12-knot seasonal VSR only

- seasonal 12-knot VSR

10-knot seasonal VSR only

- seasonal 10-knot VSR

Table 1.1 Potential management measure components.

Potential Management Measures	TSS Extension	New Western Route	ATBA Expansion	Seasonal VSR
12-knot seasonal VSR with vessel re-routing	YES	YES	YES	YES – 12 Knots
10-knot seasonal VSR with vessel re-routing	YES	YES	YES	YES – 10 Knots
12-knot seasonal VSR only	NO	NO	NO	YES – 12 Knots
10-knot seasonal VSR only	NO	NO	NO	YES – 10 Knots
Vessel re-routing only	YES	YES	YES	NO

Vessel re-routing only

- TSS extension
- new Western route
- ATBA expansion

The methods used in this analysis include estimating vessel inventory carrying costs (ICCs) and vessel transportation costs (VTCs). To predict the effects of the potential management measures, baseline estimates from 2015 are compared to estimates under the measures. While it is recognized that many types of costs may be impacted by alterations of current vessel operating characteristics, it was assumed that costs beyond ICCs and VTCs would be largely mitigated in the long-run owing to schedule revisions undertaken by shippers and ports that incorporate necessary changes. All monetary figures are expressed in 2015 dollars and t-tests at the 95% confidence interval were used to determine if differences are statistically significant[7] (hereafter termed significant). Differences in costs are measured both as total values across all vessels and in per 1,000 metric-ton nautical mile (MT-NM) units and differences in transit distance, speed, and time are measured per vessel transit.

This report is organized into five additional sections:

- Background: This section reviews the pertinent literature and background of the Los Angeles (LA)/ Long Beach (LB) Port Complex;
- Data: This section describes the various datasets and their required processing steps;
- Methods: This section describes the economic methods used;
- Results: This section provides a description of the results of the study; and
- Discussion: This final section discusses the key findings of the study.

Whale struck by ship. Credit: R. Freedman (NOAA).

[7] The term significance does not imply importance.

Section 2
Background


Los Angeles/Long Beach Port Complex. Credit: K. Louttit (Marine Exchange of Southern California).

2.0. BACKGROUND

To provide additional context for the potential management measures analyzed in this report, this section reviews the pertinent literature and background of the LA/LB Port Complex. The literature review discusses common rationales for vessel re-routing and VSRs. It also explores an example of a management measure implemented on the United States East Coast, including its effectiveness in reducing the likelihood of fatal vessel strikes on right whales and its overall economic impact to the shipping industry along the United States East Coast. The background of the LA/LB Port Complex illustrates the economic importance, trends, and major events of the region.

2.1. LITERATURE REVIEW

Marine commercial transportation is considered one of the more sustainable and efficient methods of shipping goods and resources (Corbett and Fischbeck, 1997; Corbett et al., 2003; Zis et al., 2015). As ocean going vessels (OGV) have become more commonplace and more suitable to travel at faster speeds, the issue of vessel strikes has become more prominent as well (Laist et al., 2001). The vessel strike issue has prompted conservation initiatives and management measures aimed at reducing the risk of vessels striking whales, including the establishment of time- and/or area-specific modifications to vessel routing to minimize the probability of a strike occurring, establishment of time- and/or area-specific VSRs to minimize the likelihood of lethality of a strike should it occur, and provision of incentives or education to vessel operators to influence their behavior.

Re-routing vessels around areas of high whale density has been shown to reduce the probability of a vessel strike occurring (Clyne and Leaper, 1999; Russell et al., 2001; Gende and Hendrix, 2007; Vanderlaan et al., 2009; Gende et al., 2011; Conn and Silber, 2013; Laist et al., 2014; Van der Hoop et al., 2014; Van der Hoop et al., 2016) and reducing vessel speed has been shown to reduce the severity of vessel strikes (Vanderlaan and Taggart, 2006; Wang et al., 2007; Wiley et al., 2011).

As a result, economic opportunities arise with the promise of future healthy and thriving cetacean populations. Whales are valued worldwide not only within the food and tourism industries, but also for their cultural and ecological significance. Since the decline of commercial whaling in the mid-1980s (Onofri and Nunes, 2015), the whale watching industry has become a prevalent and economically viable form of eco-tourism (Cisneros-Montemayor et al., 2010) and is a common factor in estimating the market, non-consumptive value of whales (Loomis and Larson, 1994; Hoagland and Meeks, 2000; Farr et al., 2013; Onofri and Nunes, 2015). In 2008, whale watching was estimated to have grown into a $2.1 billion industry supporting 13,000 jobs across 119 countries with North America being the dominant destination for 50% of the world's whale watchers (O'Connor et al., 2009). The CINMS, in particular, attributed 119 jobs and $1.5 million in revenue to whale watching in 1999 (Leeworthy et al., 2005).

Vessel re-routing can be implemented by creating or modifying a TSS (Merrick and Cole, 2007; Guzman et al., 2012), establishing recommended routes (Silber et al., 2012), or by establishing ATBAs (Vanderlaan and Taggart, 2009; Van der Hoop et al., 2012). VSRs have been achieved through instituting Seasonal Management Areas (SMAs) and Dynamic Management Areas (DMAs) (Federal Register, 2008). Both SMAs and DMAs are management areas established in areas of known and/or predicted high whale density in which vessels are required to travel at or below a certain speed. However, SMAs are fixed seasonal areas, whereas DMAs are temporary and established on short notice to protect aggregations of whales found at unpredictable locations outside of active SMAs.

These VSRs and routing regulations can be either voluntary or mandatory, but research has shown that mandatory measures tend to be more effective due to threat of fine or penalty (Duprey et al., 2008; Lagueux et al., 2011; McKenna et al., 2012; Silber et al., 2012; Silber and Bettridge, 2012). However, one voluntary measure that has been shown to be effective is an ATBA in the Roseway Basin of the Nova Scotian shelf, which, within five months of implementation, had a 71% compliance rate among vessels and an 82% reduction in strike risk. The effectiveness of this measure is likely due to its international recognition and outreach, including adoption by the International Maritime Organization (IMO), and the fact that recommendations for voluntary avoidance and speed reduction within the Roseway Basin Right Whale Conservation Area have been printed on the back of Canadian Hydrographic Service navigation charts since 2000 (Vanderlaan and Taggart, 2009; Van der Hoop et al., 2012).

Incentives can also be used to influence vessel operator behavior. For example, through the Green Flag Program, the Port of Long Beach rewards vessel operators for slowing cargo vessels to less than or equal to 12 knots within 20 nautical miles (NM) of the harbor with up to a 15% reduction in docking rates and rewards vessel operators that slow to less than or equal to 12 knots within 40 NM of the harbor with up to a 30% reduction in dockage rates. The program has been highly successful in reducing smog-forming emissions and diesel particulates from ships. As of 2015, compliance is over 96% within the 20 NM zone and over 88% within the 40 NM zone (Port of Long Beach, 2016a, 2016b). Moreover, if vessels use newer, cleaner engines, they are eligible to receive up to $6,000 per ship call through the Green Ship Incentive Program.

These programs, in particular, illustrate how VSRs can also be targeted to reduce pollution emissions (Corbett et al., 2009; Lack et al., 2011; Chang and Wang, 2012; Khan et al., 2012; Li et al., 2013). This is important because OGVs emit air pollutants in high volumes (Corbett and Koehler, 2003; Corbett et al., 2007; Wang et al., 2007), which negatively affect the environment and human health. For example, OGVs are responsible for 2.7% to 3% of global anthropogenic CO2 emissions, a pollutant linked to climate change, and this percentage is predicted to increase (Eyring et al., 2005; Buhaug et. al., 2009; Eyring et. al., 2010). SO2, along with NOx, emissions are a cause for concern due to their transformation into acids and the subsequent acidification of water/soil and damaging of crops, forests, and oceans.

Related to human health, ship-based emissions of SOx, NOx, CO, and PM have been shown to increase the risk of chronic and acute cardiopulmonary diseases and premature mortality in infant and adult humans (Pope et al., 2002; Corbett et al., 2007; Kampa and Castanas, 2008; Winebrake et al., 2009; Gurjar et al., 2010; Muller et al., 2011). Specific to the coastal zone, Corbett et al. (2007) modeled global PM emissions from OGVs and found that shipping-related PM emissions are responsible for 60,000 cardiopulmonary and lung cancer mortalities, mostly concentrated along coastlines in Europe and Asia. A smaller geographic scale health risk assessment in Southern California found that 1,400 (21%) and 3,400 (8%) of asthma-related bronchitis cases in Long Beach and Riverside (respectively) were attributed to OGV emissions of NO2 and ozone (Perez et. al. 2009).

Education and outreach have also been used to communicate concerns regarding vessel strikes and to influence vessel operator behavior (Russel et al., 2001; Parsons, 2012; Silber and Bettridge, 2012; Silber et al., 2014). As Wiley et al., 2016 documented in the observation of two separate vessel strikes in the North Atlantic, even the most experienced crews and observers are often incapable of reacting quickly enough to avoid a whale strike. Until innovative mitigation measures or technology are discovered and vetted, VSRs and vessel re-routing along with education of vessel operators is the best option in reducing whale strikes. Examples of this approach include Broadcast and Local Notices to Mariners, satellite-linked marine safety broadcasts, NOAA Weather Radio, the mandatory ship reporting system, the National Buoy Data Center, and e-mail notifications/monthly summaries to individual vessels.

One of the most effective sets of measures implemented to reduce lethal vessel strikes was the 2008 North Atlantic Right Whale Ship Strike Reduction Rule (RWSSRR). This mandatory measure established ten SMAs and allowed for DMAs and a seasonal ATBA to slow all vessels 65 feet in length or greater to 10 knots or less during specified times of the year.[8] These SMAs extend 20 nautical miles from major port entrances along the right whales' coastal migratory corridor between southern New England and Georgia, in feeding areas off the coast of Massachusetts, and in the core of the right whales' calving grounds off the southeastern United States coast of Georgia and Florida (Federal Register, 2008).

For the first two years following implementation of the rule, NOAA's Office of Law Enforcement sent outreach letters, rather than citations, to vessels observed traveling in excess of the specified speed. Following the first two years, NOAA's Office of General Counsel began issuing Notices of Violation and Assessment (NOVAs) of civil penalties to some of the more egregious (by distance, speed, or frequency) violators (Silber and Bettridge, 2012). From November 2010 until September 2012, 28 NOVAs were issued, with fines ranging from $5,750 to $92,000 and averaging $21,845 per violation depending on the number of previous violations (Silber et al., 2014).

These mandatory measures have proven to be effective in reducing the likelihood of fatal vessel strikes, decreasing the probability of right whale mortality from ships by 71.9% from the pre-implementation period (Lagueux et al., 2011), and achieving a significant reduction in right whales killed by ships from 2.0 (2000–2006) to 0.33 whales per year (2007–2012) (Laist et al., 2014; Van der Hoop et al., 2014).

However, vessel re-routing and vessel speed reduction may increase vessel transit times, which may cause delayed or missed port calls (Kite-Powell and Hoagland, 2002; Nathan and Associates, 2012), or avoidance of certain ports altogether (Kite-Powell, 2005), all of which will likely affect costs to the shipping industry. To estimate these effects, researchers primarily use cost-calculation models (Kite-Powell and Hoagland, 2002; Reeves et al., 2007; Chang and Wang, 2012; Nathan and Associates 2012) and profit maximization techniques (Corbett et al., 2009; Li et al., 2013) to model how management measures may affect shippers' profitability. The United States Maritime Administration's (MARAD) Port Economic Impact kit is also used to analyze the economic impacts of vessel strike reduction measures (Kite-Powell, 2005; Nathan and Associates, 2012; Silber and Bettridge, 2012) and to assess port productivity by analyzing infrastructure characteristics in ports, such as crane, berth, and land utilization, gate throughput, and truck turnaround time (Le-Griffin and Murphy, 2006).

Before the 2008 North Atlantic RWSSRR was implemented, researchers estimated the potential economic impact and found that reducing ship speed to 10 knots when traveling in and out of ports over a distance of 25 nautical miles during an annual 60-day season would result in additional costs of $2,350 per affected ship call and an overall annual cost to the United States East Coast shipping industry of $29.3 million (2015$; Kite-Powell and Hoagland, 2002).

Since implementation of the rule, the majority of studies have found the overall economic impact to the shipping industry along the United States East Coast to be minimal relative to the total volume of trade. One study that assumed 100% compliance with the 2008 rule found that the total direct impact to the United States East Coast shipping industry in 2009 was $23.8 million, roughly 0.006% of the $399.3 billion value of United States East Coast maritime trade (Nathan and Associates, 2012). The same study also found that the rule impacted commercial fishing by roughly $0.9 million (about 0.1% of total value of United States east coast commercial fishery landings), charter fishing by roughly $1 million (about 4.3% of total annual United States east coast charter fishing revenue), and had a negligible impact on ferry operations and whale watching tour vessels. Another study estimated the impacts to the shipping industry with 100% compliance to be $59.6 million (2015$) and $84.4 (2015$) million using 2009 and 2012 bunker fuel prices, respectively (Silber and Bettridge, 2012). Table 2.1 summarizes the major findings from the literature.

[8] Vessels may operate at a speed greater than 10 knots only if necessary to maintain a safe maneuvering speed in an area where conditions severely restrict vessel maneuverability as determined by the pilot or master (Ian Mathis, personal communication, November 11, 2016).

Table 2.1 Summary of relevant literature.

Study	Objective	Findings (2015$)	
Powell and Hoagland (2002)	Estimate economic effects for shipping of management efforts along US East Coast	Average cost per affected ship call Total annual cost to US East Coast shipping industry	3,086 13.1 million
Kite-Powell (2005)	Estimate economic effects of shipping management scenarios	Contribution per port call to GDP of cruise ships, container ships, tankers, and dry bulkers using Boston as their home port Loss in gross state product	1.2 million 26.3 million to 58.6 million
Reeves et al. (2007)	Evaluate effectiveness of expenditures on right whale recovery and research	Costs of all actions •2003 •2004 •2005	 16.6 million 20.6 million 18.8 million
Corbett, Wang, and Winebrake (2009)	Evaluate effectiveness of VSRs for CO2 mitigation	Amount of fuel tax per metric tonne to decrease CO2 emissions by 20 to 30 Cost per metric tonne of CO2 abated of VSR targeted to reduce CO2 emissions by 20	166 33.25 to 222
Chang and Wang (2012)	Evaluate effectiveness of vessel air pollution reduction strategies	Net cost per metric tonne of switching from residual to distillate fuel	231
Nathan Associates, Inc. (2012)	Economic impact of NARWSSRR	Direct impact on shipping industry Direct impact on commercial fishing and charter fishing Indirect impacts	26.2 million 2.1 million 20.9 million
Silber and Bettridge (2012)	Evaluate effectiveness of the NARWSSRR	Maximum total economic impacts •Using 2009 bunker fuel prices •Using 2012 bunker fuel prices	 57.5 million 82.4 million

2.2. LOS ANGELES/LONG BEACH PORT COMPLEX

International trade via cargo vessels represents a significant portion of the economy in the United States. In 2014, the Gross Domestic Product (GDP) of the United States approached $17.4 trillion (United States Bureau of Economic Analysis). The value of total imported and exported goods was almost $4 trillion dollars, or roughly 23% of GDP, and waterborne traffic represented 70.5% of the tonnage and 44.4% of the value of imported and exported goods in the United States.[9] Additionally, containerized freight represented approximately 14% of total waterborne weight and over 25% of total cargo value (see Wolfe, 2016 for details).

Encompassing seventeen underlying vessel ports and airports, the LA/LB Port Complex ranks first among the 40-plus Port Complexes in the United States in terms of the total cargo value of imported and exported goods and is consistently among the top three port complexes in terms of total tonnage handled (see Wolfe, 2016 for details). In 2014, the LA/LB Port Complex represented 10% of the tonnage and 12.8% of the value of imported and exported goods moving through United States ports. Furthermore, in the LA/LB Port Complex, 55% of the tonnage and 67% of the total cargo value is carried in containers. With the exception of finished automobiles, the average value of containerized traffic (per ton) is greater than all other commodities in the LA/LB Port Complex combined.

In 2000, there were almost 225 million containers in worldwide service. By 2014, that number had risen to over 679 million, a three-fold increase. While world GDP is scheduled to increase at a 4.0% annual rate from 2015 to 2018, container growth is forecast to increase between a 5.3% and 6.5% annual growth rate. At a 5% increase, the total container freight counts (as measured by Twenty-Foot Equivalent Units (TEUs)) will increase

[9] While the amount and value of cargo handled via water had increased in recent years, the proportion of total imports and exports has declined owing to large increases in the importation of crude oil from Canada through railroads and pipelines. Source: Association of American Railroads and the Department of Transportation's Maritime Administration (MARAD).

2.5-fold within 20 years and 3.3-fold if 6.5% annual increases are achieved. Consequently, future near-term TEU increases in the ports of LA/LB Port Complex traffic levels seem all but certain.

Several events have taken place in the LA/LB Port Complex region that have affected vessel traffic patterns. For example, the last recession, lasting from December 2007 until June 2009, decreased the amount of tonnage that came through LA/LB Port Complex and is hypothesized to have set back containerized trade growth by six to seven years (The Tioga Group, 2009).

Additionally, regulations have been specifically aimed at reducing the amount of sulfur in marine diesel fuels and thus require OGVs to use more expensive, yet cleaner distillate fuels within designated emission control areas (Khan et al., 2012). As of January 1, 2014, all OGV must use fuel with no more than 0.1% sulfur content within 24 NM of the California coast and, as of January 1, 2015, all OGV within the North American Emissions Control Area (ECA; 200 nautical miles off the United States coast) must also use fuel with no more than 0.1% sulfur content.

Furthermore, labor strife has affected the LA/LB Port Complex. Near the end of 2012, dockworkers went on an eight-day strike that shut down ten of the port complex's fourteen container terminals. This caused a large backlog of traffic, countless shipment delays, and a diversion of traffic to Northern California and Mexico. In July 2014, port traffic was slowed again for nearly eight months due to labor strife between the terminals and dockworkers over a contract expiration. A full strike or lockout never materialized, but between October 2014 and May 2015, as many as thirty-two ships were anchored near the LA/LB Port Complex, with as many as twelve vessels adrift in Mexican waters, waiting to be offloaded. Figure 2.1 delineates a timeline of significant events affecting the LA/LB Port Complex since 2005.

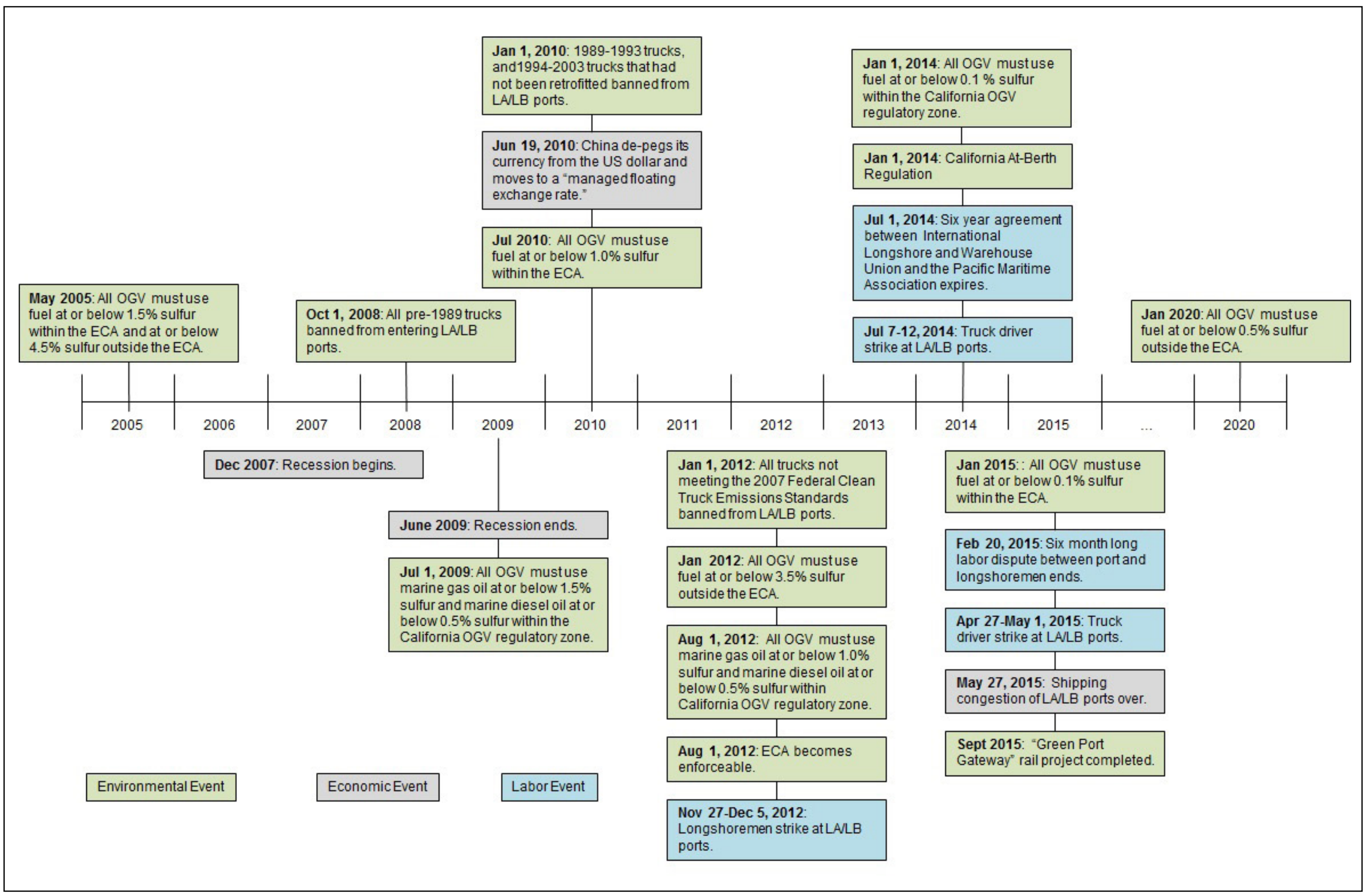

Figure 2.1. Time line of major events affecting waterborne traffic.

Section 3
Data

Los Angeles/Long Beach Port Complex. Credit: K. Louttit (Marine Exchange of Southern California).

3.0. DATA

There are two types of datasets used in this analysis: spatial and economic. The spatial dataset is comprised of data from the Automatic Identification System (AIS), which allows users to track where vessels are in a particular area as well as their speeds and directions of travel. The economic datasets include the Department of Commerce's Bureau of Census' USA Trade® Online, the United States Army Corps of Engineers' (USACE) National Navigation Operation and Maintenance Performance Evaluation and Assessment System (NNOMPEAS), and Ship and Bunker.

USA Trade® Online provides information on cargo value, which is the key component for calculating hourly ICCs. NNOMPEAS provides information on vessel fuel consumption, vessel pollution emissions, and minimum engineering viability speeds for vessel transits. Ship and Bunker provides information on vessel fuel prices. Combined, vessel fuel consumption and vessel fuel prices are the key components for calculating hourly VTCs. Finally, minimum engineering viability speeds for vessel transits allows for an estimate of vessel speed under a seasonal VSR.

The spatial and economic datasets are linked by data from the Authoritative Vessel Identification Service (AVIS), which provides information on vessel cargo and vessel dimensions for each vessel in the study area.

3.1. AUTOMATIC IDENTIFICATION SYSTEM

AIS is an automatic tracking system used to track OGV for the purposes of relaying a vessel's geographic position to maritime authorities and other vessels in the surrounding area, tracking compliance with maritime regulations, assisting in search and rescue endeavors, monitoring fishing fleets, and overseeing accident investigation. The IMO's International Convention for the Safety of Life at Sea (SOLAS) requires AIS transmitters to be fitted aboard all ships of 300 gross tons (gt) and greater on international voyages, cargo ships of 500 gross ton (GT) and greater not on international voyages, and all passenger ships regardless of size (Federal Register, 2015).

Because speed, heading, and position of a vessel are reported every 2 to 10 seconds, linear vessel track lines can be generated by joining successive AIS position report points corresponding to vessel Maritime Mobile Service Identity (MMSI) numbers. When all vessels are examined together, a snapshot of all large vessel traffic in an area can be constructed. This snapshot can aid in understanding where high-density vessel traffic occurs, if this high-density traffic overlaps with areas of relative importance for whales (e.g., mating, feeding, calving, and migrating), how vessels might be affected by speed and/or route restrictions, and if vessels ultimately comply with such restrictions.

Vessel track lines were generated following Jensen et al. (2015). First, a subset of AIS point data was selected to include only vessels identified as Container, Tanker, Ro-Ro, Ro-Ro/Combo, and Dry Bulk. This AIS point data were further subset to only include points for which the navigational status was underway using engine, restricted maneuverability, underway sailing, or was undefined. In a few cases, points were included regardless of the navigational status if speed over ground was greater than 1 knot. However, all AIS data points were removed where speed over ground was zero. Consecutive AIS data points for a given vessel were then joined into a line if the heading between consecutive points differed by less than 30° and the time elapsed was either less than one hour or greater than one hour, but less than 24 hours. Finally, consecutive lines representing unique voyages were combined into polylines until the criteria for generating a line were no longer met or a line entered the LA/LB Port Complex.

Data

In order to generate summary tables for each unique voyage that occurred in the study area, polylines representing unique voyages were overlaid on the MSWG study area polygon and the 20 NM and 40 NM VSR zones. The summary tables include the vessel MMSI, transit start and end times, direction (inbound or outbound), route (North or West), distance (NM), time (hours), and average speed (knots) for the portions of the transit occurring in the 20 NM VSR zone, the 40 NM VSR zone, and in the study area, but outside the VSR zones.

Finally, to depict spatial patterns in vessel traffic, maps depicting the length of vessel transits in 1 x 1 kilometer grid cells were generated for all vessels (Figure 3.1) as well as individually for Container, Tanker, Dry Bulk, Ro-Ro, and Ro-Ro/Combo vessels (Appendix C). Maps depicting the proportion of the vessel transit length in each 1 x 1 km grid cell where speed over ground was greater than 12 knots were also generated.

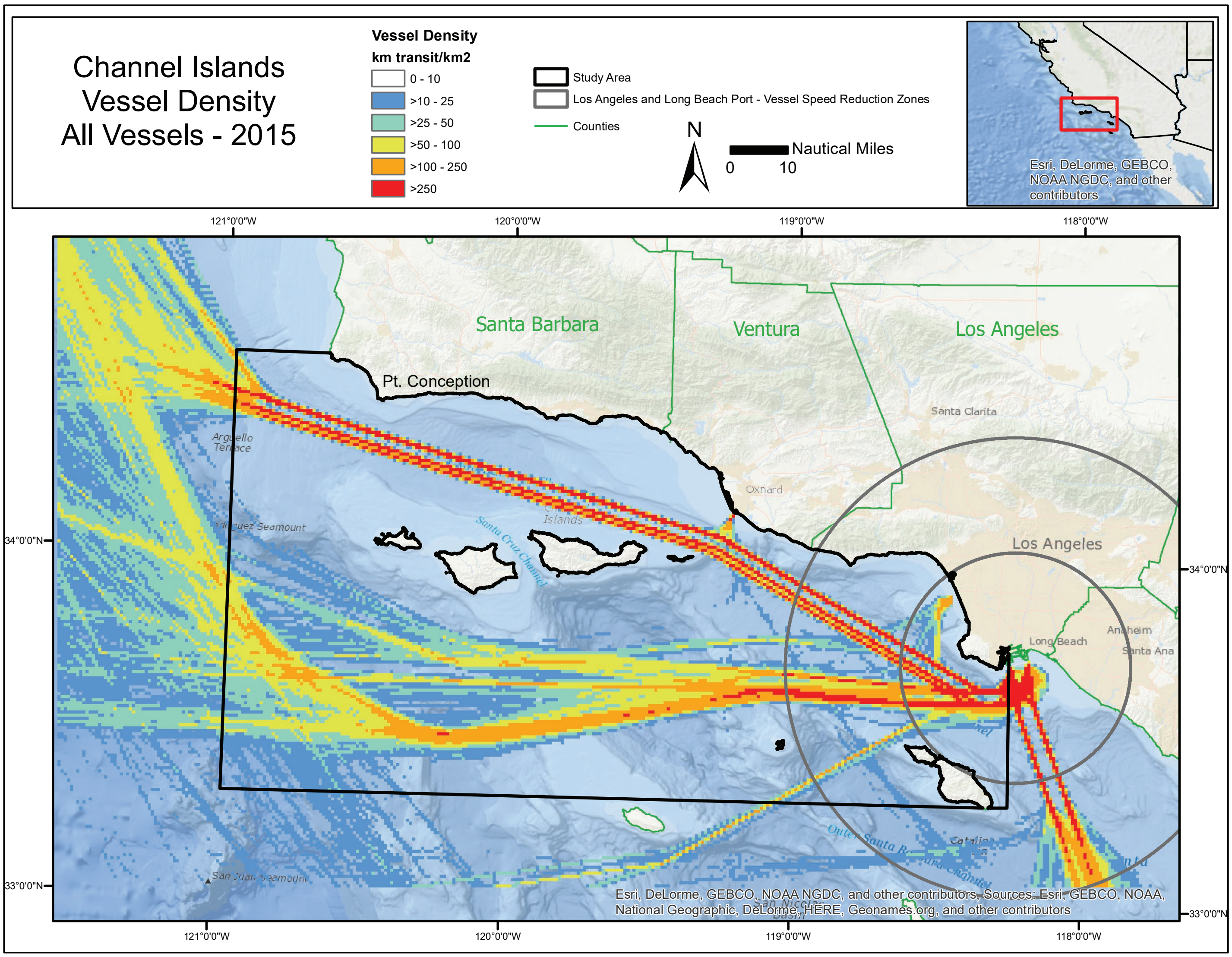

Figure 3.1. Channel Islands vessel density (all vessels, 2015).

3.2. AUTHORITATIVE VESSEL IDENTIFICATION SERVICE

AVIS was developed by the USCG to account for identification and measurement errors in AIS data transmission as multiple ships using the same MMSI in the same local region can cause safety issues and make it difficult to track the history of a vessel. To address these errors, AVIS incorporates the authoritative and verified data elements (e.g., call sign, MMSI, vessel name, and IMO) from each authoritative information source (e.g., Federal Communications Commission (FCC), USCG, and Lloyd's Register of Shipping (LRS)) in order to make comparisons with raw AIS data to yield proper decisions as to whether a vessel is properly identified.

AVIS[10] enables the AIS data to be linked with economic data as it provides vessel type, cargo type, and vessel dimensions, such as length, beam, draft, and dead weight tonnage (DWT), by MMSI.

The following steps were taken to prepare the vessel data from AVIS:

1. Vessels identified as non-vessels or scrapped were removed. Of the 8,764 unique vessels, 17 were non-vessels, 337 had been scrapped, and 29 had an MMSI value of zero. Removing these vessels left 8,433 unique vessels in the data set for analysis.
2. Vessels were parsed into six different vessel categories: Container, Tanker, Dry Bulk, Ro-Ro, Ro-Ro/Combo, and all other vessels, based on reported vessel and cargo type and on expert opinion. Generally, Container vessels carry all of their load in intermodal containers; Tanker vessels carry liquids or gases in bulk; Dry Bulk vessels carry unpackaged bulk cargo, such as grains, coal, ore, and cement, in cargo holds; and Ro-Ro vessels carry wheeled cargo, such as trucks, semi-trailer trucks, trailers, and railroad cars, that are driven on and off the ship on their own wheels or using a platform vehicle. Ro-Ro/Combo vessels were subsequently defined in order to account for Ro-Ro vessels that carry other types of cargo in addition to wheeled cargo. The remaining vessels, roughly 43% of the vessel population, included United States military ships, shoreline barges, rafts, tugboats, and cruise ships, which were removed due to a lack in economic data.
3. To determine if systematic bias exists in the reporting of data, the relationships between missing vessel dimension data and vessel and cargo type were analyzed. Nine draft values were missing for Tanker vessels, but no other vessel dimension data was missing.
4. The boxplot method was used to determine if outliers existed within the data. Nearly 6% of the data were considered outliers, with half coming from Dry Bulk vessels (Table 3.1).
5. Missing and outlier vessel dimension values were replaced with averages by vessel and cargo type. This process resulted in only eight missing Tanker vessel draft values.
6. Class sizes were defined within each vessel category to simplify the process of assigning vessel cost and revenue values during the analysis. These classifications were performed using k-means cluster analyses[11] based on estimated vessel gross tonnage. Three size class clusters were defined for Container, Tanker, Dry Bulk, and Ro-Ro vessels, and one size class cluster was defined for Ro-Ro/Combo vessels.

Table 3.1. Incidence of outliers excluded from analysis.

Vessel Category	# Length Outliers	# Beam Outliers	# Gross Ton Outliers	# Draft Outliers	# Total Outliers
Container	0	2	19	0	21
Tanker	35	14	0	15	63
Dry Bulk	6	84	58	4	152
Ro-Ro	0	0	1	0	1
Ro-Ro/Combo	33	14	0	15	62
TOTAL	**74**	**111**	**88**	**31**	**304**

[10] Vessel data were obtained on December 1, 2015 for all vessels within the study region.
[11] K-means clustering aims to partition observations into k different clusters in which each observation belongs to the cluster with the nearest mean.

7. Vessel data were joined with AIS data. Of the 4,819 unique vessels, 774 transited the study area across 4,072 transits in 2015.
8. Transit speed outliers were determined using the box-plot method. Five vessels/transits were classified as low-speed outliers (speeds less than 4.97 knots) and two vessels/transits were classified as high-speed outliers (speeds greater than 29.8 knots). These seven vessels/transits were then excluded from further analysis.
9. Transit distance outliers were also determined using the box-plot method. One hundred eighty-one vessels/511 transits were classified as low-distance outliers (distance less than 97.8 NM) and were excluded from further analysis.

Table 3.2 below shows the final number of vessels and vessel dimension statistics by size class.

Table 3.2. Vessel dimensions by category and size class. Standard errors shown in parentheses.

Vessel Category	Size Class	Count	Mean Length (meters)	Mean Beam (meters)	Mean Gross (tons)	Mean Draft (meters)
Container	Small	59	72.66 (1.27)	9.65 (0.11)	35,656 (1,098)	3.66 (0.04)
	Medium	150	90.63 (0.51)	11.51 (0.12)	63,527 (781)	4.21 (0.02)
	Large	119	103.99 (0.41)	13.56 (0.05)	103,411 (1,238)	4.51 (0.01)
Tanker	Small	17	48.09 (1.23)	7.80 (0.21)	15,474 (1,265)	3.02 (0.06)
	Medium	89	64.33 (0.90)	10.52 (0.15)	40,365 (1,252)	4.14 (0.03)
	Large	17	84.57 (1.50)	14.83 (0.20)	94,088 (5,070)	5.39 (0.13)
Dry Bulk	Small	40	53.30 (0.26)	8.56 (0.05)	19,625 (296)	3.04 (0.02)
	Medium	24	58.69 (0.46)	9.82 (0.01)	31,882 (40)	3.83 (0.02)
	Large	29	67.97 (0.43)	9.86 (0.05)	41,661 (525)	4.13 (0.07)
Ro-Ro	Small	4	42.03 (2.06)	6.86 (0.27)	11,843 (1,069)	2.74 (0.14)
	Medium	44	55.85 (0.29)	9.35 (0.07)	44,216 (623)	2.73 (0.02)
	Large	49	60.83 (0.08)	9.82 (0.01)	59,093 (280)	3.02 (0.01)
Ro-Ro/Combo	Medium	15	58.41 (0.00)	9.79 (0.02)	71,340 (844)	3.16 (0.07)

3.3. USA TRADE® ONLINE

Provided by the United States Census Bureau's Foreign Trade Division, USA Trade® Online is the official source of United States import and export statistics. The database provides current and cumulative data on more than 9,000 export commodities and 17,000 import commodities by county.

Goods are initially classified under the U.S. International Trade Commission's International Harmonized System (HS) Code, which classifies traded products into approximately 140 export and 140 import end-use categories and makes it possible to examine goods according to their principal uses.

The individual data elements employed in this analysis include:

- Container Shipping Weight - The gross weight in kilograms of shipments made by containers, including the weight of moisture content, wrappings, crates, boxes, and containers (other than cargo vans and similar substantial outer containers).
- Container Value - The value of goods that enter or leave the country by container.
- Total Shipping Weight - The gross weight in kilograms of shipments made by surface vessel and air, including the weight of moisture content, wrappings, crates, boxes, and containers (other than cargo vans and similar substantial outer containers).
- Vessel Shipping Weight - The gross weight in kilograms of shipments made by deep-sea vessels of all types (e.g., Container, Tanker, Dry Bulk, Ro-Ro), including the weight of moisture content, wrappings, crates, boxes, and containers (other than cargo vans and similar substantial outer containers).
- Vessel Value - The value of goods that enter or leave the country by surface vessels of all types (e.g., Container, Tanker, Dry Bulk, Ro-Ro).

Unlike container traffic, as other individual vessel type categories (e.g., Tanker, Dry Bulk, and Ro-Ro) are not specifically identified in the USA Trade® Online database, more granular analysis of commodities that tend to be transported in certain ships can be extracted from the data (Appendix A). Because the USA Trade® Online database also provides an up to 6-digit HS Code definition, it is possible to infer the value of cargo transported by Tanker and Ro-Ro vessels. The remainder of traffic combines Dry Bulk with general vessel traffic.

Once individual vessel categories had been identified, cargo values by vessel category were calculated based on the average weight of traffic transported within the LA/LB Port Complex from 2008 to 2014, allowing for an evaluation of both a recessionary and recovery economic period. These per metric tonne cargo values served as the basis for estimating ICCs.

3.4. NATIONAL NAVIGATION OPERATION AND MAINTENANCE PERFORMANCE EVALUATION AND ASSESSMENT SYSTEM

NNOMPEAS is a USACE tool for estimating marine transportation costs and performing economic analysis on USACE waterway projects. It is the standard source for all marine transportation cost data and is employed as the basis for considering the benefits of proposed USACE projects.

The data does not represent actual expenses to the firms for the shipment of goods as profit margin, market-pricing decisions, and competitive pricing strategies are highly sensitive and not shared by marine transportation companies. Rather, NNOMPEAS is a construct from a large number of variables, such as vessel length, breadth, draft, engine horsepower, crew, distance traveled, cost of fuel, engine fuel efficiency, and diameter of the propeller, all of which affect vessel operating costs (VOCs). It produces the best available compilation of shipping costs and gives USACE a more stable platform upon which to make comparisons across multiple years without having to consider the competitive elements of cost.

Data

In addition to costs, the NNOMPEAS provides estimates of vessel cargo carrying capacity by vessel category and size class from total DWT and estimates of fuel consumption by vessel category and size class, and estimates of up to ten environmental emissions (e.g., NOx, CO, and CO2) by vessel category and size class. These estimates are based on variables such as fuel type, engine type and size, immersed draft, and vessel speed. By employing non-linear estimation techniques, fuel consumption may be interpolated between NNOMPEAS figures provided across speed intervals.[12]

NNOMPEAS combines data from three sources:

1. Lloyd's Register of Shipping (LRS) & Lloyd's Maritime Intelligence Unit (LMIU) Sea-webTM. LRS provides information on vessel characteristics (e.g., vessel type, size class, physical dimensions, capacities, and speed) while Sea-webTM provides information on vessel itinerary for estimation of vessel transit distances over time or period of service.
2. USACE Institute for Water Resources (IWR) / Navigation Data Center (NDC) - Waterborne Commerce Statistics Center (WCSC) Statistics.
    a. Vessel information broken down by individual vessel name and identification by IMO/LRS number, tonnage handled, and transit draft, prior and post port information where available.
    b. The Port Import\Export Reporting Service (PIERS): is a proprietary product produced by the Journal of Commerce, which contains information on nature of cargo, cargo weight, and origins\destinations of cargo as well as, to some extent, vessel itinerary.
    c. Available information on project specifications from port series investigations.
    d. Estimated VOCs per unit of time as assembled by IWR.
3. Computerized\GIS generated voyage distance tables reconciled with both thumb line heading and course plots for transit as well as great distance calculators respective of ocean and waterway boundaries.[13]

3.5. SHIP AND BUNKER

Ship and Bunker is the world's most read marine fuel-focused publication and the leading independent source of quality daily industry news, exclusive features, and daily and historical bunker price indications. Bunker prices were obtained for three fuel types (IFO380, LS380, and MGO) and two ports (Singapore and Vancouver) from March 2012 to March 2016 (Figure 3.2). IFO380 is an intermediate fuel oil at or below 3.5% sulfur; MGO is marine gas oil at or below 0.1% sulfur; and LS380 is a blend of the two fuels at or below 1.0% sulfur.

Three fuel types were obtained due to changing fuel sulfur content regulations in the region and two ports were selected to represent a lower (Singapore) and upper (Vancouver) bound on prices.

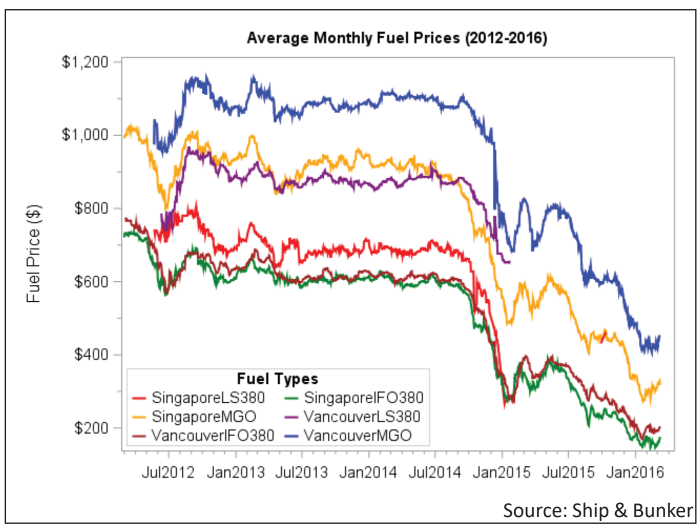

Figure 3.2. Average monthly fuel prices (2012-2016).

[12] As some of the formative and underlying information in the model is sensitive and proprietary, this information cannot be publicly released. Should an independent technical review be required, agreements for non-disclosure and non-alternative use can be put into place (Ian Mathis, personal communication, November 11, 2016).

[13] A thumb line is an arc crossing all meridians of longitude at the same angle (i.e., a path with constant bearing as measured relative to true or magnetic north).

Data

Humpback whale tail and shearwater. Credit: R. Schwemmer (NOAA).

Section 4
Methods

Whale in the path of a ship. Credit: J. Calambokidis (Cascadia Research).

4.0. METHODS

For this evaluation, the shipping cost analysis estimates the potential change in shipping costs associated with the potential management measures.

4.1. SHIPPING COST ANALYSIS

Speed and routing changes are predicted to affect the shipping industry in the following ways:

- altered VTCs owing to lower transit speeds;
- additional ICCs resulting from longer voyage times;
- foregone vessel revenue earning opportunities arising from the impact of cumulative trip slowdowns;
- added expenditures due to changes in land-based (e.g., motor carrier, railroad, etc.) supportive transportation and infrastructure;
- decline of regional income and industry support owing to potential diversion of traffic to other United States ports;
- reduction of national income and industry support resulting from diversion to foreign ports or avenues of transit (e.g., mini- and micro-bridge traffic);
- heightened costs resulting from economic dis-utilities (e.g., added waiting time) consequential from berthing congestion owing to slower transit speeds within the LA/LB Port Complex; and
- potential subsequent economic dis-utilities (e.g., missed berthing opportunities) stemming from subsequent stops at ports across differing port complexes.

In this analysis, with the exception of changes in VTCs and ICCs, it is believed that, in the long-run, scheduling and operating changes would accommodate the localized changes in the LA/LB Port Complex. Many of these factors involving future management decisions are unknown as the goals of individual vessel owners and shippers may be widely divergent (e.g., employing vessels as floating warehouse capacity, strategies in deployment based on back-haul opportunities, political decisions involving user fees and subsidies). Furthermore, VTCs account for roughly 63% of total logistics costs and ICCs account for roughly 33% (Council of Supply Chain Management Professionals (CSCMP), 2015). Consequently, these two changes in the economic environment are investigated under an all else equal set of conditions for the four vessel categories (Container, Tanker, Dry Bulk, and Ro-Ro), and three size classes (small, medium, and large). Due to the relative infrequency of Ro-Ro/Combo movements in the study area (about one percent of total), only one size of Ro-Ro vessels was employed in the study.

4.1.1. Inventory Carrying Costs

ICCs were calculated by vessel category using an annual commercial paper rate of 4% and the following:

ICC (per vessel transit) = (cargo value per tonne) * (number of tonnes carried) * (transit hours) * (hourly opportunity cost of capital [14])

4.1.1.1. Cargo Value per Tonne

Cargo value per metric tonne was estimated by vessel category and direction (inbound/import vs. outbound/export) of the shipment (Table 4.1) using data obtained from USA Trade® Online.

4.1.1.2. Number of Tonnes Carried

Cargo carrying capacities across three loading levels (minimum, medium, and maximum) were estimated for each vessel category and size class using the NNOMPEAS model. Three loading levels based on relative size were selected since vessels are loaded to their economic capacity, which is not necessarily the same as maximum capacity. The maximum estimated cargo carrying capacity, however, was used as the number of metric tonnes carried (Table 4.2) in order to provide an upper bound.[15]

[14] Hourly cost of capital = annual commercial paper rate *(1/(hours per year)) = 0.04*(1/8760)=0.0000046

[15] Note that gross tons, a unit of volume, were used to determine vessel size classes, whereas metric tonnes, a unit of weight, were used to determine carrying capacity.

Table 4.1. Cargo value per metric tonne.

Vessel Category	Cargo Value per Metric Tonne (2015$)		
	Import	Export	Total
Container	6,216	2,308	4,760
Tanker	690	723	692
Dry Bulk	4,067	928	3,201
Ro-Ro and Ro-Ro/Combo[1]	16,435	11,122	15,905

[1]As there was no way to identify the commodities carried by Ro-Ro/Combo vessels other than finished motor vehicles and trucks, cargo value for RO-RO vessels was employed for all Ro-Ro/Combos. The ultimate impact is unknown on changes in inventory carrying costs, as the mix between bulk and container movements on these vessels cannot be specifically identified from publically available records.

4.1.1.3. Transit Hours

Baseline transit hours were estimated using the AIS data. The following assumptions were made when predicting transit hours under the potential management measures:

1. Route: If a vessel traveled along the Northern or Western route in 2015, then the vessel continues to do so under any potential management measure.
2. Speed:
   a. If a vessel traveled at a speed less than or equal to the target seasonal VSR speed in 2015, then the vessel continues to do so under the potential management measure.
   b. If a vessel traveled at a speed greater than the target seasonal VSR speed in 2015
      i. and greater than its minimum engineering viability speed[16] (Table 4.2) in 2015, then the vessel slows down to either its minimum engineering viability speed or the target seasonal VSR speed, whichever is greater, under the potential management measure.
      ii. and slower than its minimum engineering viability speed[17] in 2015, then the vessel continues to do so under the potential management measure.

Table 4.2. Estimated cargo carrying capacity and minimum engineering viability speed by vessel category and size class.

Vessel Category	Size Class	Estimated Cargo Carrying Capacity (MT)	Minimum Engineering Viability Speed (Knots)
Container	Small	35,558	12.6
	Medium	58,323	13.5
	Large	98,584	14.0
Tanker	Small	27,090	7.7
	Medium	65,129	8.1
	Large	153,509	8.2
Dry Bulk	Small	22,952	7.6
	Medium	34,171	7.8
	Large	121,153	7.4
Ro-Ro	Small	14,453	10.4
	Medium	29,113	10.6
	Large	41,294	10.5
Ro-Ro/Combo	Medium	67,754	13.5

Source: United States Army Corps of Engineers; Output from the National Navigation Operation and Maintenance Performance Evaluation and Assessment System (NNOMPEAS), Reported by Ian Mathis on March 2, 22 and 29, 2016.

[16] According to USACE, vessels typically operate engines at a minimum of approximately 10% of power output for short or interim distances or else engine operation becomes unstable, and trying to run the prime mover at such loads becomes impractical and often tremendously accelerates wear or results in damage, especially given the nature of how diesels operate and more directly, given that you are typically or almost exclusively dealing with two-stroke slow speed diesels for many of the medium to larger size vessels. However, over extended distances, power consumption may be slightly higher at 12% to 17% depending on prime mover configuration to avoid excessive carbon buildup. Research is currently being conducted to determine the threshold between short and long or extended distances. (Ian Mathis, personal communication, November 11, 2016).

[17] In 2015, approximately 37.7% of transits were less than the vessel's minimum engineering viability speed (48.2% of Container transits, 2.5% of Tanker transits, 0.6% of Dry Bulk Transits, 17.1% of Ro-Ro Transits, and 48.3% of Ro-Ro/Combo transits). On average, these transits were 15.3% slower than the vessel's minimum engineering viability speed (15.5% slower for Container transits, 29.1% slower for Tanker vessels, 5.6% slower for Dry Bulk vessels, 8.5% slower for Ro-Ro vessels, and 17.7% slower for Ro-Ro/Combo vessels). These discrepancies are most likely because minimum engineering viability speeds are assigned based on size classes within vessel categories as opposed to on a per-vessel basis.

4.1.2. Vessel Transportation Costs

VTCs were calculated by vessel category and size class using the following:

VTC (per vessel transit) = (hourly fuel consumption) * (price per ton of fuel) * (transit hours)

4.1.2.1. Hourly Fuel Consumption

Hourly fuel consumption[18] across three loading levels (minimum, medium, and maximum) were estimated for each vessel category, each size class, and for various vessel speeds using the NNOMPEAS model. Based on these point estimates, minimum and maximum fuel consumption functions were estimated (Figure 4.1). For this analysis, minimum and maximum fuel consumption estimates were averaged to create expected fuel consumption estimates.

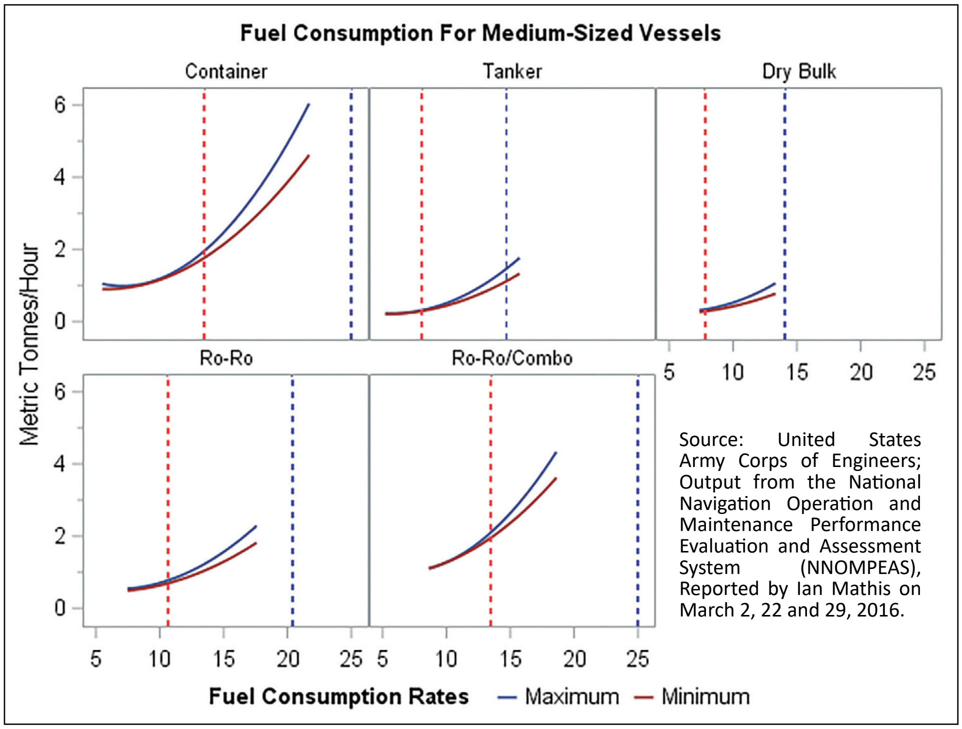

Figure 4.1. Fuel consumption for medium-sized vessels by vessel category. Dashed lines represent minimum and maximum engineering functionality speeds.

4.1.2.2. Fuel Price

Average monthly fuel prices from Singapore and Vancouver were used to represent the lower and upper bounds on fuel prices, respectively. For this analysis, average monthly 2015 MGO fuel prices from Singapore were used as expected fuel prices as this port sells the most fuel globally.

4.1.2.3. Transit Hours

The same assumptions for calculating transit hours for ICCs were used here.

[18] While the NNOMPEAS model provided fuel utilization estimates for both HFO and MDO, the difference in utilization is relatively small (normally about 3 percent) across vessel speed and size; therefore, only estimates of MDO fuels are used.

Section 5
Results

Port of Los Angeles, TraPac Container Terminal. Credit: Port of Los Angeles.

5.0. RESULTS

In 2015, there were 3,038 vessel transits through the study area. The majority of transits were by Container vessels (73.7%) and the least number of transits were by Ro-Ro/Combo vessels (1.0%). Most (77.3%) transits occurred along the Northern route.

The average speed was 13.8 knots[19], 68.2% of vessel transits were faster than 12 knots (Figure 5.1), and 93.8% of vessel transits were faster than 10 knots. Container vessels traveled the fastest and Dry Bulk vessels traveled the slowest, averaging 14.2 knots and 11.7 knots, respectively. Appendix D shows speed maps for each vessel category and how average speed varied by vessel category, size class, route, and direction and whether these average speeds are significantly different from 10 or 12 knots.

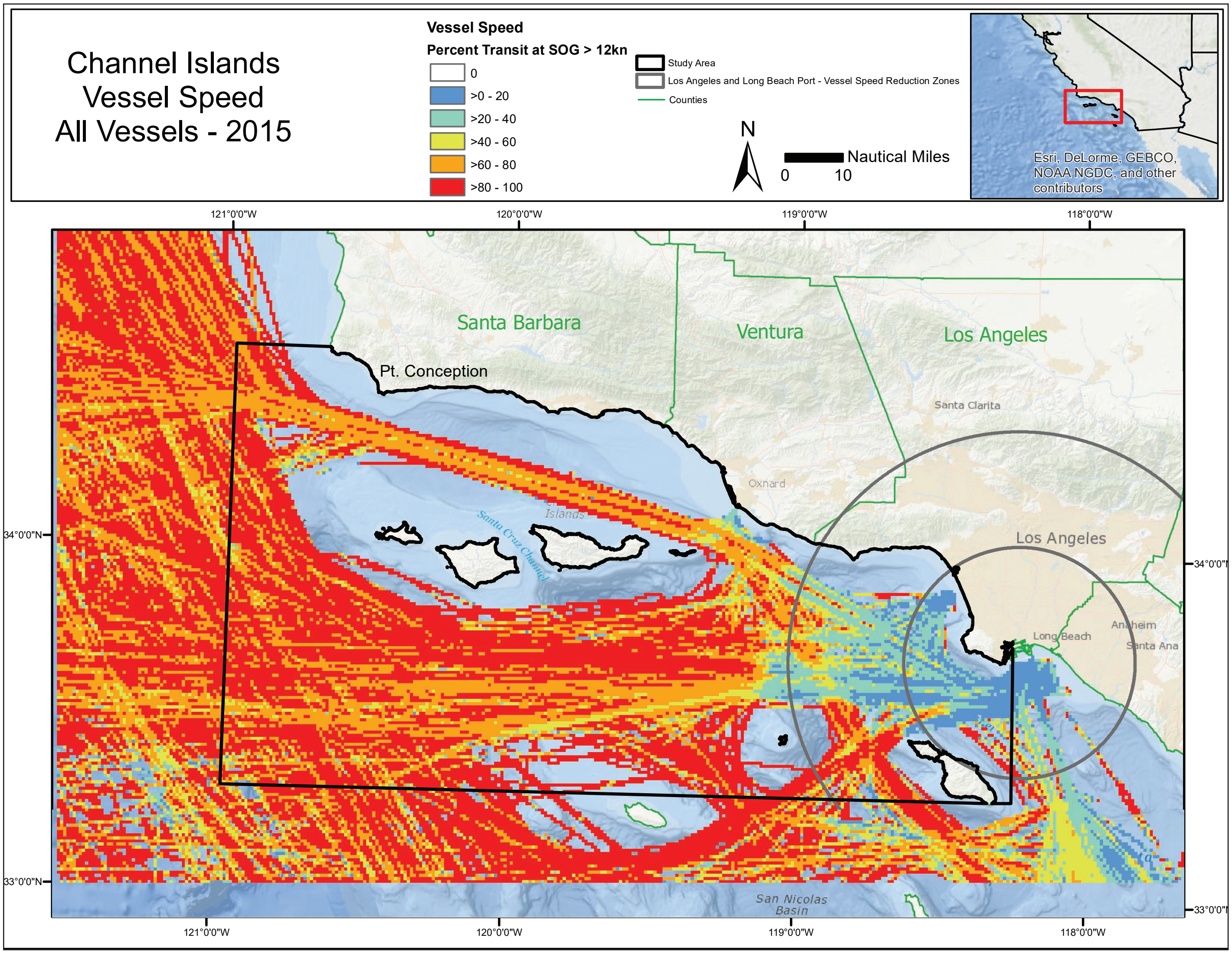

Figure 5.1. Percent of transits traveling faster than 12 knots in 2015.

[19] With a standard deviation of 3.03 knots and range of 5.2 to 22.5 knots.

Results

The total expected TCs were approximately $66.7 million, or, stated differently, $4.82 per 1,000 MT-NM. Expected TCs can be broken down into ICCs and expected VTCs. The total ICCs were approximately $43.6 million, or $3.12 per 1,000 MT-NM. The total expected VTCs were approximately $23.0 million, or $1.71 per 1,000 MT-NM.

The following sections analyze the predicted effects on shipping costs of the following potential management measures:

1. 12-knot seasonal VSR with vessel re-routing
2. 10-knot seasonal VSR with vessel re-routing
3. 12-knot seasonal VSR only
4. 10-knot seasonal VSR only
5. Vessel re-routing only

Assumptions on vessel speeds and routes under each potential management measure are provided in Section 4.1.1.3. Table 5.1 shows the predicted average transit distances, speeds, and times by route under each potential management measure, as well as the predicted seasonal VSR compliance rate based on 2015 speeds and minimum engineering viability speeds. The highest predicted seasonal VSR compliance rates are highest under the 12-knot seasonal VSR and along the Western route.

Table 5.1. Predicted transit distances, speeds, and transit times by potential management measure. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold.

Potential Management Measure	Route	Predicted Transit Distance (NM)	Predicted Transit Speed (knots)	Predicted VSR Compliance (%)	Predicted Transit Time (hours)
2015 Baseline	North	106.3	13.9	--	8.0
	West	107.2	13.6		8.4
12-knot VSR with vessel re-routing	North	**104.1**	**12.3**	42.0	**8.6**
	West	**97.7**	**12.0**	58.7	**8.3**
10-knot VSR with vessel re-routing	North	**104.1**	**12.0**	15.4	**8.8**
	West	**97.7**	**11.2**	38.0	8.9
12-knot VSR only	North	106.3	**12.3**	42.0	**8.8**
	West	107.2	**12.0**	58.7	**9.2**
10-knot VSR only	North	106.3	**12.1**	15.4	**9.0**
	West	107.2	**11.2**	38.0	**10.0**
Vessel re-routing only	North	**104.1**	13.9	--	**7.9**
	West	**97.7**	13.6		**7.6**

5.1. SHIPPING COST ANALYSIS

The results of the shipping cost analysis are detailed in the sections below and are summarized in Table 5.2 and Figures 5.2 and 5.3.

Table 5.2. Predicted changes in costs by potential management measure. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Potential Management Measure	Units	TC			ICC			VTC		
		Expected (2015$)	Change (2015$)	Change (%)	Expected (2015$)	Change (2015$)	Change (%)	Expected (2015$)	Change (2015$)	Change (%)
2015 Baseline	Total	66,658,476	--	--	43,637,547	--	--	23,020,929	--	--
	Per 1,000 MT-NM	4.83 (0.10)	--	--	3.12 (0.06)	--	--	1.71 (0.04)	--	--
12-knot seasonal VSR with vessel re-routing	Total	65,203,521	-1,454,959	-2.2	45,004,296	1,366,750	3.1	20,199,219	-2,821,710	-12.3
	Per 1,000 MT-NM	4.89 (0.10)	0.05 (0.01)	1.1	**3.35** (0.07)	0.22 (0.02)	7.1	**1.54** (0.03)	-0.17 (0.01)	-9.9
10-knot seasonal VSR with vessel re-routing	Total	65,620,003	-1,038,458	-1.6	45,674,691	2,037,145	4.7	19,945,326	-3,075,603	-13.4
	Per 1,000 MT-NM	4.92 (0.10)	0.08 (0.01)	1.7	**3.40** (0.07)	0.27 (0.02)	8.8	**1.52** (0.03)	-0.19 (0.01)	-11.2
12-knot seasonal VSR only	Total	67,539,241	880,766	1.3	46,741,530	3,103,984	7.1	20,797,711	-2,223,218	-9.7
	Per 1,000 MT-NM	4.89 (0.10)	0.05 (0.00)	1.1	**3.35** (0.07)	0.22 (0.01)	7.1	**1.54** (0.03)	-0.17 (0.01)	-9.9
10-knot seasonal VSR only	Total	68,018,508	1,360,034	2.0	47,492,598	3,855,051	8.8	20,525,912	-2,495,017	-10.8
	Per 1,000 MT-NM	4.92 (0.10)	0.08 (0.01)	1.7	**3.40** (0.07)	0.27 (0.01)	8.8	**1.52** (0.03)	-0.19 (0.01)	-11.2
Vessel re-routing only	Total	64,371,023	-2,287,472	-3.4	42,019,597	-1,617,969	-3.7	22,351,434	-669,503	-2.9
	Per 1,000 MT-NM	4.83 (0.10)	0.00 (0.01)	0.0	3.12 (0.06)	0.00 (0.01)	0.0	1.71 (0.04)	0.00 (0.00)	0.0

5.1.1. 12-knot Seasonal VSR with Vessel Re-Routing

Under a 12-knot seasonal VSR with vessel re-routing, 43.4% of vessels are predicted to comply with the seasonal VSR component and the average speed is predicted to significantly decrease to 12.3 knots[20] during the VSR season. Ro-Ro and Container vessels are predicted to decrease in speed the most by 9.3% and 8.1%, respectively.

Total expected TCs are predicted to decrease to approximately $65.2 million (2.2% decrease). Due to significant decreases in transit distance, this translates to a non-significant increase to $4.89 per 1,000 MT-NM (1.1% increase). Total ICCs are predicted to increase to approximately $45.0 million (3.1% increase), or a significant increase to $3.35 per 1,000 MT-NM (7.1% increase). Total expected VTCs are predicted to decrease to approximately $20.2 million (12.3% decrease), or a significant increase to $1.54 per 1,000 MT-NM.

Table E.1 (Appendix E) shows how costs are predicted to change for medium-sized vessels by vessel category, route, direction, fuel efficiency, and fuel costs. TCs are predicted to decrease significantly in most cases for Container and Tanker vessels and in some cases for Dry Bulk and Ro-Ro vessel groups. TCs are predicted to increase significantly

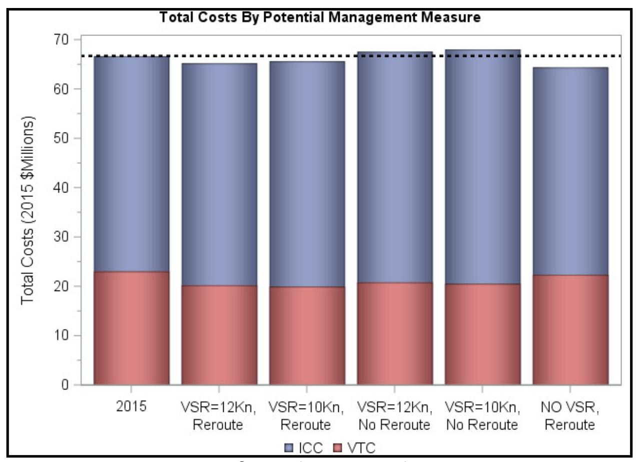

Figure 5.2. Comparison of costs by potential management measure.

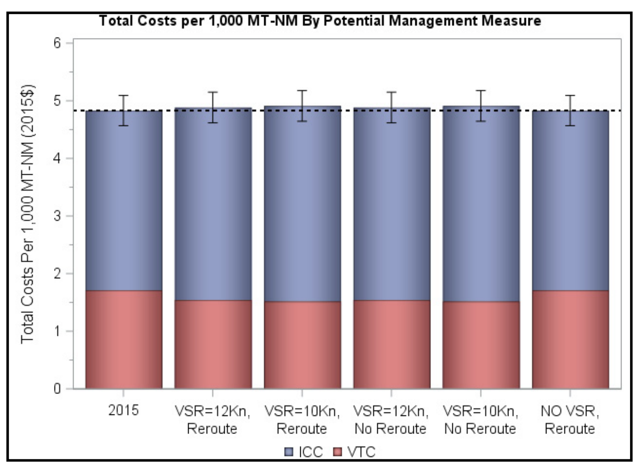

Figure 5.3. Comparison of costs per 1,000 MT-NM by potential management measure. Error bars (95% confidence) for total costs are shown in black.

[20] With a standard deviation of 1.4 and a range of between 5.2 to 14 knots.

only for Container vessels traveling inbound along the Northern route under the assumption of high fuel efficiency. ICCs are predicted to increase significantly only for Container and Tanker vessels traveling along the Northern route. VTCs are predicted to decrease significantly in all cases for Container and Tanker vessels, in most cases for Ro-Ro vessels, and in some cases for Dry Bulk and Ro-Ro/Combo vessels.

Figure 5.4 shows how costs are expected to change by 2015 speed across all vessels. For example, if a vessel that traveled at 22 knots in 2015 were to slow down to 12 knots, ICCs would be predicted to increase by about 0.6%, VTCs would be predicted to decrease by about 0.3%, and TCs would be predicted to remain roughly the same. Instead, if the vessel had traveled at 16 knots in 2015, ICCs would be predicted to increase by about 0.1%, VTCs would be predicted to decrease by about 0.15%, and TCs would still be predicted to remain roughly the same.

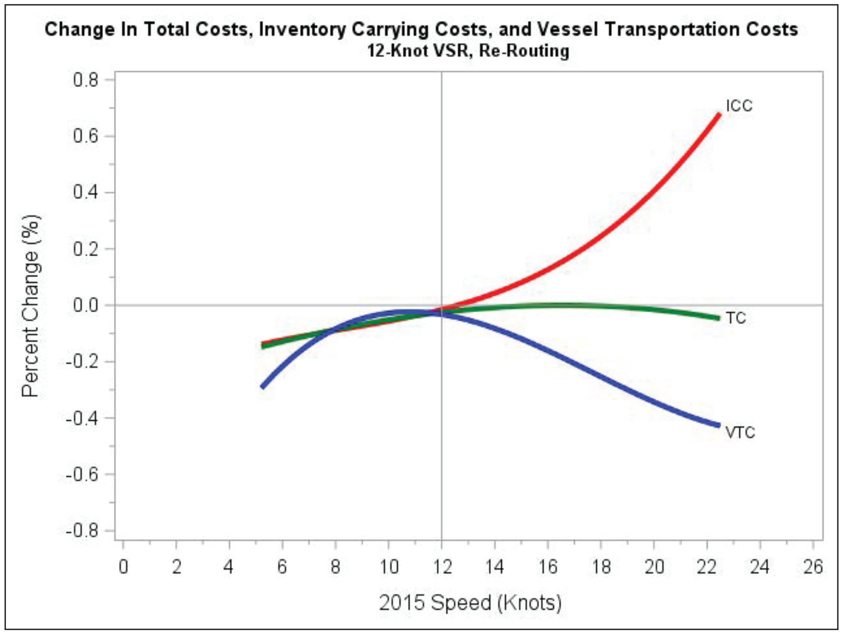

Figure 5.4. Percent change in expected TCs, ICCs, and expected VTCs by speed.

In general, expected costs are not predicted to change for vessels that traveled at 12 knots or less in 2015. However, some expected costs may decrease due to shorter transit distances. ICCs are predicted to increase and expected VTCs are predicted to decrease for vessels that traveled faster than 12 knots in 2015. Both of these changes are predicted to be relatively greater for vessels traveling at relatively faster speeds, as the predicted decreases in speed are greater. These changes appear to negate each other when summed to form expected TCs.

Figure 5.5 shows how changes in expected TCs vary by speed and vessel category. Expected TCs are predicted to remain roughly the same for Container and Dry Bulk vessels, to increase for Ro-Ro and Ro-Ro/Combo vessels, and to decrease for Tanker vessels at 2015 speeds above 12 knots.

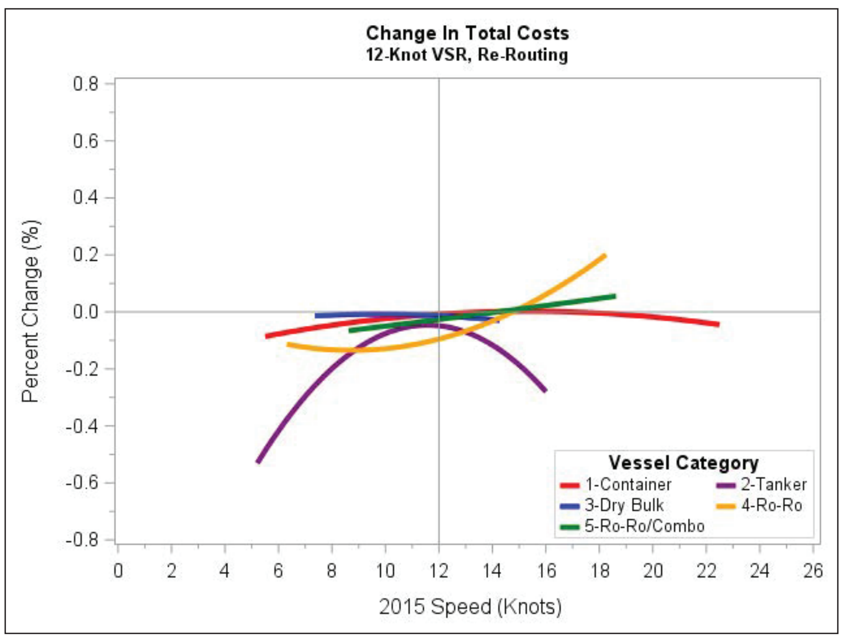

Figure 5.5. Percent change in expected TCs by speed and by vessel category.

5.1.2. 10-knot Seasonal VSR with Vessel Re-routing
Under a 10-knot seasonal VSR and vessel re-routing, 19.9% of vessels are predicted to comply with the seasonal VSR component and the average speed is predicted to significantly decrease to 12.0 knots[21] during the VSR season. Ro-Ro and Tanker vessels are predicted to decrease in speed the most by 15.1% and 14.5%, respectively.

Total expected TCs are predicted to decrease to approximately $65.6 million (1.6% decrease). Due to significant decreases in transit distance, this translates to a non-significant increase to $4.92 per 1,000 MT-NM (1.7% increase). Total ICCs are predicted to increase to approximately $45.7 million (4.7% increase), or a significant increase to $3.40 per 1,000 MT-NM (8.8% increase). Total expected VTCs are predicted to decrease to approximately $19.9 million (13.4% decrease), or a significant decrease to $1.52 per 1,000 MT-NM (11.2% decrease).

Table E.2 (Appendix E) shows how costs are predicted to change for medium-sized vessels by vessel category, route, direction, fuel efficiency, and fuel costs. TCs are predicted to decrease significantly in most cases for Container and Tanker vessels and for Dry Bulk vessels traveling outbound along the Western route under the assumption of low fuel efficiency and high fuel prices. TCs are predicted to increase significantly for Container vessels traveling inbound along the Northern route under the assumption of high fuel efficiency and in most cases for Dry Bulk vessels traveling along the Northern route. ICCs are predicted to increase significantly for Container, Tanker, and Dry Bulk vessels traveling along the Northern route, Dry Bulk vessels traveling inbound along the Western route, and Ro-Ro vessels traveling outbound along the Northern route. VTCs are predicted to decrease significantly in all cases for Container and Tanker vessels, Dry Bulk vessels traveling along the Northern route, in most cases for Ro-Ro vessels, and Ro-Ro/Combo vessels traveling inbound.

Figure 5.6 shows how costs are predicted to change by speed and vessel category. The patterns are similar to those seen under the 12-knot seasonal VSR with vessel re-routing. However, expected TCs are predicted to increase more for Ro-Ro vessels and decrease more for Tanker vessels at 2015 speeds above 12 knots.

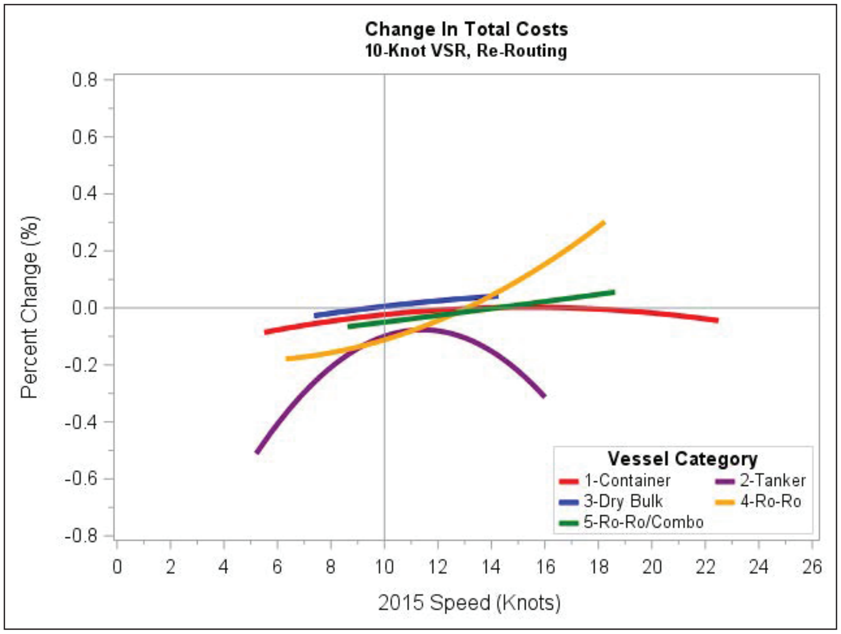

Figure 5.6. Percent change in expected TCs by speed and by vessel category.

5.1.3. 12-Knot Seasonal VSR Only
Under a 12-knot seasonal VSR only, 43.4% of vessels are predicted to be able to comply with the seasonal VSR component and the average speed is predicted to significantly decrease to 12.3 knots[22] during the VSR season. Ro-Ro and Container vessels are predicted to decrease in speed the most by 9.3% and 8.1%, respectively.

[21, 22] With a standard deviation of 1.4 and a range of between 5.2 to 14 knots.

Total expected TCs are predicted to increase to approximately $67.5 million (1.3% increase), or a non-significant increase to $4.89 per 1,000 MT-NM (1.1% increase). Total ICCs are predicted to increase to approximately $46.7 million (7.1% increase), or a significant increase to $3.35 per 1,000 MT-NM (7.1%). Total expected VTCs are predicted to decrease to approximately $20.8 million (9.7% decrease), or a significant decrease to $1.54 per 1,000 MT-NM (9.9% decrease).

Table E.3 (Appendix E) shows how costs are predicted to change for medium-sized vessels by vessel category, route, direction, fuel efficiency, and fuel costs. Expected TCs are predicted to decrease significantly for Container vessels under the assumption of low fuel efficiency and high fuel prices and in all cases for Tanker vessels. Expected TCs are predicted to increase significantly in most cases for Container vessels under the assumption of high fuel efficiency or low fuel efficiency with low fuel prices, in all cases for Ro-Ro vessels, and in some cases for Dry Bulk and Ro-Ro/Combo vessels. ICCs are predicted to increase significantly in all cases for Container, Tanker and Ro-Ro vessels and for Ro-Ro/Combo vessels traveling inbound along the Western route. Expected VTCs are predicted to decrease significantly in all cases for Container, Tanker, and Ro-Ro vessels and for Dry Bulk vessels traveling outbound along the Northern route.

Figure 5.7 shows how costs are predicted to change by speed and vessel category. The patterns are similar to those seen under the 12-knot seasonal VSR with vessel re-routing (Figure 5.5). However, expected TCs are predicted to not change for vessels that traveled at or below 12 knots in 2015 and to change less for vessels that traveled above 12 knots in 2015.

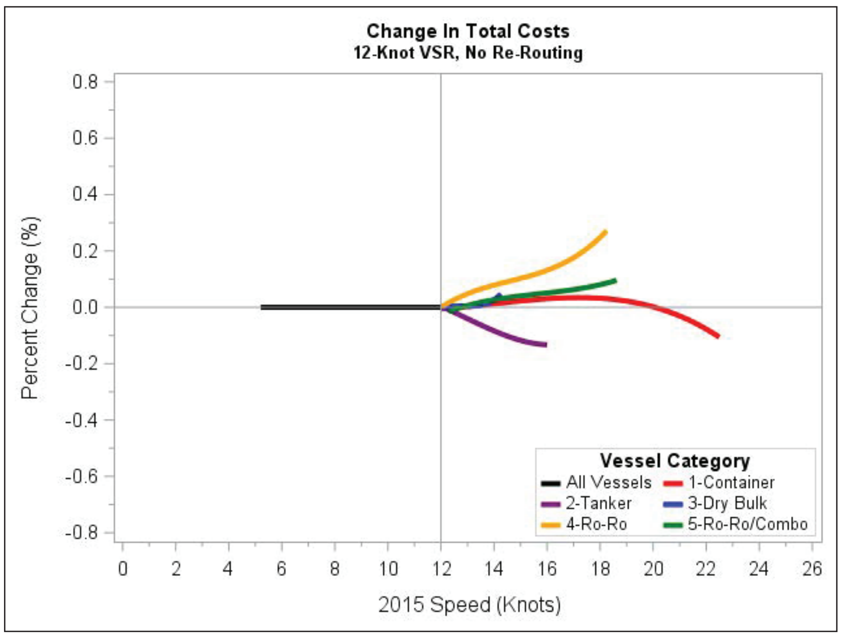

Figure 5.7. Percent change in expected TCs by speed and by vessel category.

5.1.4. 10-Knot Seasonal VSR Only

Under a 10-knot seasonal VSR only, 19.9% of vessels are predicted to comply with the seasonal VSR component and the average speed is predicted to significantly decrease to 12.0 knots during the VSR season. Ro-Ro and Tanker vessels are predicted to decrease in speed the most by 15.1% and 14.5%, respectively.

Total expected TCs are predicted to increase to approximately $68.0 million (2.0% increase), or a non-significant increase to $4.92 per 1,000 MT-NM (1.7% increase). Total ICCs are predicted to increase to approximately $47.5 million (8.8% increase), or a significant increase to $3.40 per 1,000 MT-NM (8.8% increase). Total expected VTCs are predicted to decrease to approximately $20.5 million (10.8% decrease), or a significant decrease to $1.52 per 1,000 MT-NM (11.2% decrease).

Table E.4 (Appendix E) shows how costs are predicted to change for medium-sized vessels by vessel category, route, direction, fuel efficiency, and fuel costs. TCs are predicted to decrease significantly for Container vessels under the assumption of low fuel efficiency and high fuel prices and in all cases for Tanker vessels. TCs are predicted to increase significantly in most cases for Container vessels under the assumption of high fuel efficiency or low fuel efficiency with low fuel prices, in all cases for Ro-Ro vessels, in most cases for Dry Bulk vessels traveling along the Northern route, and in all cases for Ro-Ro/Combo vessels traveling inbound along the Western route. ICCs are predicted to increase significantly in all cases for Container, Tanker and Ro-Ro vessels and for Ro-Ro/Combo vessels traveling inbound along the Western route. VTCs are predicted to decrease significantly in all cases for Container, Tanker, and Ro-Ro vessels, Dry Bulk vessels traveling along the Northern route, and Ro-Ro/Combo vessels traveling inbound along the Western route.

Figure 5.8 shows how costs are predicted to change by speed and vessel category. The patterns are similar to those seen under the 10-knot seasonal VSR with vessel re-routing (Figure 5.6). However, expected TCs are predicted to not change for vessels that traveled at or below 10 knots in 2015 and to change less for vessels that traveled above 10 knots in 2015.

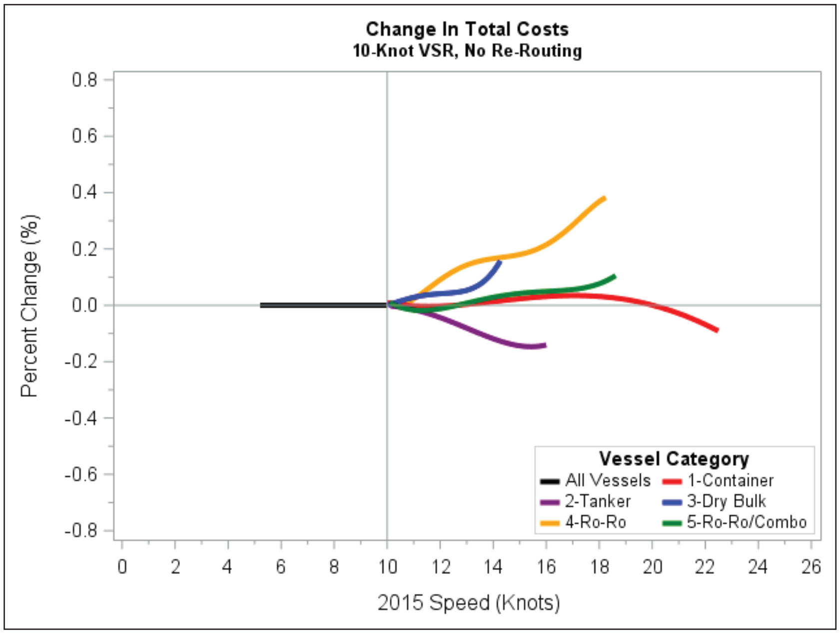

Figure 5.8. Percent change in expected TCs by speed and by vessel category.

5.1.5. Vessel Re-Routing Only

Under vessel re-routing only, speeds are predicted to remain the same.

Total expected TCs are predicted to decrease to approximately $64.4 million (3.4% decrease). Total ICCs are predicted to decrease to approximately $42.0 million (3.7% decrease). Total expected VTCs are predicted to decrease to approximately $ 22.4 million (2.9% decrease). Due to significant decreases in transit distance, there are no predicted significant changes in overall costs per 1,000 MT-NM.

Table E.5 (Appendix E) shows how costs are predicted to change for medium-sized vessels by vessel category, route, direction, fuel efficiency, and fuel costs. TCs, ICCs, and VTCs are predicted to decrease significantly in all cases for Container and Tanker vessels, Dry Bulk vessels traveling outbound along the Western route, Ro-Ro vessels traveling along the Northern route or inbound along the Western route, and Ro-Ro/Combo vessels traveling inbound.

Section 6
Discussion

Whale in the path of a ship. Credit: J. Calambokidis (Cascadia Research).

6.0. DISCUSSION

The objective of this report is to assess for CINMS and other agencies the economic effects of the following potential management measures through a shipping cost analysis:

1. 12-knot seasonal VSR with vessel re-routing (spatial approach)
2. 10-knot seasonal VSR with vessel re-routing
3. 12-knot seasonal VSR only
4. 10-knot seasonal VSR only
5. Vessel re-routing only

6.1. KEY FINDINGS

A key finding (Table 6.1) of this evaluation is that the two costs to the shipping industry, as defined in this analysis, are predicted to decrease under the three potential management measures with vessel re-routing components:

1. 12-knot seasonal VSR with vessel re-routing (-2.2%);
2. 10-knot seasonal VSR with vessel re-routing (-1.6%); and,
3. Vessel re-routing only (-3.4%).

The costs to the shipping industry are predicted to increase under the two seasonal VSR-only potential management measures:

1. 12-knot seasonal VSR only (+1.3%); and
2. 10-knot seasonal VSR only (+2.0%).

Table 6.1. Summary of expected total cost changes by potential management measure.

Potential Management Measure	Total Costs		
	Expected (2015$)	Change (2015$)	Change (%)
2015 Baseline	66,658,476	--	--
12-knot seasonal VSR with vessel re-routing	65,203,521	-1,454,959	-2.2
10-knot seasonal VSR with vessel re-routing	65,620,003	-1,038,458	-1.6
12-knot seasonal VSR only	67,539,241	880,766	1.3
10-knot seasonal VSR only	68,018,508	1,360,034	2.0
Vessel re-routing only	64,371,023	-2,287,472	-3.4

These results can be explained by the mechanisms through which the seasonal VSRs and vessel re-routing affect vessel costs. The seasonal VSRs affect ICCs through increased transit time and VTCs through both increased fuel efficiency and increased transit time.[23] The vessel re-routing affects both ICCs and VTCs through decreased transit time. Therefore, seasonal VSRs are predicted to increase ICCs and the increased fuel efficiency is predicted to outweigh the increased transit time for a net decrease in VTCs; vessel re-routing is predicted to decrease both ICCs and VTCs; and the predicted net effect of seasonal VSRs and vessel re-routing is an increase in ICCs and a decrease in VTCs.

The expected total costs (TCs) per 1,000 MT-NM, however, are not predicted to significantly change under any of the potential management measures. Distance elasticity of TCs can be used to explain how TCs change with transit distance as it is a measure that shows the responsiveness, or elasticity, of TCs to a change in transit distance. Mathematically, it is the ratio of the percentage change in TCs to the percentage change in transit distance. Under

[23] Overall transit distance is predicted to decrease by 3.6% due to the removal of fanning along the Northern route and the consolidation to a single Western route. However, it is likely that this decrease in transit distance will be offset by an increase in transit distance outside of the study area as vessels adjust their routes.

the measures with re-routing, the percentage change in transit distance (-3.6%) is predicted to be greater (in absolute value) than the percentage changes in TCs (Table 5.2). That is, for every 1.0% change in distance, a 0.6% to 1.0% change in TCs is predicted to occur depending on the potential management measure, which suggests that TCs are not elastic with respect to transit distance.

To put these results into context, consider an individual vessel transit between Hong Kong and the LA/LB Port Complex (6,300 NM). The total cost of vessel operation including fuel, crew, capital, insurance, and related administrative overhead costs on an individual vessel transit can easily range from approximately $0.6 to over $1.1 million depending on the type of vessel, fuel, and the degree to which the vessel was loaded. The estimated changes in costs from implementation of these potential management measures would therefore represent a 0.1% to 0.6% change in total VOCs on this hypothetical transit. Additionally, the estimated changes in costs would represent 0.0003% to 0.001% of LA/LB Port Complex's cargo value.

6.1.1. Feasibility

Each potential management measure has four distinct local management challenges, as well as effects on the shipping industry itself:

1. vessel strikes on endangered whales;
2. air pollution and greenhouse gas emissions;
3. navigational safety concerns; and
4. conflicts with naval operations.

When discussing the feasibility of potential management measures, their effects on these areas must be carefully considered. Additionally, the possible direct or indirect benefits derived from implementation of any of these measures should also be assessed. For instance, there is a growing literature on methods to measure the economic benefits of increased whale populations and decreased air pollution and greenhouse gas emissions.

Whales provide a wide array of ecosystem services which can, in part, be summarized by their ability to serve as ecosystem engineers in their roles as consumers, prey, detritus, and nutrient vectors throughout the water column and across the world's oceans (Nunes and Ghermandi, 2013; Roman et al., 2014; Onofri and Nunes, 2015). Several studies have demonstrated the non-consumptive value placed on whales, biodiversity, and favorable environmental conditions (Farr et al., 2013; Viana et al., 2017). Viana et al., 2017 discovered that private recreational boaters in the Channel Islands area display a higher willingness to pay for recreational sites which are higher in species richness and abundance. A healthy, thriving coastal ecosystem and non-consumptive activities, such as whale watching, not only provide opportunities for sustainable economic growth, but also provide a method of educating and engaging the public in local and global conservation initiatives.

Integrated assessment models (IAM) are used to quantify the marginal economic damages of emissions (Wang et al., 1994; Muller et al., 2011; Poycroft et al., 2011; Nordhaus, 2014; Jaramillo and Muller, 2016). IAMs include inputs such as emissions inventories and the valuation of the various damages caused by those emissions (Corbett and Koehler, 2003; Muller and Mendelsohn, 2007; Muller et al., 2011). Emissions inventories can be calculated using both bottom-up (i.e., spatially explicit/more localized) and/or top-down (i.e., aggregate/global) methodologies using ship fuel-based and activity-based datasets (Wang et al., 2007; Pokhrel and Lee, 2015; Zis et al., 2015).

Unfortunately, estimates derived from IAM are often limited by uncertainties in emission factors for certain engine types and the availability of fuel and activity data for some vessel types (Corbett and Koehler, 2003; Eyring et al., 2005). Likewise, finding reliable emission inventory data at finer scales and for specific industry sectors, such as marine transportation, can be challenging (Jaramillo and Muller, 2016). Also of concern is the transformation of gaseous pollutants (i.e., SOx, NOx, CO, CO2, VOCs) into sulfate, nitrate, and ozone, which contribute to processes, such as acidification, that negatively affect production in agriculture and forestry as well as changes in ocean chemistry (Pope et al., 2002; Laden et al., 2006; Muller et al., 2011; Bloor et al., 2014). Another limitation in IAM analyses revolves around uncertainties in the value of damages associated with specific emissions. For example, the values of statistical life (VSL) and injuries, the social cost of Carbon, and the dose-response relationship between pollutants and human mortality are all items which require further discussion and analyses (Muller et al., 2011; Pycroft et al., 2011; Nordhaus, 2014; Jaramillo and Muller, 2016).

In addition, some researchers postulate that, although reductions in emissions may be observed locally or regionally due to these regulations and VSRs, emissions may increase elsewhere due to the continued use of cheaper, low-quality fuels and increased speeds in international waters to compensate for lost time and money (Lack et al., 2011; Kotchenruther, 2015; Zis et al., 2015). However, the majority of these ship-based emissions are estimated to be concentrated within 400 km of land (Corbett et al., 1999) and along transit routes and ports (Richter et. al. 2004; Eyring et. al. 2007), while environmental factors such as local wind conditions transport those emissions hundreds of kilometers inland (Benkovitz et. al. 1994; Corbett et. al. 2007; Gonzalez et al., 2011; Pokhrel and Lee, 2015) into coastal regions where population densities are high and consistently growing (Neumann et al., 2015). Vutukuru and Dabdub (2008), for example, found that peak emissions of ozone and PM from OGVs were concentrated in the coastal areas of the South Coast Air Basin of California.

6.2. APPLICATION CONSIDERATIONS

Two primary considerations to make when applying this framework to other study areas are current and expected vessel fleet behavior and current and expected vessel fleet composition.

Key drivers of vessel fleet behavior include current management measures, such as TSSs, VSRs, and fuel regulations. For example, in the Channel Islands study region, vessels have modified their routes in response to changes in fuel regulations that may not have the same effects in other regions. Additionally, while there are two voluntary VSR zones outside the LA/LB Port Complex, other areas, such as the San Francisco region, have implemented larger scale VSRs that will affect the baseline shipping costs. Finally, the vessel re-routing measure is predicted to decrease transit distances in the Channel Island study region by about 3.6%, which will not necessarily be the case in other regions and under different management measures. Additionally, the minimum engineering viability speeds used in this analysis may not be transferable to other regions or management measures depending on the length of the TSS under a VSR.

Vessel fleet composition, as well as cargo values, depends primarily on the cargo being transported in the region. For example, in the Channel Islands study region, the total value of cargo imported and exported is greater than any other port complex in the country and most of the value is carried in container vessels.

Vessel fleet behavior and composition are also important factors to consider in any future efforts aiming to estimate the marginal economic damages associated with shipping-based emissions. Emission inventory methodologies are highly sensitive to changes in fuel consumption, vessel and engine type, traffic patterns, cargo capacity, and vessel operator behavior and compliance to local regulations. Uncertainties surrounding the values applied to damages related to the environment and human health and mortality, such as the social cost of carbon, the value of statistical life (VSL), and dose-response relationships between pollutants and human mortality, require a standardized, yet localized application in estimating the total economic impact of the shipping industry within specific regions.

The effects of potential management measures in other regions necessitates a clear understanding of current and expected vessel fleet behavior and composition. This report provides a well detailed basis for conducting future analyses.

References

Sunset. Credit: K. Willingham (NOAA).

References

Benkovitz, C.M., C.M. Berkowitz, R.C. Easter, S. Nemesure, R. Wagener, and S.E. Schwartz. 1994. Sulfate over the north atlantic and adjacent continental regions: Evaluation for October and November 1986 using a three-dimensional model driven by observation derived meteorology. J. Geophys. Res.., 99(D10), 20,725-20,756.

Birney, K., M. Byrd, S. Hastings, B. Shafritz, and R. Freedman. April 2016. Report on the 2014 Vessel Speed Reduction Incentive Trial in the Santa Barbara Channel.

Bloor, M., H. Sampson, S. Baker, and K. Dahlgren. 2014. The instrumental use of technical doubts: Technological controversies, investment decisions and air pollution controls in the global shipping industry. Science and Public Policy: 1-11.

Buhaug, Ø., J.J. Corbett, Ø. Endresen, V. Eyring, J. Faber, S. Hanayama, D.S. Lee, D. Lee, H. Lindstadt, A. Mjelde, and , C. Pålsson. 2009. Second Study on Greenhouse Gas Emissions from Ships. International Maritime Organization (IMO): London, UK.

Chang, C. and C. Wang. 2012. Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. Transportation Research. 17(3). 185-189.

Channel Islands National Marine Sanctuary Advisory Council Marine Shipping Working Group. March 2016. Final Report.

Cisneros-Montemayor, A.M., U.R. Sumaila, K. Kaschner, and D. Pauly. 2010. The global potential for whale watching. Marine Policy. 34(6): 1273-1278.

Clyne, H. and R. Leaper. 1999. Modelling collisions between whales and ships. Assessing the potential for vessels to take avoiding action in response to sightings of whales. SC/56/BC6.

Conn, P. and G. Silber. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. Ecoshpere. 4(4): Article 43.

Corbett, J.J. and P. Fischbeck. 1997. Emissions from ships. Science. 278(5339): 823-824.

Corbett, J.J., P.S. Fischbeck, and S.N. Pandis. 1999. Global Nitrogen and Sulfur Emissions Inventories for Oceangoing Ships. J. Geophys. Res. 104 (D3), 3457–3470.

Corbett, J. and H. Koehler. 2003. Updated Emissions from Ocean Shipping. Journal of Geophysical Research. 108(D20). 4650-4665.

Corbett, J., J. Winebrake, E. Green, P. Kasibhatla, V. Eyring, and A. Lauer. 2007. Mortality from Ship Emissions: A Global Assessment. Environmental Science and Technology. 41(24). 8512-8518.

Corbett, J., H. Wang, and J. Winebrake. 2009. The effectiveness and costs of speed reductions on emissions from international shipping. Transportation Research.14(8). 593-598.

Council of Supply Chain Management Professionals (CSCMP), Supply Chain and Logistics - Terms and Glossary, Updated February, 2005. Conversation and correspondence with Rosalyn Wilson, Senior Business Analyst (Delcan's Infrastructure National Business) who developed and presented the CSCMP's 2015 Annual State of the Logistics Report, National Press Club, Washington, D.C., June 23, 2015.

References

Duprey, N., J. Weir, and B. Wursig. 2008. Effectiveness of a voluntary code of conduct in reducing vessel traffic around dolphins. Ocean and Coastal Management. 51(8-9). 632-637.

Office of Air Quality Planning and Standards; Air Quality Assessment Division; Emissions Inventory and Analysis Group. Research Triangle Park, North Carolina.

Eyring, V., H.W. Köhler, J. van Aardenne, and A. Lauer. 2005. Emissions from international shipping: 1. The last 50 years. J. Geophys. Res., D: Atmos. 2005, 110 (D17), D17305.

Eyring, V., J.J. Corbett, D.S. Lee, and J.J. Winebrake. 2007. Brief summary of the impact of ship emissions on atmospheric composition, climate, and human health. Document submitted to the Health and Environment sub-group of the International Maritime Organization, 6.

Eyring, V., I.S. Isaksen, T. Berntsen, W.J. Collins, J.J. Corbett, O. Endresen, R.G. Grainger, J. Moldanova, H. Schlager, and D.S. Stevenson. 2010. Transport impacts on atmosphere and climate: Shipping, Atmospheric Environment, 44, 4735–4771, doi:10.1016/j.atmosenv.2009.04.059.

Farr, M., N. Stoeckl, and R.A. Beg. 2013. The non-consumptive (tourism) ‘value’ of marine species in the Northern section of the Great Barrier Reef. Marine Policy. 43: 89-103.

Federal Register. 2008. Endangered Fish and Wildlife; Final Rule to Implement Speed Restrictions to Reduce the Threat of Ship Collisions with North Atlantic Right Whales. Department of Commerce: National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Vol. 73; No. 198. Docket No. 040506143–7024–03.

Federal Register. 2015. Vessel Requirements for Notices of Arrival and Departure, and Automatic Identification System. Department of Homeland Security: Coast Guard. Vol. 80; No. 20. Docket No. USCG-2005-21869.

Gende, S. and N. Hendrix. 2007. Strike probabilities of humpback whales by cruise ships in Glacier Bay National Park. Southeast Alaska Coastal Program, National Park Service, Juneau, Alaska.

Gende, S., A. Hendrix, K. Harris, B. Eichenlaub, J. Nielsen, and S. Pyare. 2011. A Bayesian approach for understanding the role of ship speed in whale–ship encounters. Ecological Applications. 21(6). 2232–2240.

González, Y., S. Rodríguez, J.C.G. García, J.L. Trujillo, and R. García. 2011. Ultrafine particles pollution in urban coastal air due to ship emissions. Atmospheric Environment. 45(28): 4907-4914.

Gurjar, B.R., A. Jain, A. Sharma, A. Agarwal, P. Gupta, A.S. Nagpure, and J. Levlieveld. 2010. Human Health Risks in Megacities Due to Air Pollution. Atmospheric Environment. 44(36). 4606-4613.

Guzman, H., C. Gomez, C. Guevara, and L. Kleivane. 2012. Potential vessel collisions with Southern Hemisphere humpback whales wintering off Pacific Panama. Marine Mammal Science. 29(4). 629-642.

Hoagland, P. and A.E. Meeks. 2000. The demand for whalewatching at Stellwagen Bank National Marine Sanctuary. The economic contribution of whale-watching to regional economies: perspectives from two National Marine Sanctuaries.

Jaramillo, P. and N.Z. Muller. 2016. Air pollution emissions and damages from energy production in the US: 2002–2011. Energy Policy. 90: 202-211.

Jensen, C.M., E. Hines, B.A. Holzman, T.J. Moore, J. Jahncke, and J.V. Redfern. 2015. Spatial and Temporal Variability in Shipping Traffic Off San Francisco, California. Coastal Management 43(6). 575-88.

Kampa, M. and E. Castanas. 2008. Human Health Effects of Air Pollution. Environmental Pollution. 151(2). 362-367.

Khan, M.Y., M. Giordano, J. Gutierrez, W.A. Welch, A. Asa-Awuku, J.W. Miller, and D.R. Cocker III. 2012. Benefits of two mitigation strategies for container vessels: cleaner engines and cleaner fuels. Environmental Science and Technology. 46(9): 5049-5056.

Kite-Powell, H. and P. Hoagland. 2002. Economic Aspects of Right Whale Ship Strike Management Measures. Final Project Report to the National Marine Fisheries Service, Service, NOAA. Marine Policy Center, Woods Hole Oceanographic Institution.

Kite-Powell, H. 2005. Economic Implications of Possible Reductions in Boston Port Calls due to Ship Strike Management Measures. Report to NMFS and MASSPORT.

Kotchenruther, R.A. 2015. The effects of marine vessel fuel sulfur regulations on ambient PM 2.5 along the west coast of the US. Atmospheric Environment. 103: 121-128.

Lack, D.A., C.D. Cappa, J. Langridge, R. Bahreini, G. Buffaloe, C. Brock, K. Cerully, D. Coffman, K. Hayden, J. Holloway, B. Lerner, P. Massoli, S.-M. Li, R. McLaren, A.M. Middlebrook, R. Moore, A. Nenes, I. Nuaaman, T.B. Onasch, J. Peischl, A. Perring, P.K. Quinn, T. Ryerson, J.P. Schwartz, R. Spackman, S.C. Wofsy, D. Worsnop, B. Xiang, and E. Williams. 2011. Impact of fuel quality regulation and speed reductions on shipping emissions: implications for climate and air quality. Environmental Science and Technology. 45(20): 9052-9060.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. American Journal Of Respiratory And Critical Care Medicine. 173(6): 667-672.

Lagueux, K., M. Zani, A. Knowlton, and S. Kraus. 2011. Response by vessel operators to protection measures for right whales (Eubalaena glacialis) in the southeast US calving ground. Endangered Species Research. 14(1). 69-77.

Laist, D., A. Knowlton, J. Mead, A. Collet, and M. Podesta. 2001. Collisions between ships and whales. Marine Mammal Science. 17(1). 35-75.

Laist, D., A. Knowlton, and D. Pendleton. 2014. Effectiveness of mandatory vessel speed limits for protecting North Atlantic right whales. Endangered Species Research. 23(2). 133-147.

Le-Griffin, H. and M. Murphy. 2006. Container terminal productivity: experiences at the ports of Los Angeles and Long Beach. Department of Civil Engineering, University of Southern California.

Leeworthy, V.R., P.C. Wiley, and E.A. Stone. 2005. A Socioeconomic Impact Analysis of Marine Reserve Alternatives for the Channel Islands National Marine Sanctuary. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects. October 7, 2005.

Li, G., H. Xu, and W. Liu. 2013. Option of operating speed for vessels under low-carbon economy. Journal of Industrial Engineering and Management. 6(1). 289-296.

References

Loomis, J.B. and D.M. Larson. 1994. Total economic values of increasing gray whale populations: results from a contingent valuation survey of visitors and households. Marine Resource Economics. 9(3): 275-286.

Marine Mammal Commission. 2008. Annual Report to Congress: 2007. Bethesda, Maryland. Pp. 207. The in text citation should read, (Marine Mammal Commission, 2008).

Mathis, I. (2016, November 11). Personal communication.

McKenna, M., S. Katz, C. Condit, and S. Walbridge. 2012. Response of Commercial Ships to a Voluntary Speed Reduction Measure: Are Voluntary Strategies Adequate for Mitigating Ship-Strike Risk? Coastal Management. 40(6). 634-650.

Merrick, R. and T. Cole. 2007. Evaluation of Northern Right Whale Ship Strike Reduction Measures in the Great South Channel of Massachusetts. US Department of Commerce: NOAA Technical Memorandum NMFS-NE-202.

Monnahan, C., T. Branch, and A. Punt. 2014. Do ship strikes threaten the recovery of endangered eastern North Pacific blue whales? Marine Mammal Science. 31(1). 279-297.

Muller, N.Z. and R. Mendelsohn. 2007. Measuring the damages of air pollution in the United States. Journal of Environmental Economics and Management. 54(1): 1-14.

Muller, N., R. Mendelsohn, and W. Nordhaus. 2011. Environmental Accounting for Pollution in the United States Economy. American Economic Review. 101(5). 1649-1675.

Nathan Associates, Inc. 2012. Economic Analysis of North Atlantic Right Whale Ship Strike Reduction Rule. Final Report to NMFS. Update of Economic Impact and Scoping Assessment for Study of Potential Modifications. Final Report to NOAA NMFS.

Neumann, B., A.T. Vafeidis, J. Zimmermann, and R.J. Nicholls. 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. PloS one. 10(3): e0118571.

Nordhaus, W. 2014. Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. Journal of the Association of Environmental and Resource Economists. 1(1/2): 273-312.

Nunes, P.A. and A. Ghermandi. 2013. The economics of marine ecosystems: reconciling use and conservation of coastal and marine systems and the underlying natural capital. 459-465.

O'Connor, S., R. Campbell, H. Cortez, and T. Knowles. 2009. Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits, a special report from the International Fund for Animal Welfare. Yarmouth MA, USA, prepared by Economists at Large. 228.

Onofri, L. and P.A. Nunes. 2015. Microeconomic framework for the economics of whales. Marine Ecology Progress Series. 530: 213-222.

Parsons, E. 2012. The Negative Impacts of Whale Watching. Journal of Marine Biology. Vol: 2012. Article ID 807294.

References

Perez, L., N. Künzli, E. Avol, A.M. Hricko, F. Lurmann, E. Nicholas, F. Gilliland, J. Peters, and R. McConnell. 2009. Global goods movement and the local burden of childhood asthma in southern California. American Journal of Public Health, 99(S3), pp.S622-S628.

Pokhrel, R. and H. Lee. 2015. Estimation of air pollution from the OGVs and its dispersion in a coastal area. Ocean Engineering. 101: 275-284.

Pope III, C.A., R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama. 287(9): 1132-1141.

Port of Long Beach. 2016a. Green Flag Incentive Program Monthly Report: Operator Compliance at 20 nm. 1/1/2015-12/31/2015.

Port of Long Beach. 2016b. Green Flag Incentive Program Monthly Report: Operator Compliance at 40 nm. 1/1/2015-12/31/2015.

Pycroft, J., L. Vergano, C. Hope, D. Paci, and J.C. Ciscar. 2011. A tale of tails: uncertainty and the social cost of carbon dioxide.

Roman, J., J.A. Estes, L. Morissette, C. Smith, D. Costa, J. McCarthy, J. B. Nation, S. Nicol, A. Pershing, and V. Smetacek. 2014. Whales as marine ecosystem engineers. Frontiers in Ecology and the Environment. 12(7): 377-385.

Reeves, R., A. Read, L. Lowry, S. Katona, and D. Boness. 2007. Report of the North Atlantic right whale program review. Report prepared for the Marine Mammal Commission; Woods Hole, Massachusetts.

Richter, A., V. Eyring, J.P. Burrows, H. Bovensmann, A. Lauer, B. Sierk, and P.J. Crutzen. 2004. Satellite measurements of NO2 from international shipping emissions, Geophys. Res. Lett., 31, L23110, doi:10.1029/2004GL020822.

Russell, B., A. Knowlton, and B. Zoodsma. 2001. Recommended Measures to Reduce Ship Strikes of North Atlantic Right Whales. International Fund for Animal Welfare Report submitted to NMFS.

Silber, G., J. Adams, and S. Bettridge. 2012. Vessel operator response to a voluntary measure for reducing collisions with whales. Endangered Species Research. 17(3). 245-254.

Silber, G. and S. Bettridge. 2012. An Assessment of the Final Rule to Implement Vessel Speed Restrictions to Reduce the Threat of Vessel Collisions with North Atlantic Right Whales. US Department of Commerce: NOAA Technical Memorandum NMFS- OPR-48.

Silber, G., A. Vanderlaan, A. Arceredillo, L. Johnson, C. Taggart, M. Brown, S. Bettridge, and R. Sagarminaga. 2012. The Role of the International Maritime Organization in Reducing Vessel Threat to Whales: Process, Options, Action and Effectiveness. Marine Policy. 36(6). 1221-1233.

Silber, G., J. Adams, and C. Fonnesbeck. 2014. Compliance with vessel speed restrictions to protect North Atlantic right whales. PeerJ DOI 10.7717/peerj.399.

The Tioga Group Inc. and HIS Global Insight. 2009. San Pedro Bay Container Forecast Update. Report Prepared for the Ports of Long Beach and Los Angeles.

References

Van der Hoop, J., A. Vanderlaan, and C. Taggart. 2012a. Absolute probability estimates of lethal vessel strikes to North Atlantic right whales in Roseway Basin, Scotian Shelf. Ecological Applications. 22(7). 2021–2033.

Van der Hoop, J., M. Moore, S. Barco, T. Cole, P. Daoust, A. Henry, D. McAlpine, W. McLellan, T. Wimmer, and A. Solow. 2012b. Assessment of Management to Mitigate Anthropogenic Effects on Large Whales. Conservation Biology. 27(3). 121-133.

Van der Hoop, J., A. Vanderlaan, T. Cole, A. Henry, L. Hall, B. Mase-Guthrie, T. Wimmer, and M. Moore. 2014. Vessel Strikes to Large Whales Before and After the 2008 Ship Strike Rule. Conservation Letters. 8(1). 24-32.

Van der Hoop, J., A. Vanderlaan, T. Cole, A. Henry, L. Hall, B. Mase-Guthrie, T. Wimmer, and M. Moore. 2016. Erratum to Vessel strikes to large whales before and after the 2008 Ship Strike Rule. Conservation Letters, 9(3), pp.236-236.

Vanderlaan, A. and C. Taggart. 2006. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Marine Mammal Science. 23(1). 144-156.

Vanderlaan, A. and C. Taggart. 2009. Efficacy of a Voluntary Area to Be Avoided to Reduce Risk of Lethal Vessel Strikes to Endangered Whales. Conservation Biology. 23(6). 1467-1474.

Vanderlaan, A., J. Corbett, S. Green, J. Callahan, C. Wang, R. Kenney, C. Taggart, and J. Firestone. 2009. Probability and mitigation of vessel encounters with North Atlantic right whales. Endangered Species Research. 6(3). 273-285.

Viana, D., K. Gornik, C. Lin, G. McDonald, N.S.R. Ng, C. Quigley, and M. Potoski. 2017. Recreational boaters value biodiversity: The case of the California Channel Islands National Marine Sanctuary. Marine Policy. 81: 91-97.

Vutukuru, S. and D. Dabdub. 2008. Modeling the effects of ship emissions on coastal air quality: A case study of southern California. Atmospheric Environment, 42(16), pp.3751-3764.

Wang, M., D. Santini, and S. Warinner. 1994. Methods of Valuing Air Pollution and Estimated Monetary Values of Air Pollutants in Various US Regions. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne, Illinois. ANL/ESD-26.

Wang, C., J. Corbett, and J. Firestone. 2007. Modeling Energy Use and Emissions from North American Shipping: Application of the Ship Traffic, Energy, and Environment Model. Environmental Science and Technology. 41(9). 3226-3232.

Wang, C., S.B. Lyons, J. Corbett, and J. Firestone. 2007. Using ship speed and mass to describe potential collision severity with whales: an application of the Ship Traffic, Energy and Environment Model (STEEM). University of Delaware, College of Marine and Earth Studies.

Wiley, D., M. Thompson, R. Pace, and J. Levenson. 2011. Modeling speed restrictions to mitigate lethal collisions between ships and whales in the Stellwagen Bank National Marine Sanctuary, USA. Biological Conservation. 144(9). 2377-2381.

Wiley, D.N., C.A. Mayo, E.M. Maloney, and M.J. Moore. 2016. Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (Eubalaena glacialis). Marine Mammal Science. 32(4): 1501-1509.

References

Winebrake, J.J., J.J. Corbett, E.H. Green, A. Lauer, and V. Eyring. 2009. Mitigating the health impacts of pollution from oceangoing shipping: an assessment of low-sulfur fuel mandates. Environmental Science and Technology. 43: 4776-4782.

Wolfe, E.K. 2016. Estimation of Operating Costs and Associated Pollutant Levels Involving Deep-Sea Vessel Transportation in the Los Angeles Port District and Channel Islands National Marine Sanctuary (CINMS) Region. NOAA, National Ocean Service. Version 3.0. Internal White Paper. April 1.

Zis, T., R.J. North, P. Angeloudis, W.Y. Ochieng, and M.G.H. Bell. 2015. Environmental balance of shipping emissions reduction strategies. Transportation Research Record: Journal of the Transportation Research Board. 2479: 25-33.

Appendices

Anacapa Island's light house. Credit: R. Schwemmer (NOAA).

APPENDIX A: Commodities Used to Assign Vessel Category

This appendix presents a list of commodities normally carried by vessel category (visit https://hts.usitc.gov/ for more information).

Container Vessels

- Identified as cargo loaded into containers including Freight All Kinds (FAK and NESOI – Not Elsewhere Specified or Identified)

Tanker Vessels

- 270710 Benzene
- 270720 Toluene
- 270730 Xylenes
- 270740 Naphthalene
- 270750 Arom Hydc Nesoi 65pct Ao Dstls A 250dc Astm D 86
- 270760 Phenols
- 270791 Creosote Oils
- 270799 Oils & Products Nesoi As Coal Tar Distillates Etc
- 270810 Pitch From Coal And Other Mineral Tars
- 270900 Crude Oil From Petroleum And Bituminous Minerals
- 271011 Light Oils& Prep (not Crude) From Petrol & Bitum
- 271012 Lt Oils, Preps Gt=70% Petroleum/bitum Nt Biodiesel
- 271019 Petrol Oil Bitum Mineral (nt Crud) Etc Nt Biodiesel
- 271020 Petroleum Oils And Preps Containing Biodiesel, Etc
- 271091 Waste Oil Cont.polychlorina.biphenyl (pcb)/pct/pbb
- 271099 Waste Oils, Nesoi

Ro-Ro Vessels

- 870323 Pass Veh Spk-ig Int Com Rcpr P Eng >1500 Nov 3m cc
- 870324 Pass Veh Spk-ig Int Com Rcpr P Eng > 3000 c

Dry Bulk and All Other

- Residual of total minus Container, Tanker, Ro-Ro vessels

APPENDIX B: 2015 Vessel Count, Mean Distance Traveled, and Mean Metric Tonnes by Vessel Category, Size Class, Route, and Direction

This appendix shows the vessel count, mean distance traveled, and mean metric tonnes in the study area in 2015 by vessel category, size class, route, and direction.

Table B.1. 2015 vessel count, mean distance traveled, and mean total metric tonnes by vessel category, size class, route, and direction.

Vessel Category	Size Class	Route	Direction	Vessel Count	Mean Distance Traveled (NM)	Mean Total Cargo Weight (MT)
Container	Small	North	Inbound	43	502.60 (61.73)	332,541.96 (55,172.46)
			Outbound	40	486.49 (50.11)	291,841.33 (38,448.01)
		West	Inbound	19	452.31 (91.19)	349,148.25 (63,502.68)
			Outbound	17	193.73 (56.20)	504,860.26 (165,194.83)
	Medium	North	Inbound	104	359.66 (23.13)	206,684.50 (17,140.15)
			Outbound	134	397.97 (20.88)	228,386.85 (16,473.30)
		West	Inbound	46	256.58 (26.09)	154,247.02 (21,459.84)
			Outbound	37	211.76 (18.47)	123,826.93 (15,663.62)
	Large	North	Inbound	90	343.48 (22.52)	194,245.99 (16,748.96)
			Outbound	101	395.85 (22.47)	222,175.53 (17,554.77)
		West	Inbound	43	271.52 (35.19)	181,287.75 (30,952.12)
			Outbound	33	217.09 (37.10)	144,340.07 (30,441.26)
Tanker	Small	North	Inbound	12	139.00 (19.47)	28,734.43 (4,431.97)
			Outbound	6	191.68 (49.62)	37,899.27 (7,387.29)
		West	Inbound	7	173.65 (43.51)	35,155.85 (8,153.74)
			Outbound	8	184.18 (51.95)	38,565.00 (7,765.95)
	Medium	North	Inbound	32	121.15 (8.44)	51,979.85 (9,171.61)
			Outbound	34	147.87 (13.74)	92,735.64 (20,151.97)
		West	Inbound	27	395.23 (84.99)	212,950.48 (91,173.82)

Source: United States Coast Guard, Automatic Identification System (AIS) data, 2015

Table B.1 continued. 2015 vessel count, mean distance traveled, and mean total metric tonnes by vessel category, size class, route, and direction.

Vessel Category	Size Class	Route	Direction	Vessel Count	Mean Distance Traveled (NM)	Mean Total Cargo Weight (MT)
Tanker	Medium	West	Outbound	36	336.38 (60.24)	202,018.31 (69,290.92)
	Large	North	Inbound	3	150.62 (46.63)	84,437.66 (896.09)
			Outbound	3	102.94 (2.47)	133,851.13 (24,548.25)
		West	Inbound	10	628.37 (191.58)	492,665.68 (142,262.48)
			Outbound	12	516.68 (147.83)	381,400.16 (118,591.80)
Dry Bulk	Small	North	Inbound	28	134.43 (11.90)	37,013.62 (3,407.47)
			Outbound	27	128.81 (11.59)	38,888.45 (4,498.09)
		West	Inbound	7	109.09 (5.29)	36,354.64 (3,986.74)
			Outbound	2	90.28 (13.85)	21,316.69 (5,129.01)
	Medium	North	Inbound	13	160.45 (25.44)	49,568.41 (10,490.77)
			Outbound	11	132.94 (20.33)	46,677.08 (9,379.54)
		West	Inbound	4	99.73 (1.54)	27,931.16 (4,283.74)
			Outbound	6	101.12 (1.10)	24,501.49 (2,466.21)
	Large	North	Inbound	18	104.16 (0.26)	31,839.90 (2,213.49)
			Outbound	20	133.87 (16.83)	42,477.01 (6,149.02)
		West	Inbound	5	143.85 (50.56)	48,221.03 (11,390.49)
			Outbound	5	122.47 (48.61)	40,073.34 (7,893.33)
Ro-Ro	Small	North	Inbound	3	101.86 (1.98)	10,365.63 (217.86)
			Outbound	2	159.09 (53.23)	15,552.00 (4,750.68)
		West	Inbound	1	103.53 -	10,801.32 -
			Outbound	1	103.75 -	13,913.76 -
	Medium	North	Inbound	19	160.83 (19.30)	73,397.66 (11,053.65)
			Outbound	19	209.17 (39.71)	90,751.01 (18,638.20)
		West	Inbound	18	292.80 (57.56)	117,783.18 (22,683.14)

Source: United States Coast Guard, Automatic Identification System (AIS) data, 2015

Table B.1 continued. 2015 vessel count, mean distance traveled, and mean total metric tonnes by vessel category, size class, route, and direction.

Vessel Category	Size Class	Route	Direction	Vessel Count	Mean Distance Traveled (NM)	Mean Total Cargo Weight (MT)
Ro-Ro	Medium	West	Outbound	14	202.91 (37.45)	93,346.37 (19,998.91)
	Large	North	Inbound	18	151.09 (23.37)	76,764.02 (10,826.52)
			Outbound	39	204.17 (22.17)	97,089.26 (11,812.49)
		West	Inbound	14	221.20 (31.29)	104,816.68 (18,328.39)
			Outbound	30	120.55 (11.50)	58,434.59 (3,325.67)
Ro-Ro/Combo	Medium	North	Inbound	8	186.88 (31.90)	110,583.50 (19,513.77)
			Outbound	2	114.09 (2.33)	60,483.82 (7,733.65)
		West	Inbound	10	153.12 (23.86)	88,331.26 (14,491.80)
			Outbound	1	98.26 -	57,892.39 -

Source: United States Coast Guard, Automatic Identification System (AIS) data, 2015

APPENDIX C: Vessel Density by Vessel Category

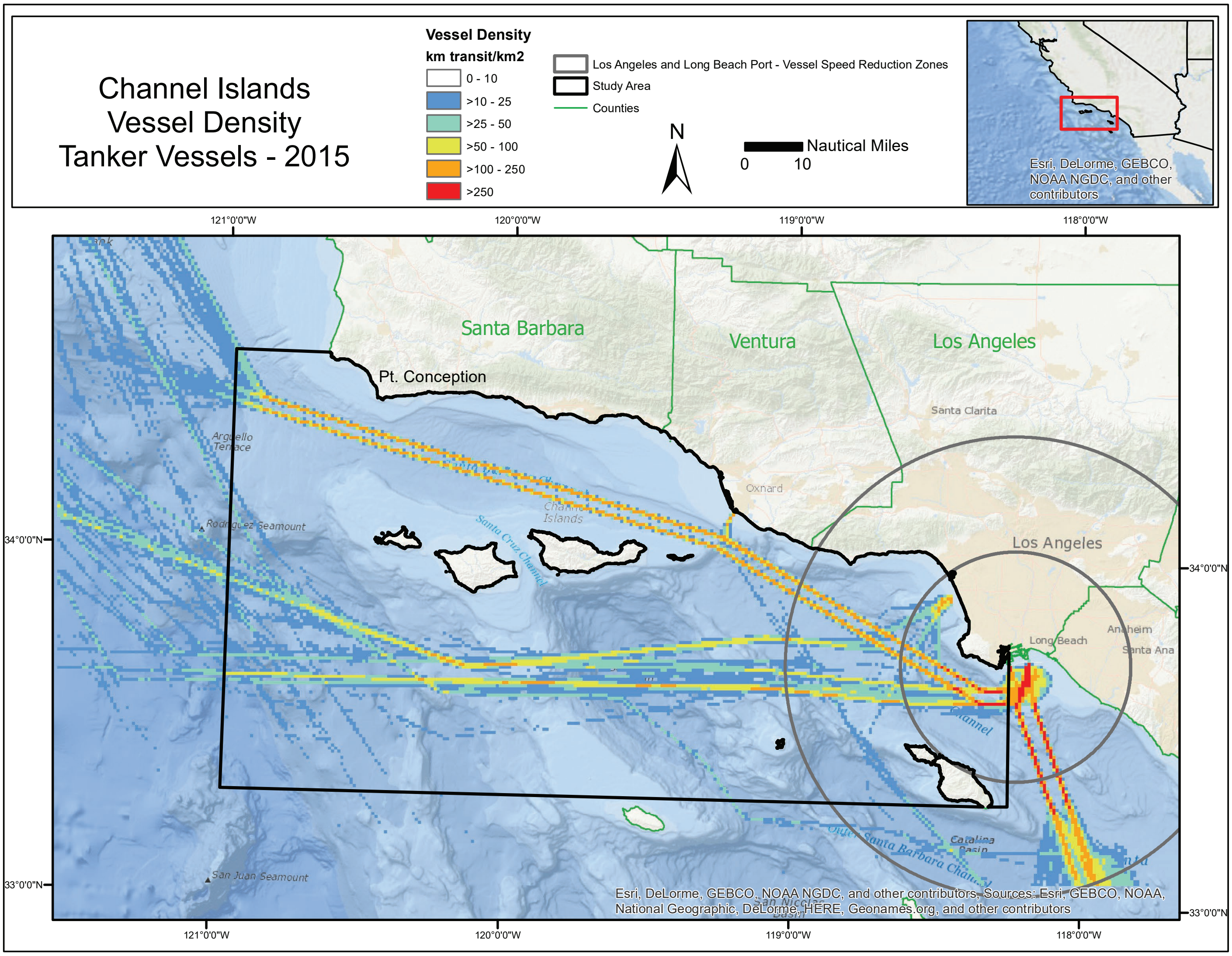

Figure C.1. 2015 vessel density map for Container vessels.

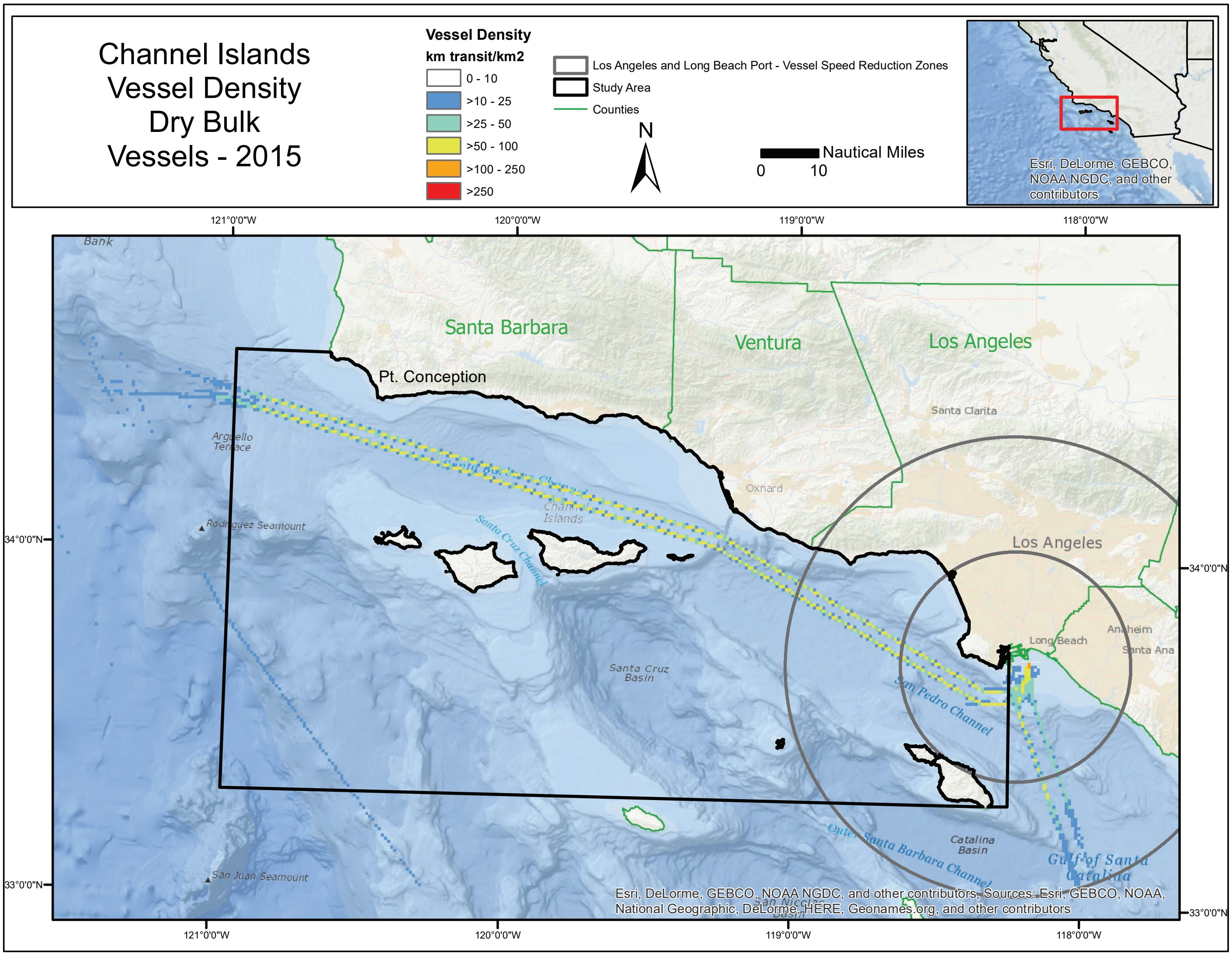

Figure C.2. 2015 vessel density map for Tanker vessels.

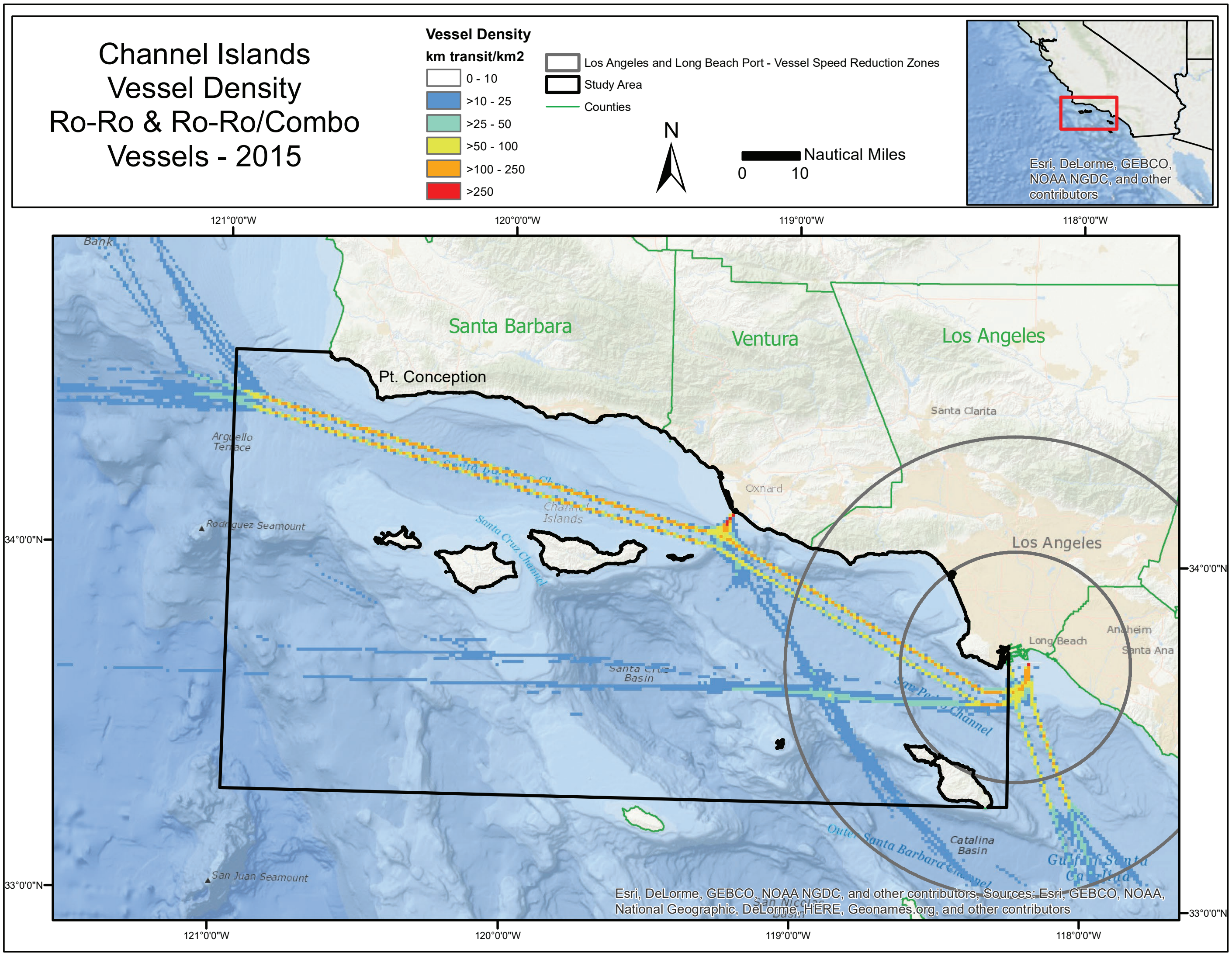

Figure C.3. 2015 vessel density map for Dry Bulk vessels.

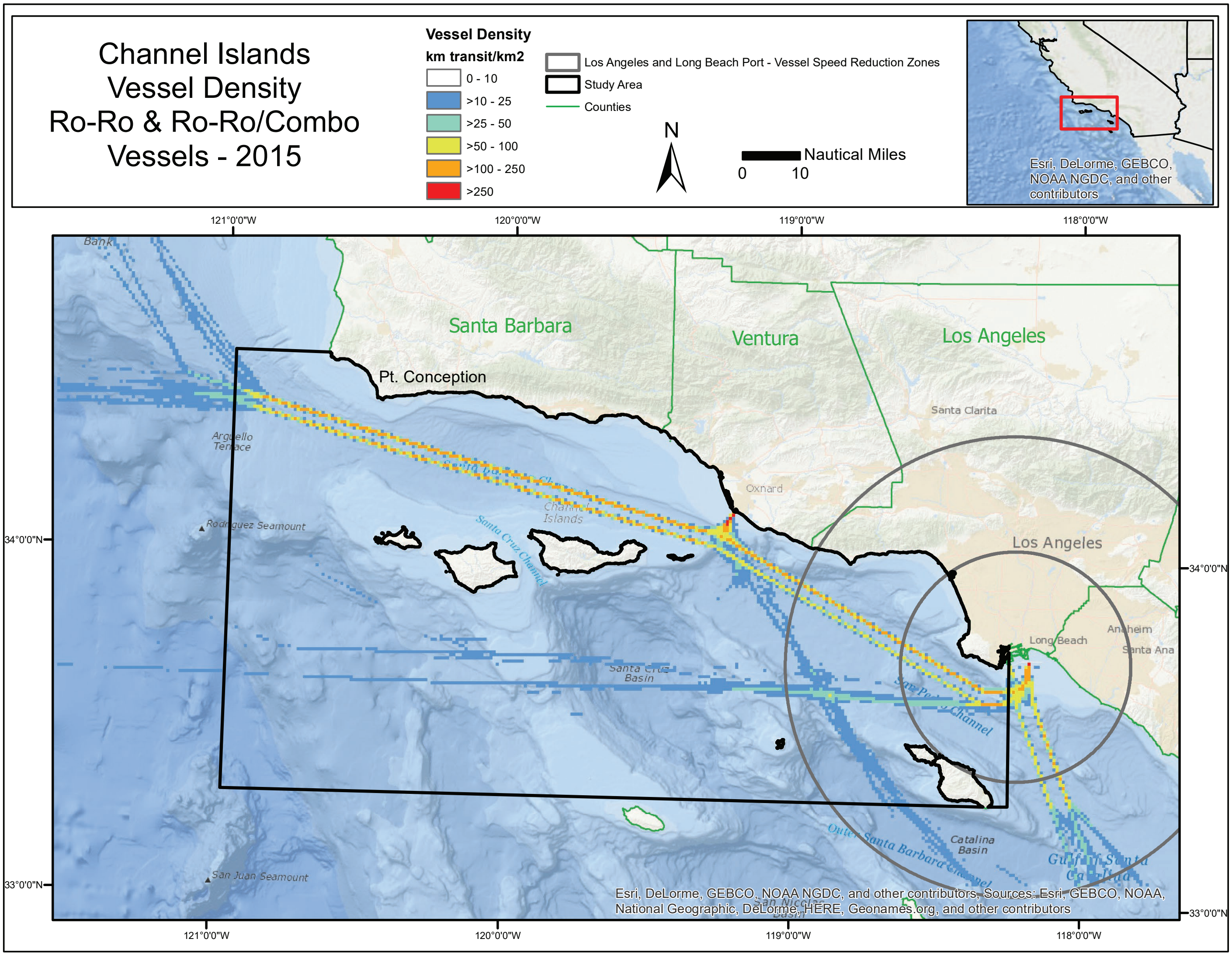

Figure C.4. 2015 vessel density map for Ro-Ro and Ro-Ro/Combo vessels.

APPENDIX D: Average Speed by Vessel Category, Size Class, Route, and Direction

Table D.1. 2015 speeds by vessel category, size class, route, and direction. Significance is at the 95% confidence interval and standard errors are shown in parentheses.

Vessel Category	Size Class	Route	Direction	Mean Speed (knots)	Significantly Different From	
					10 Knots	12 knots
Container	Small	North	Inbound	12.59 (0.12)	YES	YES
			Outbound	12.51 (0.16)	YES	YES
		West	Inbound	12.93 (0.28)	YES	YES
			Outbound	13.03 (0.42)	YES	YES
	Medium	North	Inbound	12.36 (0.09)	YES	YES
			Outbound	12.90 (0.09)	YES	YES
		West	Inbound	12.84 (0.24)	YES	YES
			Outbound	14.01 (0.32)	YES	YES
	Large	North	Inbound	12.61 (0.09)	YES	YES
			Outbound	13.07 (0.10)	YES	YES
		West	Inbound	12.51 (0.22)	YES	YES
			Outbound	13.11 (0.41)	YES	YES
Tanker	Small	North	Inbound	10.69 (0.37)	YES	NO
			Outbound	11.20 (0.62)	YES	NO
		West	Inbound	10.59 (0.31)	YES	YES
			Outbound	10.75 (0.73)	NO	NO
	Medium	North	Inbound	10.57 (0.19)	YES	NO
			Outbound	10.32 (0.13)	YES	YES
		West	Inbound	10.86 (0.17)	YES	NO
			Outbound	10.54 (0.25)	YES	NO
	Large	North	Inbound	10.99 (0.99)	NO	NO
			Outbound	10.91 (1.15)	NO	NO

Table D.1 continued. 2015 speeds by vessel category, size class, route, and direction. Significance is at the 95% confidence interval and standard errors are shown in parentheses.

Vessel Category	Size Class	Route	Direction	Mean Speed (knots)	Significantly Different From	
					10 Knots	12 knots
Tanker	Large	West	Inbound	11.11 (0.28)	YES	YES
			Outbound	10.41 (0.38)	NO	NO
Dry Bulk	Small	North	Inbound	10.35 (0.16)	YES	YES
			Outbound	10.39 (0.14)	YES	YES
		West	Inbound	10.73 (0.39)	NO	NO
			Outbound	11.57 (0.00)	--	--
	Medium	North	Inbound	10.63 (0.32)	YES	NO
			Outbound	10.29 (0.17)	NO	YES
		West	Inbound	11.20 (0.69)	NO	NO
			Outbound	10.61 (0.37)	NO	YES
	Large	North	Inbound	10.57 (0.24)	YES	YES
			Outbound	10.74 (0.20)	YES	YES
		West	Inbound	10.57 (0.38)	NO	NO
			Outbound	10.91 (0.55)	NO	NO
Ro-Ro	Small	North	Inbound	11.27 (0.87)	NO	NO
			Outbound	13.32 (0.10)	YES	YES
		West	Inbound	9.43 (0.00)	--	--
			Outbound	11.68 (0.00)	--	--
	Medium	North	Inbound	10.65 (0.25)	YES	YES
			Outbound	10.91 (0.27)	YES	NO
		West	Inbound	10.97 (0.28)	YES	NO
			Outbound	11.92 (0.69)	YES	NO
	Large	North	Inbound	10.82 (0.28)	YES	YES
			Outbound	11.16 (0.26)	YES	NO

Table D.1 continued. 2015 speeds by vessel category, size class, route, and direction. Significance is at the 95% confidence interval and standard errors are shown in parentheses.

Vessel Category	Size Class	Route	Direction	Mean Speed (knots)	Significantly Different From	
					10 Knots	12 knots
Ro-Ro	Large	West	Inbound	11.50 (0.58)	YES	NO
			Outbound	11.37 (0.41)	YES	NO
Ro-Ro/Combo	Medium	North	Inbound	12.80 (0.61)	YES	NO
			Outbound	13.59 (0.87)	NO	NO
		West	Inbound	12.57 (0.71)	YES	NO
			Outbound	13.31 (0.00)	--	--

Appendices

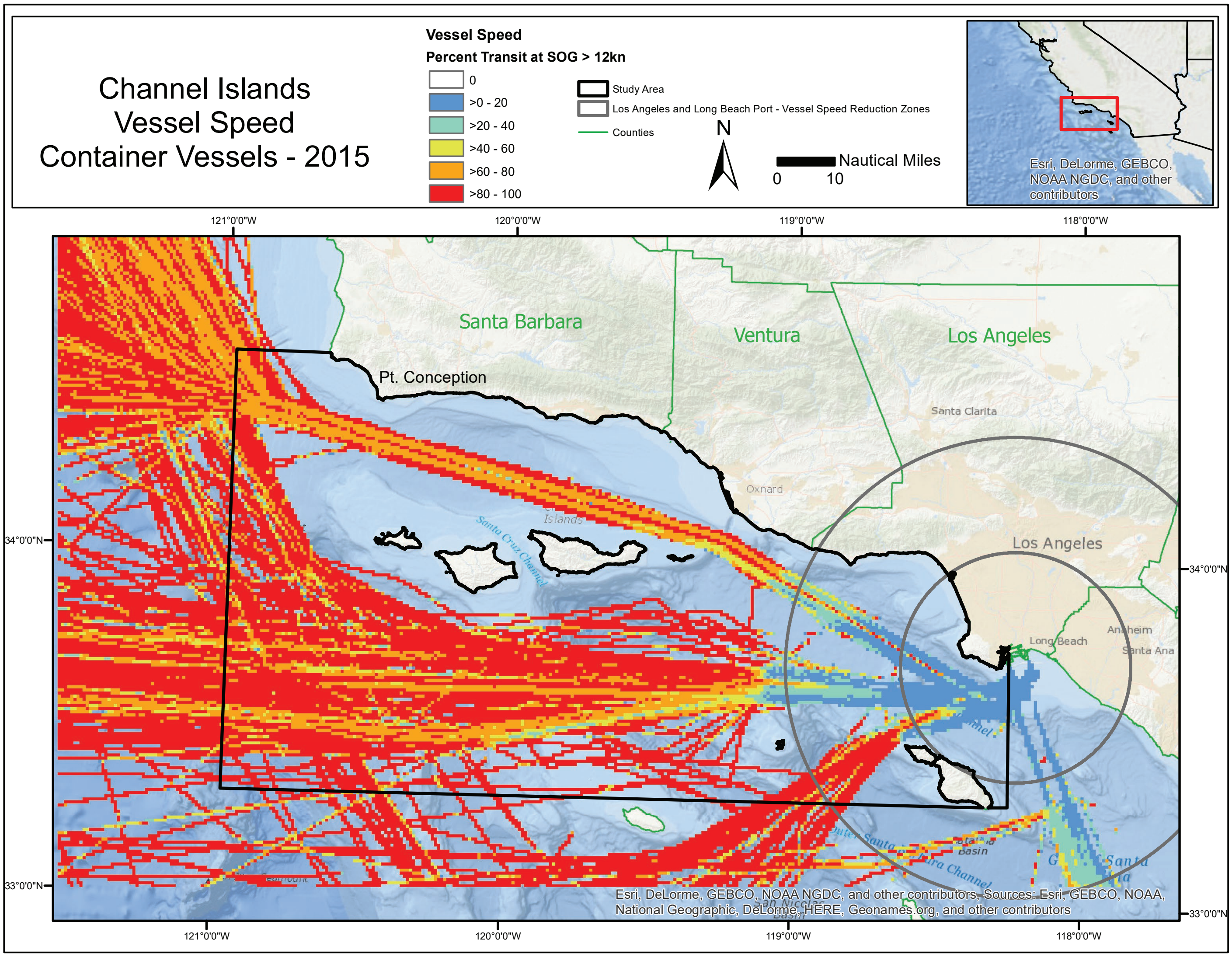

Figure D.1. 2015 speed map for Container vessels.

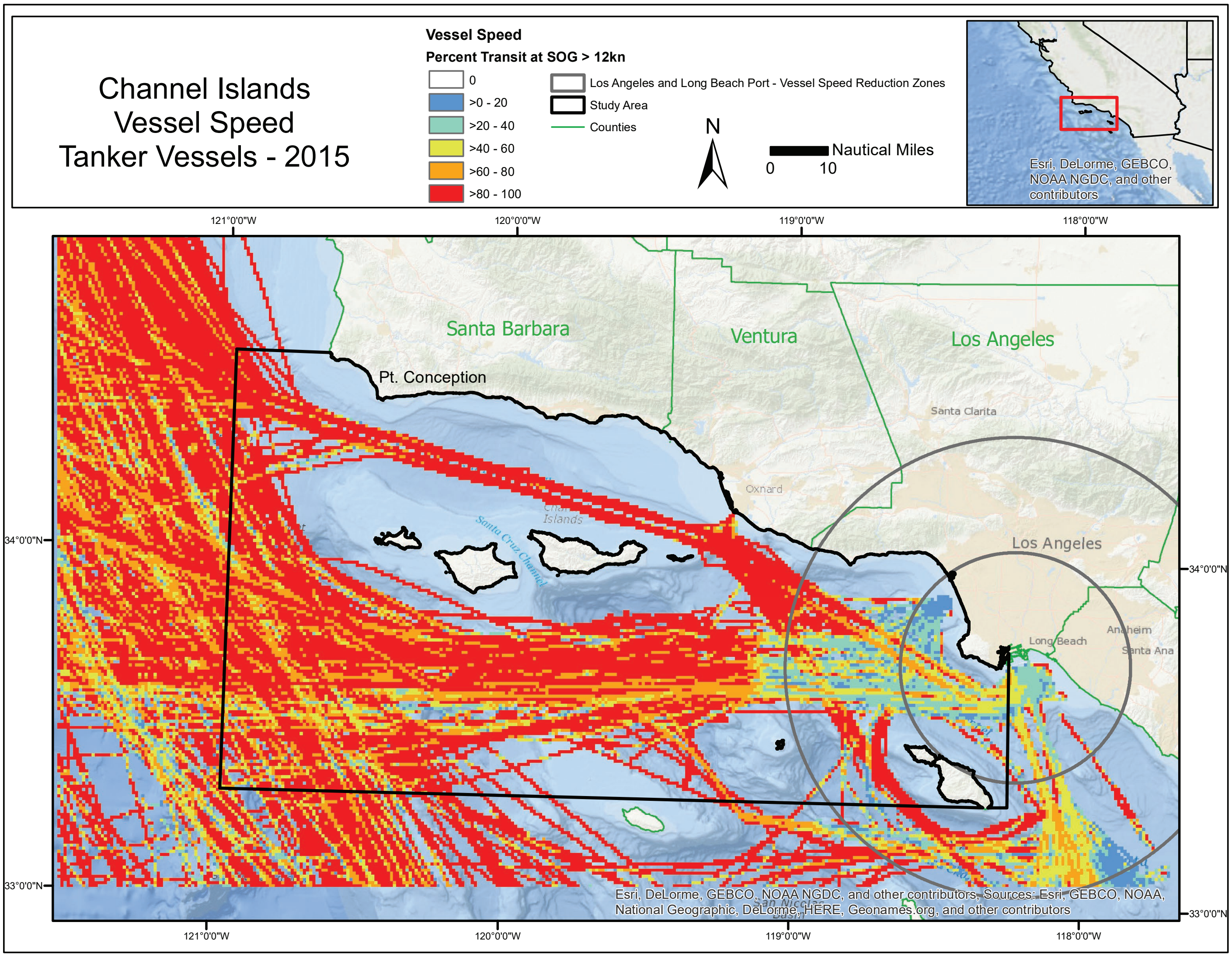

Figure D.2. 2015 speed map for Tanker vessels.

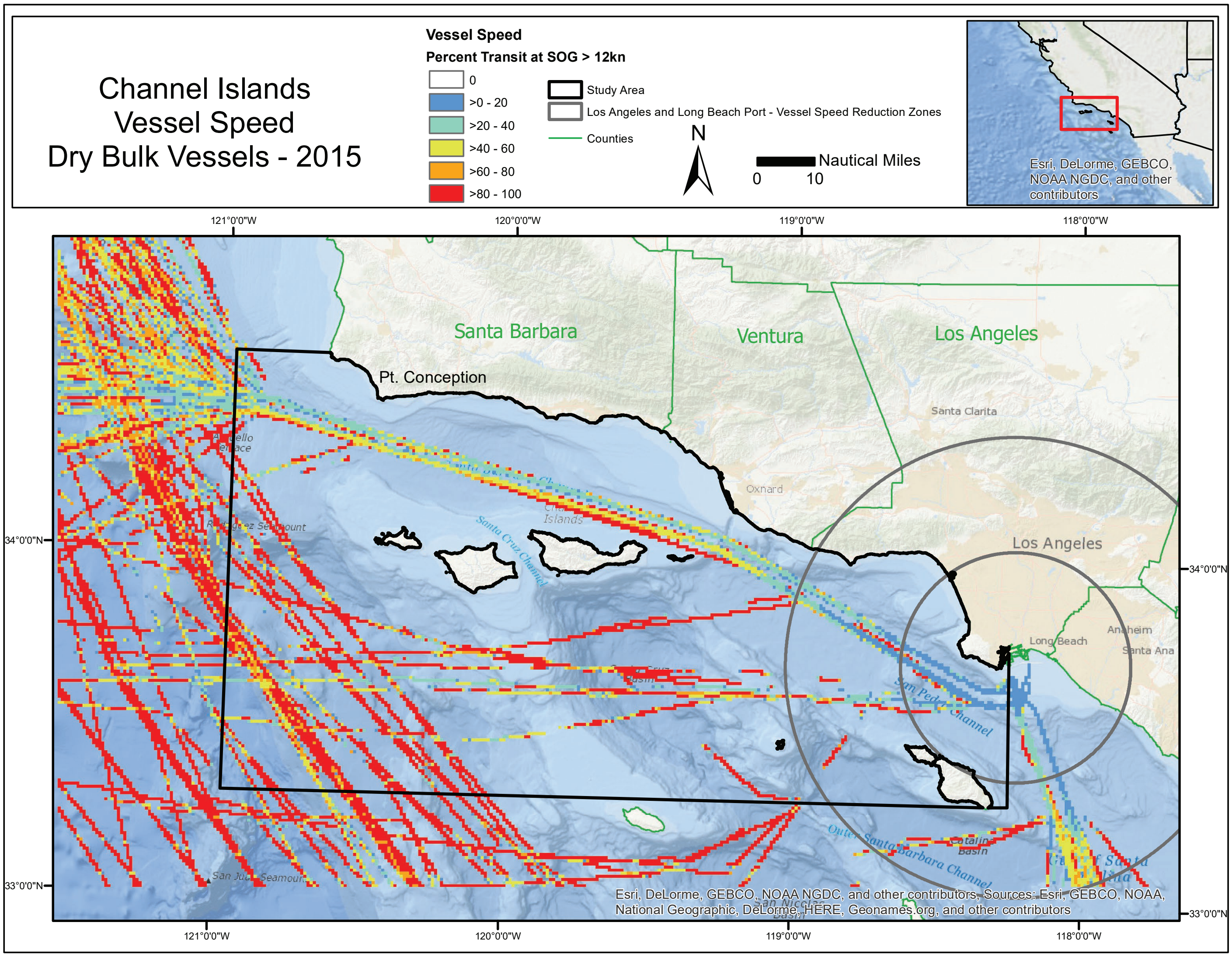

Figure D.3. 2015 speed map for Dry Bulk vessels.

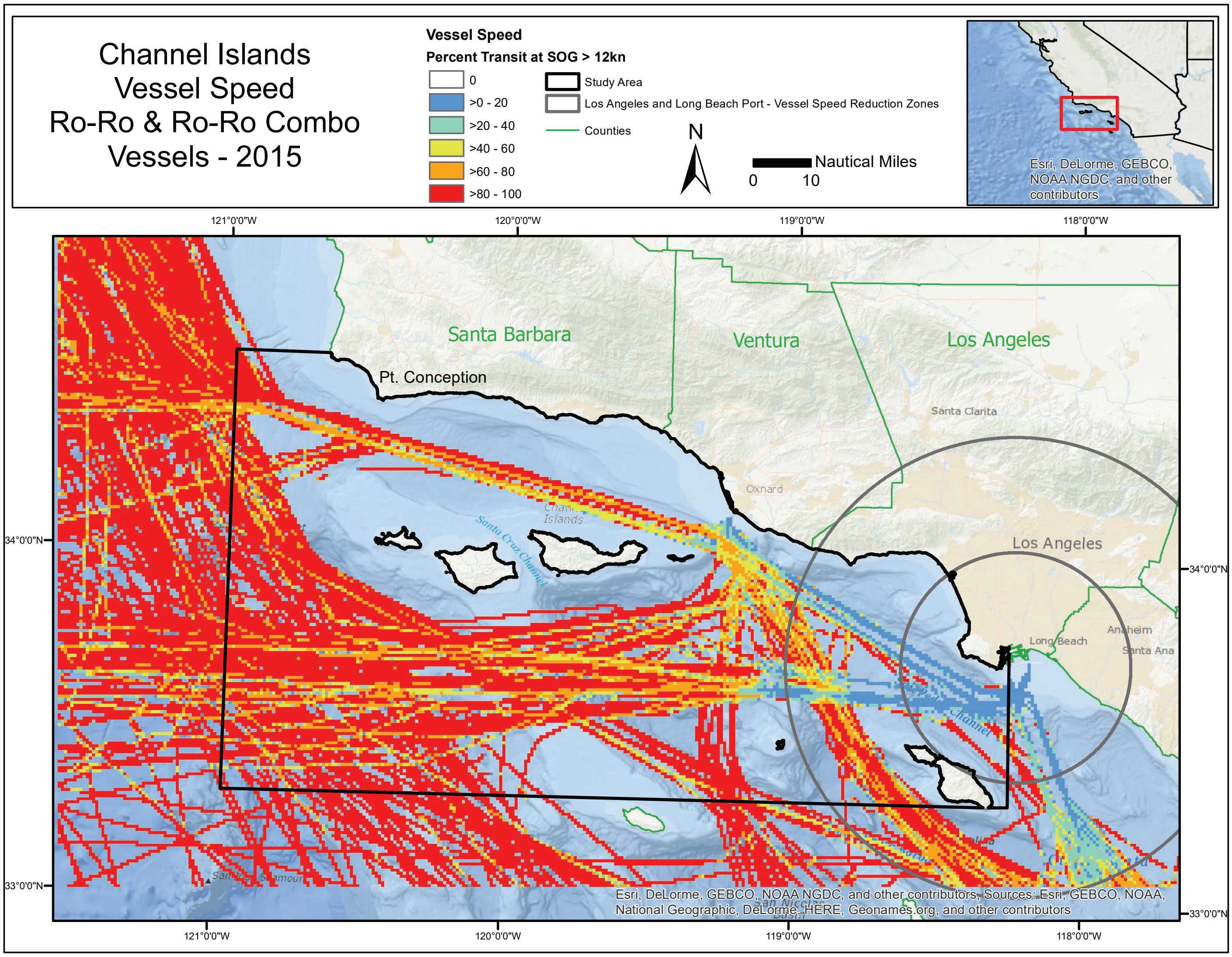

Figure D.4. 2015 speed map for Ro-Ro and Ro-Ro/Combo vessels.

Appendices

APPENDIX E: Predicted Changes in Costs by Potential Management Measure

Table E.1. Predicted changes in costs per 1,000 NM-MT under a 12-knot seasonal VSR with vessel re-routing measure by vessel category, route, direction, fuel efficiency, and fuel price for medium-sized vessels. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Vessel Category	Route	Direction	Change in TC (2015$)				Change in ICC (2015$)	Change in VTC (2015$)			
			High Fuel Efficiency		Low Fuel Efficiency			High Fuel Efficiency		Low Fuel Efficiency	
			High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price		High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price
Container	North	Inbound	**0.03** (0.01)	**0.08** (0.02)	**-0.08** (0.02)	0.00 (0.01)	**0.22** (0.05)	**-0.19** (0.04)	**-0.14** (0.03)	**-0.31** (0.06)	**-0.23** (0.05)
		Outbound	**-0.06** (0.01)	0.03 (0.01)	**-0.24** (0.03)	**-0.10** (0.01)	**0.26** (0.05)	**-0.32** (0.05)	**-0.23** (0.03)	**-0.49** (0.08)	**-0.36** (0.06)
	West	Inbound	**-0.16** (0.06)	-0.10 (0.06)	**-0.26** (0.07)	**-0.17** (0.06)	0.05 (0.04)	**-0.22** (0.04)	**-0.16** (0.03)	**-0.31** (0.06)	**-0.22** (0.04)
		Outbound	**-0.30** (0.05)	**-0.20** (0.05)	**-0.47** (0.07)	**-0.32** (0.05)	0.08 (0.06)	**-0.38** (0.06)	**-0.27** (0.04)	**-0.55** (0.10)	**-0.39** (0.07)
Tanker	North	Inbound	**-0.08** (0.02)	**-0.05** (0.02)	**-0.13** (0.04)	**-0.09** (0.03)	**0.02** (0.01)	**-0.10** (0.03)	**-0.07** (0.02)	**-0.15** (0.05)	**-0.11** (0.03)
		Outbound	**-0.10** (0.02)	-0.07 (0.01)	**-0.15** (0.03)	**-0.11** (0.02)	**0.02** (0.01)	**-0.12** (0.02)	**-0.08** (0.01)	**-0.17** (0.03)	**-0.12** (0.02)
	West	Inbound	**-0.17** (0.03)	**-0.12** (0.02)	**-0.24** (0.04)	**-0.17** (0.03)	0.00 (0.01)	**-0.17** (0.03)	**-0.13** (0.02)	**-0.25** (0.04)	**-0.18** (0.03)
		Outbound	**-0.32** (0.05)	**-0.24** (0.04)	**-0.42** (0.06)	**-0.32** (0.04)	-0.04 (0.02)	**-0.28** (0.04)	**-0.20** (0.03)	**-0.39** (0.06)	**-0.28** (0.04)
Dry Bulk	North	Inbound	-0.01 (0.01)	0.00 (0.01)	-0.03 (0.01)	-0.01 (0.01)	0.02 (0.01)	**-0.03** (0.01)	**-0.02** (0.01)	-0.05 (0.02)	-0.04 (0.02)
		Outbound	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	-0.01 (0.00)	0.00 (0.00)	-0.01 (0.00)	-0.01 (0.00)
	West	Inbound	-0.07 (0.04)	-0.06 (0.04)	-0.09 (0.05)	-0.07 (0.04)	-0.03 (0.03)	-0.04 (0.02)	-0.03 (0.01)	-0.05 (0.02)	-0.04 (0.02)
		Outbound	**-0.12** (0.03)	**-0.10** (0.03)	**-0.18** (0.04)	**-0.14** (0.03)	-0.02 (0.05)	-0.10 (0.04)	-0.08 (0.03)	-0.16 (0.07)	-0.12 (0.06)
Ro-Ro	North	Inbound	**-0.27** (0.12)	-0.24 (0.12)	**-0.31** (0.13)	**-0.26** (0.12)	-0.14 (0.11)	**-0.13** (0.03)	**-0.10** (0.02)	**-0.17** (0.04)	**-0.12** (0.03)
		Outbound	-0.13 (0.15)	-0.05 (0.15)	-0.25 (0.15)	-0.13 (0.15)	0.18 (0.16)	**-0.31** (0.04)	**-0.23** (0.03)	**-0.43** (0.05)	**-0.31** (0.04)
	West	Inbound	-0.96 (0.50)	-0.86 (0.47)	**-1.06** (0.52)	-0.93 (0.49)	-0.59 (0.40)	**-0.37** (0.11)	**-0.27** (0.08)	**-0.47** (0.13)	**-0.34** (0.10)
		Outbound	-0.92 (0.87)	-0.81 (0.81)	-1.04 (0.91)	-0.89 (0.84)	-0.49 (0.66)	-0.43 (0.22)	-0.31 (0.16)	-0.55 (0.27)	-0.40 (0.20)
Ro-Ro/ Combo	North	Inbound	-0.04 (0.07)	-0.03 (0.08)	-0.05 (0.07)	-0.04 (0.07)	0.00 (0.09)	**-0.04** (0.01)	**-0.03** (0.01)	**-0.05** (0.02)	**-0.04** (0.02)
		Outbound	-0.74 (0.38)	-0.69 (0.36)	-0.76 (0.38)	-0.70 (0.36)	-0.57 (0.32)	-0.18 (0.06)	-0.13 (0.04)	-0.19 (0.06)	-0.13 (0.05)
	West	Inbound	-0.22 (0.27)	-0.16 (0.27)	-0.29 (0.25)	-0.21 (0.25)	0.00 (0.28)	**-0.22** (0.07)	**-0.16** (0.05)	**-0.29** (0.10)	**-0.22** (0.07)
		Outbound	-0.04 --	-0.04 --	-0.04 --	-0.04 --	-0.03 --	-0.01 --	-0.01 --	-0.01 --	-0.01 --

Table E.2. Predicted changes in costs per 1,000 NM-MT under a 10-knot seasonal VSR with vessel re-routing measure by vessel category, route, direction, fuel efficiency, and fuel price for medium-sized vessels. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Vessel Category	Route	Direction	Change in TC (2015$)				Change in ICC (2015$)	Change in VTC (2015$)			
			High Fuel Efficiency		Low Fuel Efficiency			High Fuel Efficiency		Low Fuel Efficiency	
			High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price		High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price
Container	North	Inbound	**0.03**	**0.08**	**-0.08**	0.00	**0.22**	**-0.19**	**-0.14**	**-0.31**	**-0.23**
			(0.01)	(0.02)	(0.02)	(0.01)	(0.05)	(0.04)	(0.03)	(0.06)	(0.05)
		Outbound	**-0.06**	0.03	**-0.24**	**-0.10**	**0.26**	**-0.32**	**-0.23**	**-0.49**	**-0.36**
			(0.01)	(0.01)	(0.03)	(0.01)	(0.05)	(0.05)	(0.03)	(0.08)	(0.06)
	West	Inbound	**-0.16**	-0.10	**-0.26**	**-0.17**	0.05	**-0.22**	**-0.16**	**-0.31**	**-0.22**
			(0.06)	(0.06)	(0.07)	(0.06)	(0.04)	(0.04)	(0.03)	(0.06)	(0.04)
		Outbound	**-0.30**	**-0.20**	**-0.47**	**-0.32**	0.08	**-0.38**	**-0.27**	**-0.55**	**-0.39**
			(0.05)	(0.05)	(0.07)	(0.05)	(0.06)	(0.06)	(0.04)	(0.10)	(0.07)
Tanker	North	Inbound	**-0.15**	**-0.08**	**-0.27**	**-0.17**	**0.09**	**-0.24**	**-0.17**	**-0.35**	**-0.26**
			(0.03)	(0.02)	(0.06)	(0.04)	(0.02)	(0.05)	(0.04)	(0.08)	(0.05)
		Outbound	**-0.17**	**-0.10**	**-0.29**	**-0.19**	**0.09**	**-0.26**	**-0.19**	**-0.38**	**-0.28**
			(0.03)	(0.02)	(0.05)	(0.03)	(0.02)	(0.04)	(0.03)	(0.07)	(0.05)
	West	Inbound	**-0.24**	**-0.15**	**-0.38**	**-0.25**	**0.07**	**-0.31**	**-0.22**	**-0.45**	**-0.32**
			(0.03)	(0.02)	(0.05)	(0.03)	(0.01)	(0.04)	(0.03)	(0.06)	(0.04)
		Outbound	**-0.38**	**-0.27**	**-0.55**	**-0.39**	0.02	**-0.40**	**-0.29**	**-0.57**	**-0.41**
			(0.05)	(0.04)	(0.07)	(0.05)	(0.03)	(0.05)	(0.04)	(0.08)	(0.06)
Dry Bulk	North	Inbound	**0.09**	**0.12**	0.01	**0.06**	**0.19**	**-0.11**	**-0.08**	**-0.18**	**-0.13**
			(0.02)	(0.03)	(0.02)	(0.02)	(0.05)	(0.03)	(0.02)	(0.06)	(0.04)
		Outbound	**0.08**	**0.10**	**0.02**	**0.06**	**0.16**	**-0.08**	**-0.06**	**-0.14**	**-0.10**
			(0.02)	(0.02)	(0.01)	(0.01)	(0.03)	(0.02)	(0.01)	(0.03)	(0.02)
	West	Inbound	-0.02	0.01	-0.09	-0.05	0.10	-0.12	-0.09	-0.19	-0.14
			(0.08)	(0.09)	(0.05)	(0.06)	(0.15)	(0.08)	(0.06)	(0.14)	(0.11)
		Outbound	-0.01	0.05	**-0.15**	-0.06	0.24	-0.25	-0.18	-0.39	-0.29
			(0.06)	(0.08)	(0.04)	(0.04)	(0.16)	(0.10)	(0.08)	(0.18)	(0.13)
Ro-Ro	North	Inbound	-0.05	-0.01	-0.11	-0.05	0.11	**-0.17**	**-0.12**	**-0.22**	**-0.16**
			(0.15)	(0.15)	(0.15)	(0.14)	(0.14)	(0.03)	(0.02)	(0.04)	(0.03)
		Outbound	0.18	0.28	0.04	0.17	**0.54**	**-0.36**	**-0.26**	**-0.50**	**-0.37**
			(0.17)	(0.17)	(0.16)	(0.16)	(0.18)	(0.04)	(0.03)	(0.06)	(0.05)
	West	Inbound	-0.71	-0.60	-0.82	-0.68	-0.30	**-0.41**	**-0.30**	**-0.53**	**-0.39**
			(0.49)	(0.46)	(0.50)	(0.47)	(0.39)	(0.11)	(0.08)	(0.14)	(0.10)
		Outbound	-0.68	-0.56	-0.82	-0.66	-0.21	-0.47	-0.34	**-0.61**	-0.44
			(0.86)	(0.81)	(0.90)	(0.83)	(0.66)	(0.23)	(0.17)	(0.28)	(0.20)
Ro-Ro/ Combo	North	Inbound	-0.04	-0.03	-0.05	-0.04	0.00	**-0.04**	**-0.03**	**-0.05**	**-0.04**
			(0.07)	(0.08)	(0.07)	(0.07)	(0.09)	(0.01)	(0.01)	(0.02)	(0.02)
		Outbound	-0.74	-0.69	-0.76	-0.70	-0.57	-0.18	-0.13	-0.19	-0.13
			(0.38)	(0.36)	(0.38)	(0.36)	(0.32)	(0.06)	(0.04)	(0.06)	(0.05)
	West	Inbound	-0.22	-0.16	-0.29	-0.21	0.00	**-0.22**	**-0.16**	**-0.29**	**-0.22**
			(0.27)	(0.27)	(0.25)	(0.25)	(0.28)	(0.07)	(0.05)	(0.10)	(0.07)
		Outbound	-0.04	-0.04	-0.04	-0.04	-0.03	-0.01	-0.01	-0.01	-0.01
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Table E.3. Predicted changes in costs per 1,000 NM-MT under a 12-knot seasonal VSR only measure by vessel category, route, direction, fuel efficiency, and fuel price for medium-sized vessels. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Vessel Category	Route	Direction	Change in TC (2015$)				Change in ICC (2015$)	Change in VTC (2015$)			
			High Fuel Efficiency		Low Fuel Efficiency			High Fuel Efficiency		Low Fuel Efficiency	
			High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price		High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price
Container	North	Inbound	**0.06**	**0.11**	**-0.05**	**0.03**	**0.25**	**-0.18**	**-0.13**	**-0.30**	**-0.22**
			(0.01)	(0.02)	(0.02)	(0.01)	(0.05)	(0.04)	(0.03)	(0.06)	(0.05)
		Outbound	**0.05**	**0.12**	**-0.12**	0.00	**0.31**	**-0.27**	**-0.20**	**-0.43**	**-0.32**
			(0.01)	(0.02)	(0.03)	(0.01)	(0.05)	(0.04)	(0.03)	(0.07)	(0.05)
	West	Inbound	**0.04**	**0.07**	**-0.03**	**0.02**	**0.16**	**-0.12**	**-0.08**	**-0.19**	**-0.14**
			(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.04)	(0.03)
		Outbound	0.02	**0.08**	**-0.12**	-0.02	**0.25**	**-0.23**	**-0.16**	**-0.37**	**-0.26**
			(0.01)	(0.02)	(0.04)	(0.02)	(0.05)	(0.06)	(0.04)	(0.09)	(0.06)
Tanker	North	Inbound	**-0.07**	**-0.04**	**-0.12**	**-0.08**	**0.02**	**-0.09**	**-0.07**	**-0.14**	**-0.10**
			(0.02)	(0.02)	(0.04)	(0.03)	(0.01)	(0.03)	(0.02)	(0.05)	(0.03)
		Outbound	**-0.07**	**-0.04**	**-0.12**	**-0.08**	**0.03**	**-0.09**	**-0.07**	**-0.14**	**-0.10**
			(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.03)	(0.02)
	West	Inbound	**-0.08**	**-0.05**	**-0.13**	**-0.09**	**0.03**	**-0.11**	**-0.08**	**-0.16**	**-0.12**
			(0.01)	(0.01)	(0.02)	(0.02)	(0.00)	(0.02)	(0.01)	(0.03)	(0.02)
		Outbound	**-0.12**	**-0.08**	**-0.20**	**-0.13**	**0.04**	**-0.16**	**-0.11**	**-0.24**	**-0.17**
			(0.03)	(0.02)	(0.04)	(0.03)	(0.01)	(0.03)	(0.02)	(0.05)	(0.04)
Dry Bulk	North	Inbound	0.00	**0.01**	-0.02	0.00	0.03	-0.03	-0.02	-0.04	-0.03
			(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
		Outbound	0.00	0.00	**0.00**	0.00	0.01	**-0.01**	**0.00**	**-0.01**	**-0.01**
			(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	West	Inbound	0.00	0.00	0.00	0.00	0.01	-0.01	-0.01	-0.01	-0.01
			(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
		Outbound	0.00	0.01	-0.03	-0.01	0.05	-0.05	-0.04	-0.08	-0.06
			(0.00)	(0.01)	(0.03)	(0.01)	(0.05)	(0.04)	(0.03)	(0.08)	(0.06)
Ro-Ro	North	Inbound	**0.13**	**0.14**	**0.10**	**0.12**	**0.17**	**-0.05**	**-0.03**	**-0.07**	**-0.05**
			(0.04)	(0.04)	(0.03)	(0.03)	(0.05)	(0.02)	(0.01)	(0.02)	(0.02)
		Outbound	**0.38**	**0.43**	**0.28**	**0.36**	**0.57**	**-0.19**	**-0.14**	**-0.29**	**-0.21**
			(0.06)	(0.07)	(0.04)	(0.06)	(0.09)	(0.03)	(0.03)	(0.05)	(0.04)
	West	Inbound	**0.25**	**0.28**	**0.20**	**0.24**	**0.36**	**-0.11**	**-0.08**	**-0.16**	**-0.12**
			(0.05)	(0.06)	(0.04)	(0.05)	(0.08)	(0.02)	(0.02)	(0.04)	(0.03)
		Outbound	**0.30**	**0.33**	**0.23**	**0.29**	**0.43**	**-0.14**	**-0.10**	**-0.20**	**-0.14**
			(0.09)	(0.10)	(0.07)	(0.09)	(0.13)	(0.05)	(0.03)	(0.07)	(0.05)
Ro-Ro/ Combo	North	Inbound	0.08	0.08	0.07	0.07	0.09	-0.02	-0.01	-0.03	-0.02
			(0.06)	(0.07)	(0.06)	(0.06)	(0.08)	(0.01)	(0.01)	(0.02)	(0.02)
		Outbound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	West	Inbound	**0.30**	**0.33**	**0.24**	**0.28**	**0.42**	-0.12	-0.09	-0.19	-0.14
			(0.11)	(0.12)	(0.08)	(0.10)	(0.17)	(0.06)	(0.05)	(0.10)	(0.07)
		Outbound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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Table E.4. Predicted changes in costs per 1,000 NM-MT under a 10-knot seasonal VSR only measure by vessel category, route, direction, fuel efficiency, and fuel price for medium-sized vessels. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Vessel Category	Route	Direction	Change in TC (2015$)				Change in ICC (2015$)	Change in VTC (2015$)			
			High Fuel Efficiency		Low Fuel Efficiency			High Fuel Efficiency		Low Fuel Efficiency	
			High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price		High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price
Container	North	Inbound	**0.06** (0.01)	**0.11** (0.02)	**-0.05** (0.02)	**0.03** (0.01)	**0.25** (0.05)	**-0.18** (0.04)	**-0.13** (0.03)	**-0.30** (0.06)	**-0.22** (0.05)
Container	North	Outbound	**0.05** (0.01)	**0.12** (0.02)	**-0.12** (0.03)	0.00 (0.01)	**0.31** (0.05)	**-0.27** (0.04)	**-0.20** (0.03)	**-0.43** (0.07)	**-0.32** (0.05)
Container	West	Inbound	**0.04** (0.01)	**0.07** (0.01)	**-0.03** (0.01)	**0.02** (0.01)	**0.16** (0.03)	**-0.12** (0.02)	**-0.08** (0.02)	**-0.19** (0.04)	**-0.14** (0.03)
Container	West	Outbound	0.02 (0.01)	**0.08** (0.02)	**-0.12** (0.04)	-0.02 (0.02)	**0.25** (0.05)	**-0.23** (0.06)	**-0.16** (0.04)	**-0.37** (0.09)	**-0.26** (0.06)
Tanker	North	Inbound	**-0.14** (0.03)	**-0.07** (0.02)	**-0.25** (0.06)	**-0.16** (0.04)	**0.09** (0.02)	**-0.23** (0.05)	**-0.17** (0.04)	**-0.34** (0.08)	**-0.25** (0.05)
Tanker	North	Outbound	**-0.14** (0.02)	**-0.07** (0.01)	**-0.26** (0.05)	**-0.16** (0.03)	**0.10** (0.02)	**-0.24** (0.04)	**-0.17** (0.03)	**-0.36** (0.06)	**-0.26** (0.05)
Tanker	West	Inbound	**-0.14** (0.02)	**-0.08** (0.01)	**-0.26** (0.04)	**-0.16** (0.02)	**0.10** (0.01)	**-0.24** (0.03)	**-0.17** (0.02)	**-0.36** (0.05)	**-0.26** (0.04)
Tanker	West	Outbound	**-0.18** (0.03)	**-0.10** (0.02)	**-0.32** (0.06)	**-0.21** (0.04)	**0.10** (0.02)	**-0.28** (0.05)	**-0.20** (0.04)	**-0.42** (0.07)	**-0.30** (0.05)
Dry Bulk	North	Inbound	**0.10** (0.02)	**0.12** (0.03)	0.03 (0.02)	**0.07** (0.02)	**0.20** (0.05)	**-0.10** (0.03)	**-0.08** (0.02)	**-0.18** (0.06)	**-0.13** (0.04)
Dry Bulk	North	Outbound	**0.08** (0.02)	**0.10** (0.02)	**0.03** (0.01)	**0.06** (0.01)	**0.16** (0.03)	**-0.08** (0.02)	**-0.06** (0.01)	**-0.14** (0.03)	**-0.10** (0.02)
Dry Bulk	West	Inbound	0.05 (0.05)	0.07 (0.07)	-0.01 (0.01)	0.03 (0.03)	0.14 (0.14)	-0.09 (0.09)	-0.07 (0.07)	-0.15 (0.15)	-0.11 (0.11)
Dry Bulk	West	Outbound	0.12 (0.05)	0.17 (0.08)	-0.01 (0.03)	0.07 (0.03)	0.31 (0.16)	-0.19 (0.11)	-0.14 (0.08)	-0.32 (0.18)	-0.24 (0.14)
Ro-Ro	North	Inbound	**0.35** (0.07)	**0.37** (0.07)	**0.31** (0.06)	**0.34** (0.07)	**0.43** (0.09)	**-0.08** (0.02)	**-0.06** (0.02)	**-0.12** (0.03)	**-0.09** (0.02)
Ro-Ro	North	Outbound	**0.69** (0.09)	**0.75** (0.10)	**0.57** (0.07)	**0.66** (0.09)	**0.93** (0.13)	**-0.24** (0.04)	**-0.18** (0.03)	**-0.36** (0.06)	**-0.27** (0.04)
Ro-Ro	West	Inbound	**0.51** (0.09)	**0.55** (0.10)	**0.44** (0.08)	**0.49** (0.09)	**0.65** (0.12)	**-0.14** (0.03)	**-0.10** (0.02)	**-0.21** (0.04)	**-0.16** (0.03)
Ro-Ro	West	Outbound	**0.53** (0.16)	**0.58** (0.17)	**0.45** (0.13)	**0.52** (0.15)	**0.71** (0.21)	**-0.17** (0.05)	**-0.12** (0.04)	**-0.26** (0.08)	**-0.19** (0.06)
Ro-Ro/ Combo	North	Inbound	0.08 (0.06)	0.08 (0.07)	0.07 (0.06)	0.07 (0.06)	0.09 (0.08)	-0.02 (0.01)	-0.01 (0.01)	-0.03 (0.02)	-0.02 (0.02)
Ro-Ro/ Combo	North	Outbound	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Ro-Ro/ Combo	West	Inbound	**0.30** (0.11)	**0.33** (0.12)	**0.24** (0.08)	**0.28** (0.10)	**0.42** (0.17)	-0.12 (0.06)	-0.09 (0.05)	-0.19 (0.10)	-0.14 (0.07)
Ro-Ro/ Combo	West	Outbound	0.00 --	0.00 --	0.00 --	0.00 --	0.00 --	0.00 --	0.00 --	0.00 --	0.00 --

Table E.5. Predicted changes in costs per 1,000 NM-MT under a re-routing measure by vessel category, route, direction, fuel efficiency, and fuel price for medium-sized vessels. Values that are significantly different (95% confidence) from the 2015 baseline are shown in bold. Standard errors are shown in parentheses.

Vessel Category	Route	Direction	Change in TC (2015$)				Change in ICC (2015$)	Change in VTC (2015$)			
			High Fuel Efficiency		Low Fuel Efficiency			High Fuel Efficiency		Low Fuel Efficiency	
			High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price		High Fuel Price	Low Fuel Price	High Fuel Price	Low Fuel Price
Container	North	Inbound	**-0.03**	**-0.03**	**-0.04**	**-0.03**	**-0.02**	**-0.01**	**-0.01**	**-0.01**	**-0.01**
			(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
		Outbound	**-0.11**	**-0.09**	**-0.12**	**-0.10**	**-0.06**	**-0.05**	**-0.04**	**-0.06**	**-0.04**
			(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
	West	Inbound	**-0.21**	**-0.18**	**-0.22**	**-0.19**	**-0.11**	**-0.10**	**-0.07**	**-0.12**	**-0.08**
			(0.06)	(0.05)	(0.07)	(0.06)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)
		Outbound	**-0.32**	**-0.28**	**-0.35**	**-0.30**	**-0.17**	**-0.15**	**-0.11**	**-0.18**	**-0.13**
			(0.05)	(0.05)	(0.06)	(0.05)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)
Tanker	North	Inbound	**-0.01**	**-0.01**	**-0.01**	**-0.01**	**0.00**	**-0.01**	**-0.01**	**-0.01**	**-0.01**
			(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
		Outbound	**-0.03**	**-0.02**	**-0.04**	**-0.03**	**-0.01**	**-0.02**	**-0.02**	**-0.03**	**-0.02**
			(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
	West	Inbound	**-0.09**	**-0.07**	**-0.11**	**-0.09**	**-0.02**	**-0.07**	**-0.05**	**-0.09**	**-0.06**
			(0.02)	(0.02)	(0.03)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)
		Outbound	**-0.20**	**-0.16**	**-0.22**	**-0.18**	**-0.07**	**-0.12**	**-0.09**	**-0.15**	**-0.11**
			(0.04)	(0.04)	(0.05)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)
Dry Bulk	North	Inbound	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	-0.01	0.00
			(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
		Outbound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	West	Inbound	-0.07	-0.06	-0.08	-0.07	-0.04	-0.03	-0.02	-0.04	-0.03
			(0.04)	(0.04)	(0.05)	(0.04)	(0.02)	(0.02)	(0.01)	(0.03)	(0.02)
		Outbound	**-0.13**	**-0.11**	**-0.15**	**-0.12**	**-0.07**	**-0.06**	**-0.04**	**-0.08**	**-0.06**
			(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Ro-Ro	North	Inbound	**-0.40**	**-0.37**	**-0.41**	**-0.39**	**-0.31**	**-0.09**	**-0.06**	**-0.10**	**-0.07**
			(0.11)	(0.10)	(0.11)	(0.10)	(0.08)	(0.03)	(0.02)	(0.03)	(0.02)
		Outbound	**-0.51**	**-0.47**	**-0.53**	**-0.49**	**-0.39**	**-0.12**	**-0.08**	**-0.14**	**-0.10**
			(0.13)	(0.12)	(0.13)	(0.12)	(0.10)	(0.03)	(0.02)	(0.03)	(0.02)
	West	Inbound	**-1.21**	**-1.14**	**-1.26**	**-1.18**	**-0.95**	**-0.26**	**-0.19**	**-0.31**	**-0.23**
			(0.51)	(0.48)	(0.53)	(0.50)	(0.41)	(0.10)	(0.08)	(0.12)	(0.09)
		Outbound	-1.22	-1.14	-1.27	-1.18	-0.92	-0.29	-0.22	-0.35	-0.26
			(0.88)	(0.82)	(0.92)	(0.86)	(0.66)	(0.22)	(0.16)	(0.26)	(0.19)
Ro-Ro/ Combo	North	Inbound	**-0.11**	**-0.11**	**-0.12**	**-0.11**	**-0.09**	**-0.02**	**-0.01**	**-0.02**	**-0.02**
			(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
		Outbound	-0.74	-0.69	-0.76	-0.70	-0.57	-0.18	-0.13	-0.19	-0.13
			(0.38)	(0.36)	(0.38)	(0.36)	(0.32)	(0.06)	(0.04)	(0.06)	(0.05)
	West	Inbound	**-0.52**	**-0.49**	**-0.53**	**-0.50**	**-0.42**	**-0.10**	**-0.07**	**-0.11**	**-0.08**
			(0.21)	(0.20)	(0.21)	(0.20)	(0.18)	(0.03)	(0.02)	(0.03)	(0.03)
		Outbound	-0.04	-0.04	-0.04	-0.04	-0.03	-0.01	-0.01	-0.01	-0.01
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