15 NM SHIPPING LANE SHIFT

IMPACT ASSESSMENT REPORT

2022

Source: Oceanswell

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1. EXECUTIVE SUMMARY

A Context

Ocean blue whales, Balaenoptera musculus indica. These whales are currently under threat from collisions in heavily trafficked shipping routes hugging the Sri Lankan coast. Shifting these shipping routes a further 15 nautical miles (nm) offshore to a total of 20 nm may reduce blue whale mortality with other added economic benefits. In this scenario, ship traffic would be rerouted by shifting the location of the eastward and westward Dondra Traffic Separation Scheme (henceforth referred to as TSS) on Sri Lanka's southern coast.

B Research Questions and Methodology

Q1. What are the costs and benefits of moving shipping routes 20 nm further offshore off southern Sri Lanka?
Q2. What is the economic and ecological value of blue whales? What is the current threat to blue whales from vessels?

To analyze the impacts of moving the TSS 15 nm south of their current position along the Sri Lanka southern coast, a cost-benefit analysis (henceforth referred to as CBA) and a geographic information system analysis (henceforth referred to as GIS) were conducted.

C Key Findings

In considering best case or optimistic scenarios, this CBA yielded a projected 8.30% increase in value to the Sri Lankan government. These 60.645 million USD in value are distributed across 6 economic metrics: Ecosystem Impact Estimate, Cost of Carbon to Sri Lanka from Shipping, Shipping Industry Gas Cost, Coastal Fisheries Impact, Impact to Tourism Industry, and Port Revenues. GIS mapping visualized the proposed TSS movement as well as whale sightings, blue whale density and commercial ship density off of Sri Lanka's southern coast along the current shipping route.

D Recommendations

Key recommendations for Oceanswell include shifting the TSS lane 15 nm offshore and highlighting this lane change's accompanying economic benefits with both Sri Lankan government and shipping industry stakeholders.

2. INTRODUCTION

2.1 The Issue

Blue whales play an essential role in local ecosystems, regional economies, and global climate change. In general, whales influence ecosystems through nutrient cycling and delay global warming by acting as carbon sinks (22). Impressively, a whale can draw close to 190,000 tons of carbon from the atmosphere, equivalent to the amount of carbon produced by 80,000 cars in one year (11). In addition to supporting climatic anthropogenic interests, nations can capitalize on healthy whale populations through tourism within blue economies.

The Northern Indian Ocean blue whale lives permanently off the coast of Sri Lanka. Non-migratory behavior, small size, time of the breeding season, dialect for communication, and feeding behavior all distinguish the Northern Indian Ocean blue whale from other blue whale subspecies. Concurrently, Sri Lankan waters host one of the busiest series of global shipping routes. Thus, ship collisions pose the most significant threat to Sri Lanka's unique blue whale population (24).

Currently, the vast majority of ships entering Sri Lanka's waters do not stop at their ports and thus provide no economic value to Sri Lanka (12). Our client Oceanswell is proposing that shipping routes be moved 20 nm off of the southern coast of Sri Lanka. Vessel collisions with smaller fishing boats and whales are inherently hazardous and could pose financial consequences with regards to industry liability. Concern from the Sri Lankan government on the basis of negative economic repercussions exists and will be addressed through our two deliverables.

This report talks about the economic and environmental effects of moving the existing shipping route a further 15 nm off the southern coast of Sri Lanka. These effects are explored through the following 6 parameters: Ecosystem Impact Estimate, Cost of Carbon to Sri Lanka from Shipping, Shipping Industry Gas Cost, Coastal Fisheries Impact, Impact to Tourism Industry, and Port Revenues. A GIS analysis further supplements the analysis of the impacts and value of moving shipping routes, considering the protection of Sri Lanka’s blue whales and coastal communities, as well as the economic wellbeing of the nation of Sri Lanka. More specifically, effects on shipping dynamics, coastal economies, local blue whale populations, risk of disasters, air pollution, and other relevant sectors are considered.

2.2 Literature Review Insights

A preliminary literature review indicates that the coastal population of blue whales thrives where the current shipping route is located, and that Oceanswell's current research suggests that the proposed move of 15 nm would decrease blue whale mortality risk (24). This literature review also cites blue whales as powerful vectors of nutrient and material flux in their role as catalysts for ecosystem development by contributing to primary production in an energy transfer known as a "whale pump" (14). Furthermore, whales stabilize ecosystems in their role as predator and prey; they manage krill populations at the top of the food chain and act as essential carbon sinks offsetting global anthropogenic emissions when their carcasses sink to sustain ecosystems on the ocean floor (24).. Therefore, this report considers a reduction in whale mortality to positively impact the overall health of the Sri Lankan coastal ecosystem, with potential for additional economic benefits. To this effect, this review suggests that the current shipping route may impede the success of the Sri Lankan fishery and coastal economy through noise pollution, fishing bans, and contaminated fish stock due to vessel accidents (5). While both the IMO and international shipping companies appear to acknowledge the benefits of Oceanswell's proposed lane shift, concern regarding shipping industry revenue still needs to be assuaged for Sri Lankan government approval (4). Based on current shipping lane location and related valuation of coastal economies, port revenues, ecosystem value of blue whales, risk of shipping disasters, and vessel pollution, this report asserts that the proposed shipping route move will result in a net benefit to Sri Lanka's economy.

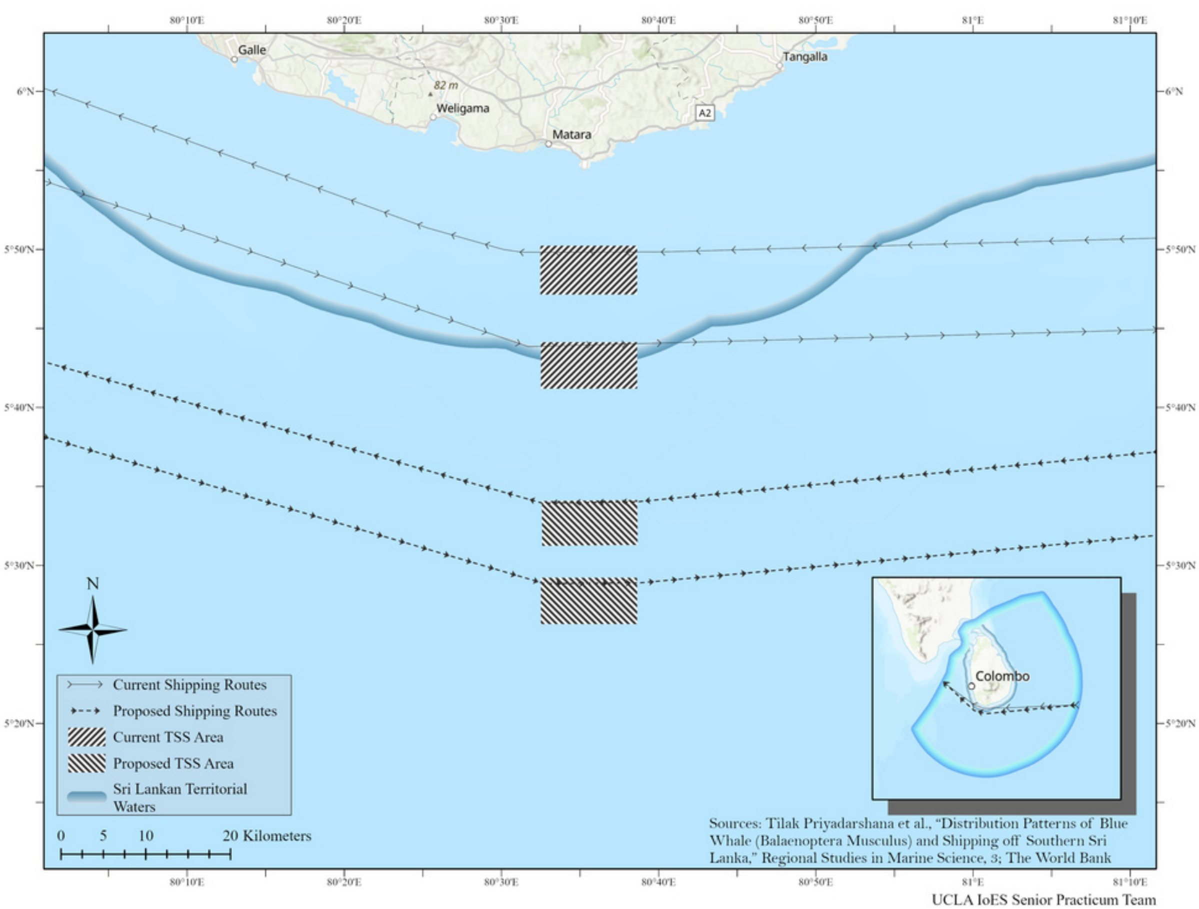

Figure 1. Current and proposed shipping routes and Traffic Separation Schemes (TSS) off of Sri Lanka's southern coast. This is showing the average route a vessel passing through the current Sri Lanka TSS but not calling at a Sri Lanka port makes in light gray. In addition, it visualizes the vessel passing through Sri Lanka if the TSS were to be moved 20 from the coastline as the proposed shipping routes.

3. METHODS

3.1 Cost Benefit Analysis Modelling

In order to conduct this CBA, six models were created. These six models evaluate Ecosystem Impact Estimate, Cost of Carbon to Sri Lanka from Shipping, Shipping Industry Gas Cost, Coastal Fisheries Impact, Impact to Tourism Industry, and Port Revenues. This CBA operates under the assumption that all ships currently travel at an average speed of 13.9 knots based upon studies of ships off of Matara, Sri Lanka. Data from 2020-2022 was excluded when possible to avoid making calculations that would reflect unusual circumstances due to the COVID-19 pandemic. Rationales for each component of the CBA are broken down below.

Indicator	Data Used	Calculation
Ecosystem Impact Estimate	Replacement cost of Sri Lankan whales carbon offset with other removal methods.	Increase in whale population due to decrease in collisions leads to more carbon drawdown.
Cost of Carbon to Sri Lanka from Shipping	Social cost of carbon emissions from ships passing through the shipping lane.	Decrease in carbon reaching Sri Lanka due to the shipping lane being farther away.
Shipping Industry Gas Cost	Information gathered about average vessel fuel efficiency and the cost of fuel per ton.	Increase in fuel costs due to additional mileage added to the shipping lane.
Coastal Fisheries Impact	Industry GDP from local fisherman fishing in areas affected by the international shipping lane.	Increase in local fishermen hours fishing and deadweight catch due to increased safety from shipping lane change.
Impact to Tourism Industry	Direct revenues from whale watching, and indirect revenues from whale watchers spending money in other areas of Sri Lanka.	Increase in revenues due to higher perceptions of Sri Lanka as an ecotourism destination, and due to land used for ecotourism accounting for far higher value than other industries.
Port Revenues	Revenue obtained through leases of port buildings and properties, marine terminals, fuel sales, and associated fees from vessels docking.	Negligible change based off of an interview with the Vice President of the World Shipping Council.

I. Ecosystem Impact Estimate Model Justification

This model takes the elusive endangered blue whale population number of Balaenoptera musculus indica as 37, as cited by the International Whaling Commission (23). Blue whales have the potential to sequester up to 33 metric tons of carbon in their lifetimes (3). This lifetime can span anywhere between 50 and 110 years, and blue whales reach peak maturity between 5 and 15 years (15). For the sake of this analysis, the average blue whale lifespan was taken to be 80 years, with peak maturity at 10 years. The number of annual collisions assumed under current conditions was 1016, with 11 resulting fatalities (20). This model was set up to reflect three scenarios: current collision rates, optimistic projected change, and conservative projected change.

Optimistic projected change assumes that collisions are reduced to 5% of current incidences, and conservative projected change assumes that collisions are reduced to 50% of current incidences. The number of years lost in carbon offsets is the number of incidences multiplied by the degree of harm, characterized as 10 years for non-fatal collision and 70 years for fatal collision (assuming 80 years = average life span, and 10 is the age at which the whale is killed). In the final calculation for ecosystem estimates, current ecosystem value is estimated at 0 to show net gain in value for conservative and optimistic conditions presented.

II. Cost of Carbon to Sri Lanka from Shipping

This study used data from The International Council of Clean Transportation for the average Energy Efficiency Operational Index (EEOI) of a number of different types of ships and extrapolated these numbers to attain a world average. EEOI is a measure of grams of CO2 released per deadweight tonnage of a ship, per nautical mile traveled. Due to the size and scale of Sri Lanka's shipping route, this study assumes that the world average EEOI for shipping is the same as that of ships using the Sri Lankan shipping route. Since this lane is primarily used for international shipping, the world average EEOI may be an underestimate. Furthermore, the UNCTAD Handbook of Statistics was used to find numbers for the total world fleet deadweight tonnage, as well as total number of ships to calculate average deadweight tonnage of the merchant fleet (16). Using this number and the average EEOI, the average amount of CO2 released per nautical mile traveled was calculated (EEOI / Deadweight Tonnage).

After obtaining numbers for the length in nautical miles of the Sri Lankan shipping route with or without our proposed change, the social cost of carbon for Sri Lanka was estimated to be around $9 per ton of CO2 (21). The social cost of carbon estimates the economic damages to a country emitting one ton of carbon dioxide into the atmosphere. Using the EEOI and social cost of carbon, the economic cost of reducing ship emissions and accompanied benefits can be estimated. In comparison to the US EPA’s estimate of $51 per ton for the US, social cost of carbon for Sri Lanka's levels was taken to be between $5-10 per ton (21).

III. Shipping Industry Gas Cost Model

Additional Fuel Costs=GPM*F*M
Where:
GPM = Expected Gallons per Mile
F = Cost of VLSFO per Metric Ton
M = Additional Mileage

In order to properly calculate the change in shipping industry gas cost, this analysis needed to identify the efficiency of large ocean-going vessels (LOGV), the cost of fuel per metric ton, and the additional time traveled. An average fuel cost of $738 per metric ton of very low sulfur fuel oil (VLSFO) was established as the typical fuel used to operate LOGVs (18). These calculations do not consider the inflated costs caused by world conflicts, inflation, and the COVID-19 pandemic as in years prior, the cost is much lower (ranging anywhere from $300 - $500 per metric ton). After obtaining the fuel price found through utilizing a mix of online sources and the insights of previous LOGV crewmen, the average efficiency of LOGVs was calculated to be 125 to 200 gallons per mile. The following formula was used to calculate the expected additional fuel costs for the shipping industry.

IV. Coastal Fisheries Impact

To generate accurate estimates for the effect of a shipping lane change on coastal fisheries, data from the Ministry of Fisheries 2020 statistics book was used to consider 5 key fishing districts (9). Only Single-Day boats were considered as multi day boats, as they tend to fish in deeper seas and would not be affected by a movement of shipping lanes. From this data, a total number of 5777 boats in Sri Lanka were taken as potentially affected by a shipping lane change. Assuming that most of the deep sea catch in Sri Lanka comes from Multi-Day vessels, all other vessels were inferred to account for coastal catch. Using total marine fishery revenues and percent of catch that is coastal, total coastal fishery revenue was estimated.

Using these numbers for percent of coastal fishing boats that are affected by a shipping lane change, a GDP for total affected boats was calculated (% weight coastal catch * total fishery GDP * % of coastal boats in the affected area). Based on these calculations and De Vos et. al, 2018 as a reference, this model assumes that a shipping lane shift will allow for safer travels of local fisherman.

This model was estimated based on the monthly reports submitted by the Fisheries Inspectors (FI) of the Defense Federal Acquisition Regulation for their FI Divisions and log book information with 1995-2014 High seas IMUL boats and 1995-2000 Beach Seine Crafts (9).

Key:
IMUL - Inboard Multi-day Boats
IDAY - Inboard Single-day Boats
OFRP - Out-board engine Fiberglass Reinforced Plastic Boats
MTRB - Motorized Traditional Boats
NTRB - Non-motorized Traditional Boats.

V. Impact to Tourism Industry

Impact to Sri Lankan tourism industry was split into two submodels, whale watching revenue and indirect tourism revenue. The first submodel was calculated using data from local and recent studies on visitor perceptions of whale watching in Sri Lanka, as well as studies on individual economic expenditure in the tourism sector pertaining to whale watching in Sri Lanka. This proposed shipping route shift has the potential to open multiple economic avenues related to whale watching. The increasing importance of education and conservation with regards to tourism indicates that further promotion of conservation of animals such as whales will lead to a positive effect directly on the whale watching industry and the tourism industry as a whole (13). Research indicates that the desire to participate in whale watching tours substantially contributes to the desire to visit whale watching towns such as Galle and Mirisa (2). Average expenditure in for international tourists that visit Sri Lanka and partake in whale watching was found to be $1,300. Furthermore, this model assumes that whale watching tours associated with tourism in Sri Lanka are a motivating factor for international tourist visitation, as 94% of tourists participating in whale watching tours are international (2).

VI. Port Revenue

Only around 10% of vessels that frequent the current TSS use the Colombo port, the largest of Sri Lanka's 5 ports (24). However, this model assumes that ships already docking at Colombo will continue to see the port as an important calling location, regardless of the small increase in distance to their routes.While moving the shipping lane further south increases the distance that ships need to travel to call at the Sri Lankan ports, the distance increase to the most frequented port, Colombo, is estimated to increase by 15 nautical miles. This model assumes that the change in distance (15 nm) will not increase costs enough to deter to ships already calling at Colombo port. This assumption was confirmed through an interview with the Vice President of the World Shipping Council, Bryan Wood-Thomas, who concluded that despite such changes, vessels will still need to dock at the Colombo Port due to its location and vicinity to the East Asian trading market.

3.2 GIS Modelling

This report includes several GIS maps to visualize the high intersectionality between the blue whale habitats and the international shipping routes occurring off of the Sri Lankan coast, in addition to aiding in the cost-benefit analysis portion of our proposal. The majority of data used was extracted from the public domain and scholarly research studies pertaining to Sri Lanka. Ship density acquired from the World Bank spanned from 2015-2020 and was restricted to only commercial vehicles to highlight the shipping route as international usage (7). Blue whale locations was sourced from Russel Leaper (19), and while seemingly limited in scope, it was found to be reliable using the transect methodology to survey the density of whales in the highlighted region (19). TSS coordinates were obtained from the MarineTraffic map (10). By taking the coordinates of the official Dondra TSS, ESRI ArcGISPro were used to relocate the TSS 15 nm south to situate the new and proposed TSS that would avoid the majority of whale collisions.

Current shipping routes were drawn to represent an average path taken by ships passing through Sri Lanka's waters and through the TSS without stopping at any Sri Lanka ports. In the bounds of highest ship density (excluding the routes to Colombo and Galle port), the average eastward and westward routes in the Dondra TSS was drawn in ArcGis Pro (7). Raw whale sighting data was converted into a hot spot analysis within the study region by using the ArcGIS Pro tool, 'Optimized Hot Spot Analysis' (19). The Optimized Hot Spot Analysis created a map of statistically significant hot and cold spots using the Getis-Ord Gi* statistics (17).

To estimate a common shipping route, ship density data from 2015 to 2020 was referenced to draw a line tracing the most densely occupied part of Sri Lanka's EEZ. The shipping route represented a vessel passing close to Sri Lanka's shoreline but not stopping at any Sri Lanka ports. The route was drawn so that vessels entered and exited Sri Lanka EEZ waters at the same coordinates currently intersected; however, the ships would also pass through the moved TSS. Additionally, to the West of the TSS, vessels make more drastic navigation northward so the shape was mirrored when drawing the new shipping route. The average speed of ships in the TSS was 13.9 knots, which is highlighted to be the speed correlating to 70-80% whale fatality (6). In order to assess the efficiency of the proposed route, the number of days traveled by shipping vessels was calculated (assumed at a speed of 13.9 knots) in comparison to the current route. The average additional distance traveled by vessels if the TSS were to move was calculated by measuring the distances traveled on the current and new average shipping routes and comparing the distances.

GIS Mapping Tool

ArcGIS Pro, Esri

4. RESULTS

4.1 Cost Benefit Analysis Results

Across the submodels of Ecosystem Impact Estimate, Shipping Industry Impact, Coastal Fisheries Impact, and total Sri Lankan economy impact, results indicate a base case net positive gain of $ 31,321,984.64 USD across all categories. This reflects the conservative impact of a shipping lane change, and a best case scenario is also included, indicating a total projected increase in revenues of $ 59,316,999.99 across the submodels. This represents a 4.77% change in USD and an 8.67% change with regards to the total percent change from current values. It is important to note that this percent change does not show the percent impact on Sri Lanka's economy as a whole, but just for the variables analyzed within these four submodels.

4. RESULTS CONT.

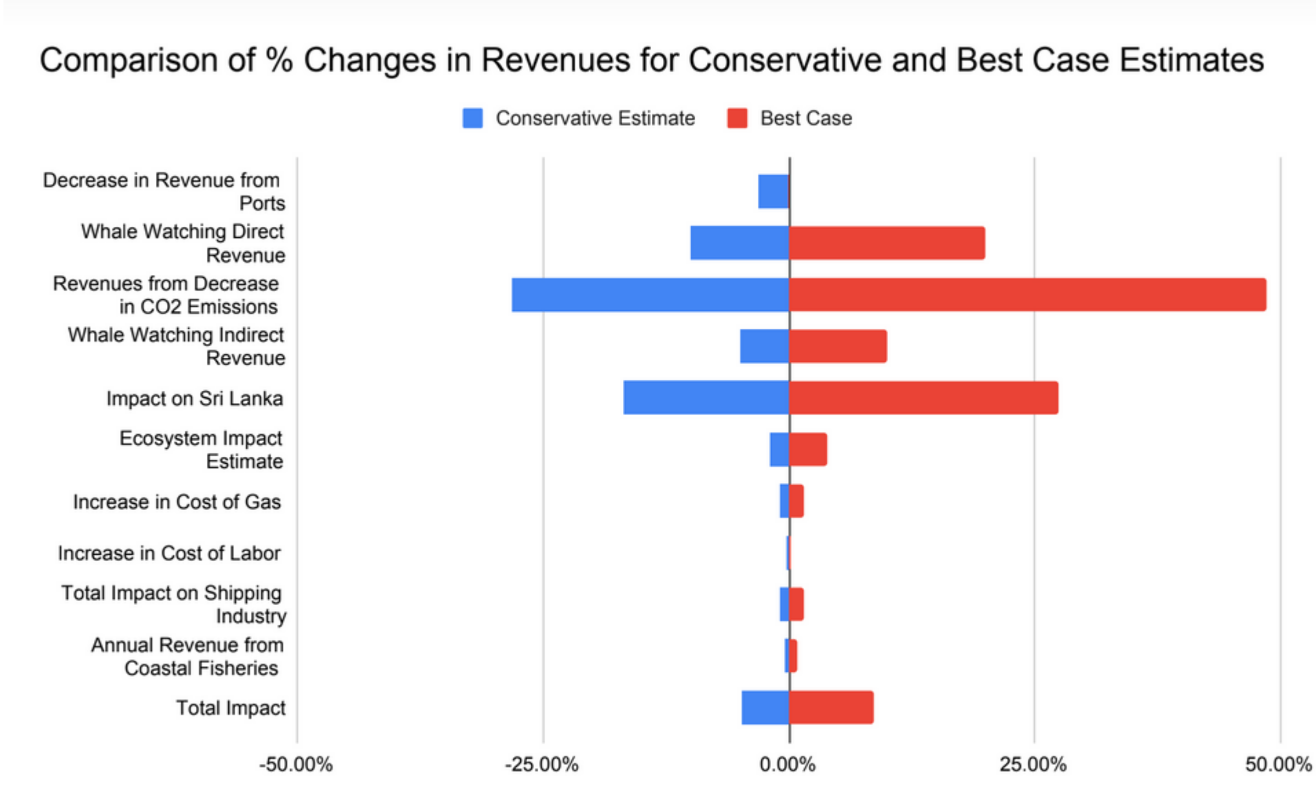

Figure 2. Tornado chart showcasing the differences in percent changes of our variables based off of two scenarios (Best Case and Conservative Estimates). Each scenario indicates a percent change relative to the baseline scenario of not moving the shipping lane at all.

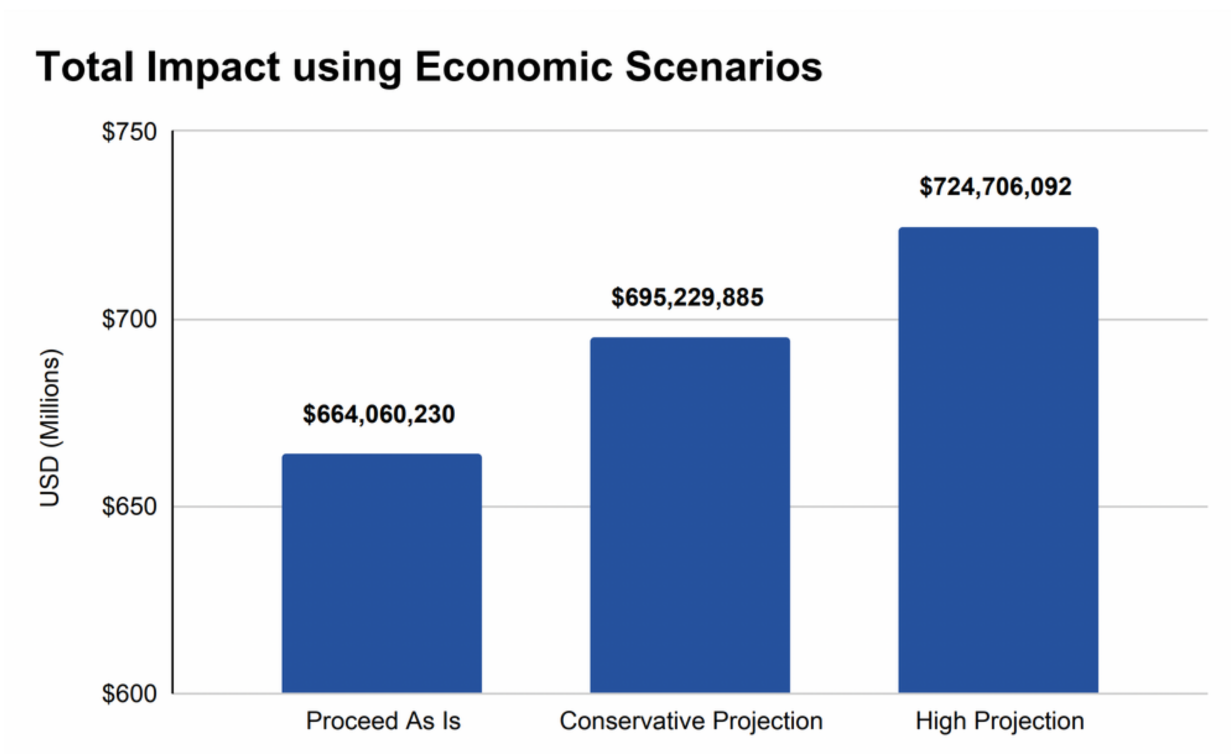

Figure 3. Summed total revenues of all variables indicating difference between projections yearly annual revenues vs. a scenario where the shipping lane is not moved.

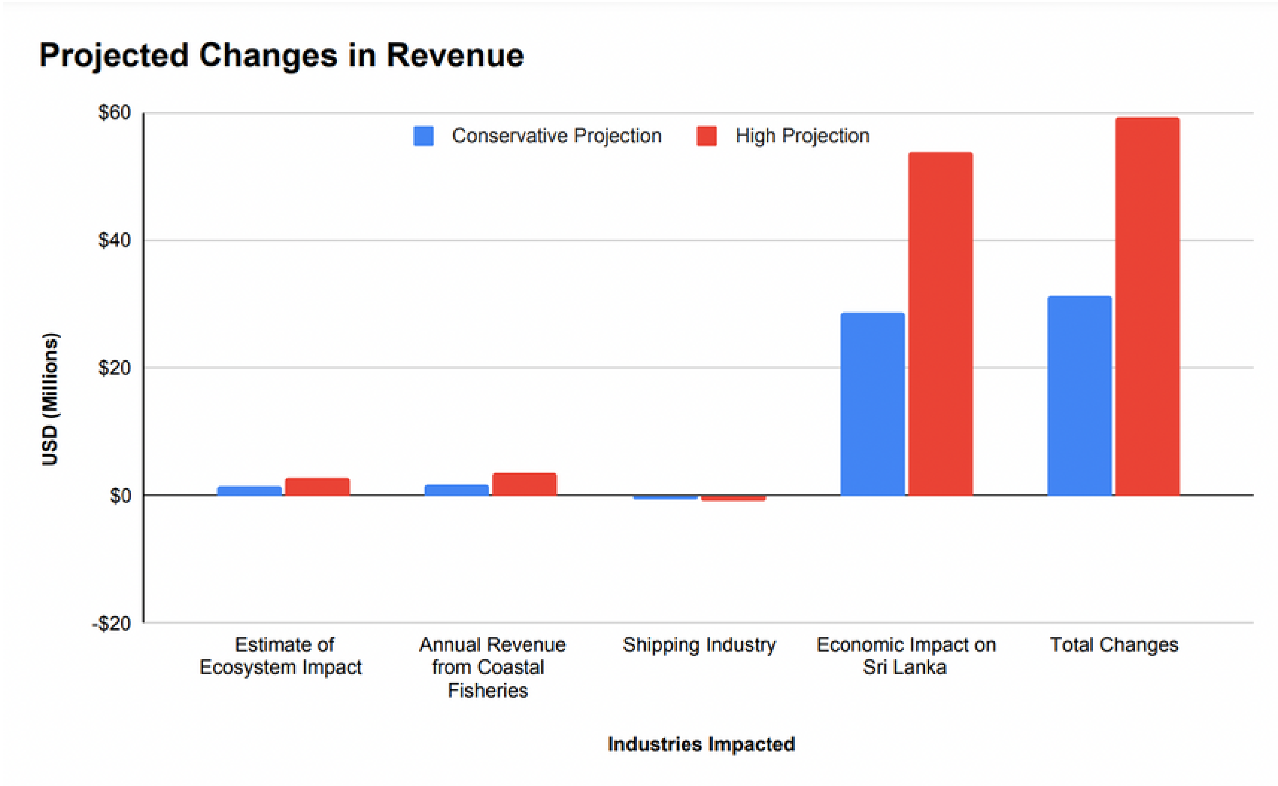

Figure 4. Comparison of projected marginal changes in revenue for conservative and best case scenarios visualized in USD per million.

4.2 Ecosystem Impact Estimate

The results of this model show that among the three collision rates projected, Scenario B results in a net carbon sequestration potential of 3976 tons with 0 whale fatalities. Scenario B is preferable to Scenario A (the current collision rate) or Scenario C (a conservative collision rate). Scenario A represents where there is a current net carbon sequestration potential of 0 tons and maintained fatality rate of 11 whales. Scenario C is the model which results in a net carbon sequestration potential of 1951 tons, and a decreased fatality rate of 5 whales. These results are displayed in the graphic on the following page. Given that the amount of USD required to remove 1 ton of carbon from the atmosphere is assumed to be $700, Scenarios A, B, and C, imply $0, $2,783,200 and $1,365,700 net savings in future carbon removal costs respectively.

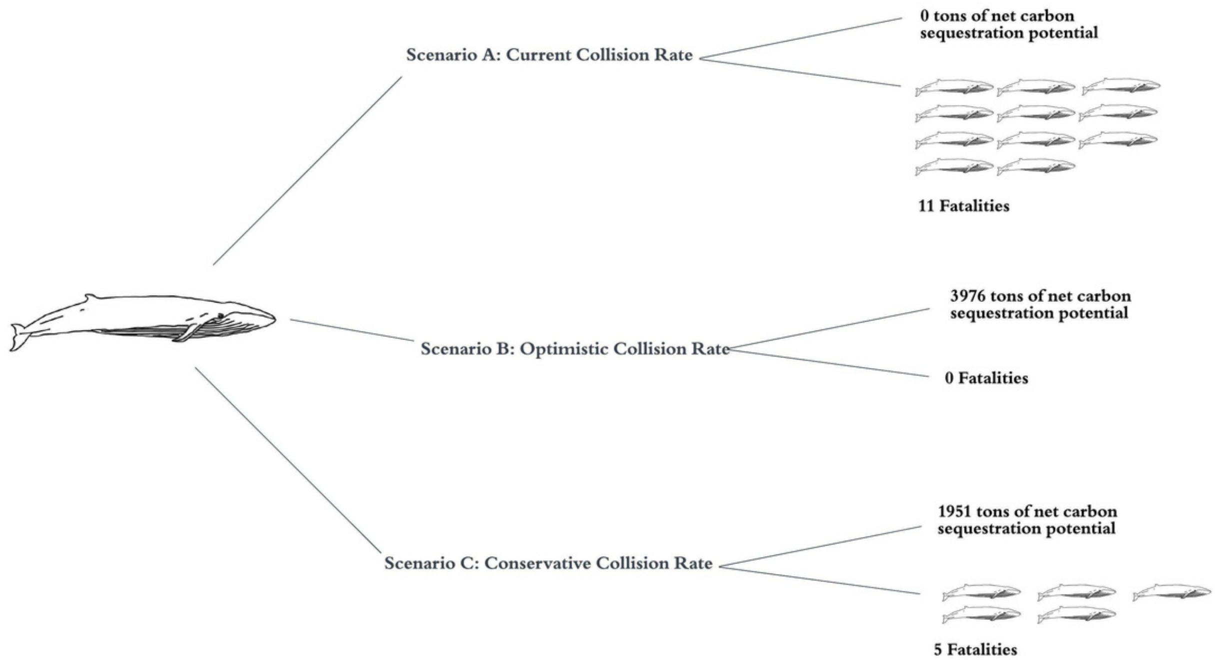

Figure 5. Net Carbon Sequestration Potential (in tons) and Fatalities across three Collision Scenarios.

In collaboration with the company Raja and the Whales and marine mammal scientist Russel Leaper, data was retrieved on blue whale locations in southern Sri Lanka. Raja and the Whales is a well-known local whale watching company in Mirissa, Sri Lanka. Russel Leaper is a contributor to the International Whaling Commission, Global Fishing Watch, and the International Fund for Animal Welfare. Russel Leaper along with Raja and the Whales have collaborated with the University of Ruhuna, Sri Lanka, and the Biosphere Foundation to initiate the Indian Ocean Marine Mammal Research & Conservation Project (IOMMRC) in efforts to progress education and marine conservation practices in Sri Lanka. The whale density portrayed in Figure 6. is a hot spot density model based off of the sightings at these transects. It is immediately evident that current routes go directly through the waters with the highest concentration of blue whales when the density of these sightings is shown overlaid with current shipping routes.

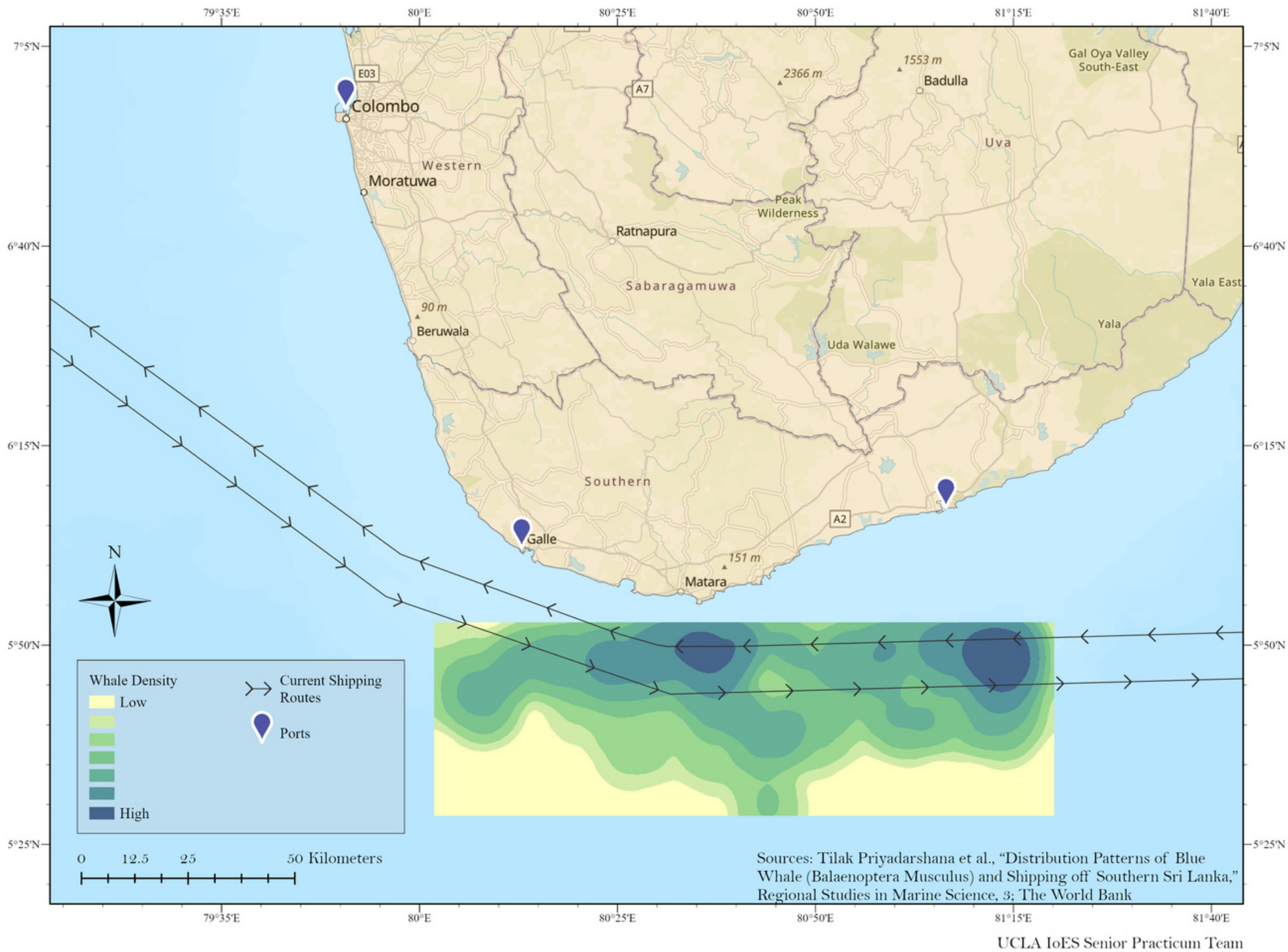

Figure 6. Blue Whale Density and Current Shipping Routes off of Sri Lanka's Southern Coast. Optimized Hot Spot Analysis of whale sightings compared with a common shipping route shows that the current shipping routes passes through the region with the highest blue whale density. The proposed shipping routes will decrease the chances and frequency of whale strike collision in this region.

In the figure below, individual whale sightings can be seen as the semi-transparent gray dots. Raja and the Whales measured these individuals through transects, or straight lines vertically across the water, which explains the cut-off boundaries in longitudinal and latitudinal intervals. While observations have only been accurately recorded at these transects, it is assumed that the whales inhabit all the waters within the transects and can be found anywhere in the region.

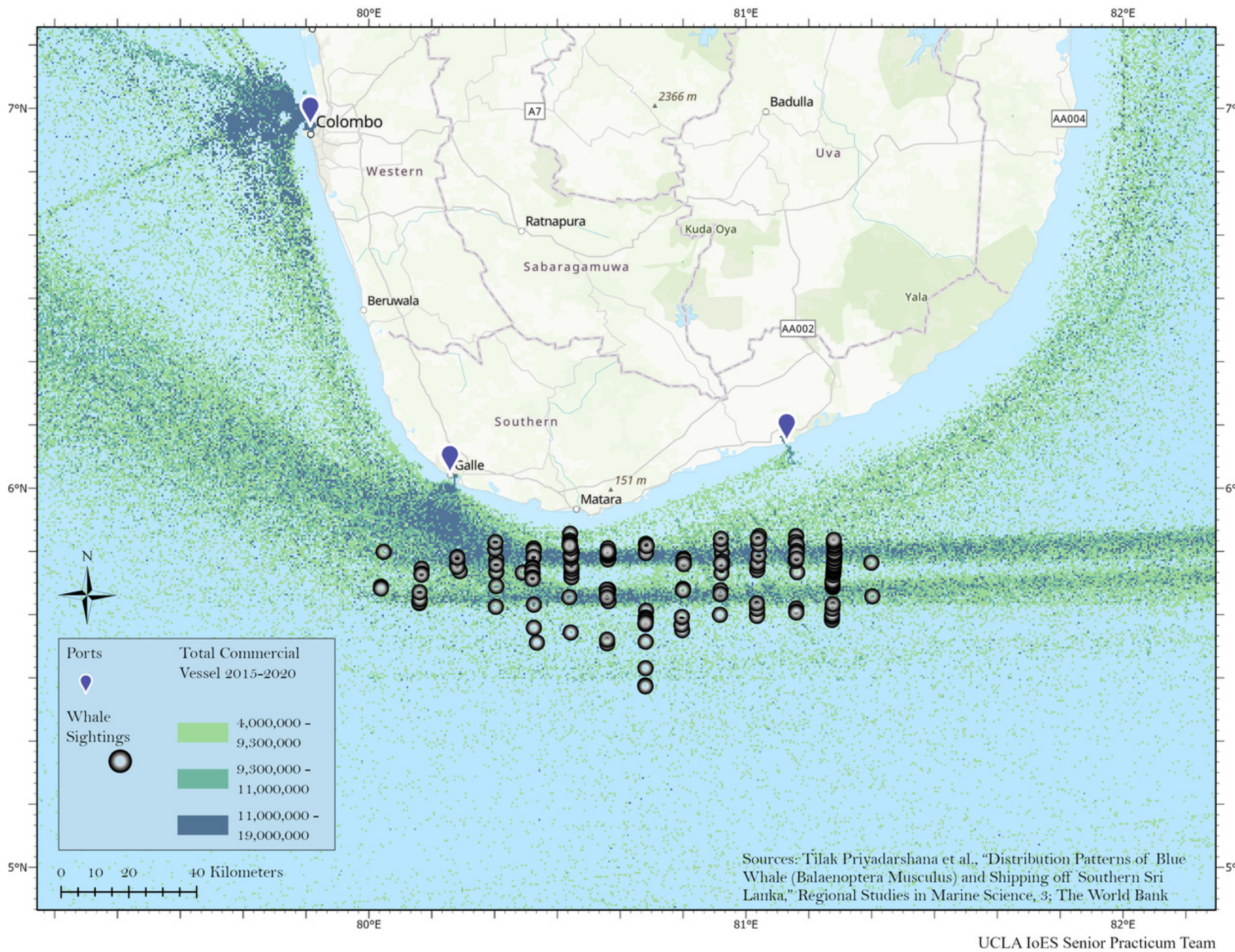

Figure 7. Whale Sightings and Commercial Ship Density off of Sri Lanka's Southern Coast. Global commercial ship density from 2015 to 2020 is represented in green to blue dots in comparison with the transect locations of whale sightings found in a 2015 study in Sri Lanka.

4.2 Cost of Carbon to Sri Lanka

In analyzing the cost of carbon, it was important to assume that all emissions from the shipping route may not make landfall over Sri Lanka, and moving the shipping route further south would reduce the amount of landfall emissions. Due to the proximity of the current shipping route to the country of Sri Lanka, it is safe to assume that the majority of emissions from ships make landfall, however in order to not overestimate the SCC, this model predicted that only about 60% of current emissions make landfall. This model predict that moving the shipping route over twice as far away from land would significantly reduce emissions reaching Sri Lanka. Based on wind models and scholarly articles, this model used a best case scenario of 50% reduction in emissions reaching Sri Lanka and a conservative/best case estimate of 30% reduction to emissions making landfall in Sri Lanka.

4.3 Shipping Industry Gas Cost

In order to properly calculate the shipping industry gas cost change, this report needed to discover the efficiency of LOGVs, the cost of fuel per metric ton, and the additional time traveled through our proposal. This model came to an average cost of $738 per metric ton of VLSFO, the typical fuel used to operate LOGVs. GIS analysis concluded that the proposal would net an additional 21 km. In extrapolating both ends of the projected efficiency, a result in an additional cost ranging from $4,012 to $6,420 was found. Comparing this number to the current gas cost incurred by the shipping industry of $57.75M, the proposed lane shift would result in a 0.0069% to 0.011% increase in fuel costs. As inefficiency of the LOGVs increases, the more fuel is consumed per mile, which increases the project costs with salary costs considered.

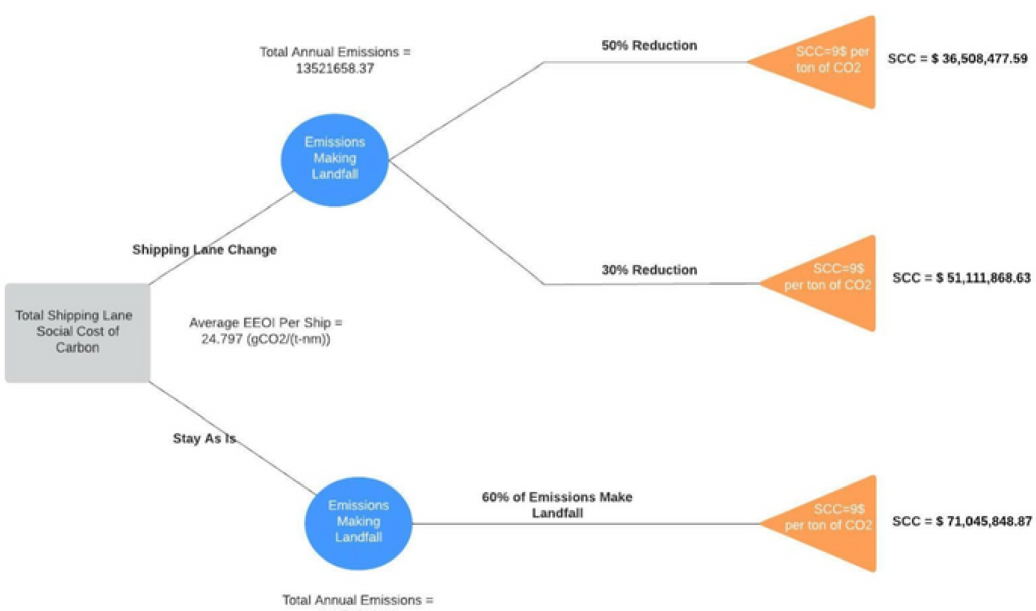

Figure 8. Total Annual Social Cost of Carbon to Sri Lanka Across 3 Different Emissions Scenarios

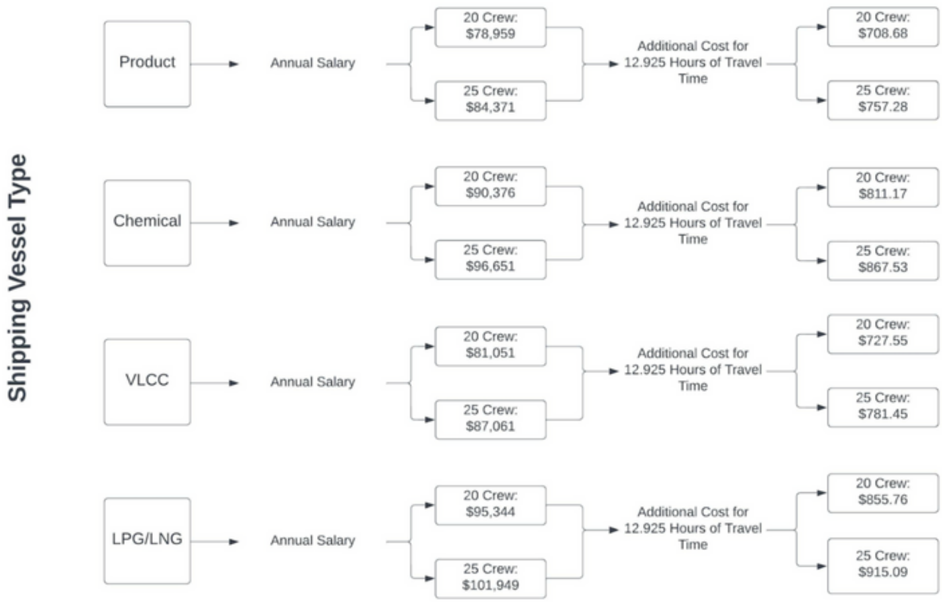

Figure 9. Salary Cost for Crewmates with an Increased Shipping Time of 5 nm

The flow chart above describes the four main types of large ocean going vessels, their averaged annual salary, and what the increased pay will look like as a result of the increased distance from the shipping lane movement. Salaries were gathered from testimonies from fellow crewmen on these vessels in addition to expert reports in the field. Assumptions were made pertaining to crew size and expected pay since companies vary and the numbers used here was the average pay for all international vessels. The differing pay between the 20 and 25 crewmen included the addition of an electrician, a second mate, fitter, wiper, and an additional steward.

4.4 Coastal Fisheries Impact

A 5% increase in affected boats fishing can be estimated, assuming stable fish supply. As the shipping lane is moved further south, more local fishermen will occupy coastal waters, increasing the amount of catch and thus the amount of revenues. Keeping in mind that these coastal affected boats make up only a fraction of the total fishing fleet, this model assumes these numbers are not an overestimate of the effect of a shipping lane change on coastal fishery revenues.

4.5 Impact to Sri Lankan Economy

Using a variety of peer reviewed studies, at least a 10% increase in whale watching is estimated, with a best case scenario of a 20% increase in participants. Using the data sourced from tourism research, a minimum of 5% increase in the revenue of the tourism industry is estimated, with ecotourism boosting this industry significantly.

4.6 Port Revenues

This model outlines that in a worst case scenario, port revenues could decrease by 3%.

5. DISCUSSION

5.1 Key Findings

If the shipping lane is shifted an additional 15nm, changes to port revenue will be small, with a margin of approximately 0-3%. Therefore, this report contends that if the shipping lane shift were to occur, neither the Colombo port not the Sri Lankan shipping industry at large stand to suffer economically. This conclusion was supported by an interview with Bryan Wood-Thomas, the Vice President of the World Shipping Council. Furthermore, Mr. Wood-Thomas recommended that if the shipping lane were moved out by an additional 15 nautical miles, the spread of harmful emissions such as nitrogen oxides (NOx), sulfur oxides (SOx), and PM2.5 would be reduced given the additional distance the emissions would need to travel.

This report recommends that the shipping lane be shifted 15 nm to the proposed 20 nm offshore in order to achieve:

- Ecosystem Impact Estimate: Scenario B, corresponding to a 3976 metric ton net carbon sequestration and $2,783,200 USD in savings.
- Cost of Carbon to Sri Lanka from Shipping: Scenario C, resulting in a decrease of impact of carbon emissions to Sri Lanka valued at $19,933,980 USD in savings.
- Shipping Industry Gas Cost: roughly $4,012.51 to $6,420.01 increase.
- Coastal Fisheries Impact: A 5% increase in fishing industry revenues resulting in a marginal increase of over $1,800,000 USD in industry GDP.
- Impact to Tourism Industry: Leveraging the shipping lane shift to promote Sri Lanka as a popular ecotourism destination which would lead to an increase in both direct and indirect tourism revenues from whale watching, resulting in a total increase in tourism revenues of $9,615,000 USD to Sri Lanka.
- Port Revenues: No substantial change to port revenues.

These recommendations take into consideration the economic and ecological benefits the country would gain through these actions while also imposing no severe changes or costs to the country. Our recommendations would further support economic growth through new revenue streams, such as an increase in the ecotourism market and fisheries. Additionally, the increased spend on fuel regarding shipping industry gas costs would not be imposed upon by the government, but rather the shipping companies who have already expressed interest in the shipping lane being moved.

5.2 Limitations

This report's primary limitation was a lack in quantity and breadth of whale location and small fishing boat location data in Sri Lanka. Given that GIS analysis were unable to track the location of all fishing vessels, it was not possible to completely assess the overlap with the fishing industry and commercial vessels. To improve our understanding of the overlap between whales and commercial vessels and overcome this report's limitations regarding whale location, a habitat suitability modeling should be conducted to expand the hot spot analysis of blue whales. Additionally, temporal conditions such as monsoon patterns and whale feed activity near the Sri Lankan coast were not detailed in public domains and thus unable to be used in analysis. Alternatively, further data collection via remote sensing, acoustic data, and satellite tagging would further strengthen the understanding of where blue whales are located.

This limitation extends to CBA analysis, where data regarding shipping industry gas cost and coastal fisheries impact was extremely limited. In order to calculate the social cost of carbon to Sri Lanka, this analysis used worldwide shipping industry data assuming those metrics to be the same for ships passing through the Sri Lankan shipping route, given that exact data on the EEOI of ships passing through the specific shipping route was unavailable. Furthermore, similar worldwide data on total fleet size and deadweight tonnage was used to find the average weight of a ship in the worldwide fleet, assuming these numbers to be the same for the Sri Lankan shipping lane. Future research can bridge this limitation by using raw data driven analysis of ships passing through the shipping lane and docking at the Colombo port over the course of a week. Estimates for changes in carbon pollution reaching Sri Lanka were based on wind models online, however, more accurate estimates would have used an expert in meteorology to predict the total airflow reaching Sri Lanka from each shipping lane. Fishery revenue data was based off of the Sri Lankan Ministry of Fisheries handbook of statistics (9). Using this handbook as a credible baseline of data to work with, this report made the assumption that only single day fishing boats found off the Southern and Western Sri Lankan coast were affected in analyzing the effect of the proposed shipping lane change on local fisheries. This analysis was also made under the assumption that only coastal fishery revenue would be affected by the proposed shipping lane change; deep sea fishing boats are likely out of range from contact with ships and are technologically equipped to handle safety issues.

5.3 Areas for Further Exploration

These findings would be strengthened by further exploration into the harmful emissions described by expert Bryan Wood-Thomas. After discussing the cost of gas with shipping industry experts, more detailed raw data on gas consumption, efficiency, and cost depends on the ship's age, the engine size, vessel size, what port the gas was obtained at, and the vessel's speed could be leveraged for a more robust analysis. More complex modeling software would have allowed us to chart potential wind patterns of emissions to get a visual representation of how moving the shipping lane out more would reduce NOx SOx, and PM2.5 from reaching land, as well as creating modeling for potential ship-based disasters to project how it would end up impacting the local fisheries.

External consequences of this analysis' recommendations might include increased safety for small-scale fishers and whale watch operators in these navigable waters, ship-based pollution for coastal populations, and potential effects on oil spills and ship-based disasters in nearshore waters. More specific research on these impacts (particularly using local data i.e. surveys) is needed to affirm this assertion.

7. ACKNOWLEDGMENTS

"Your strength becomes someone else's inspiration... Be courageous, believe in yourself, support one another, take time to understand each other."- Dr. Asha de Vos

Our team of 6 undergraduates is grateful to everyone that contributed their time and energy to supporting us through the creation of this report.

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Thank you to Dr. Asha de Vos for working with us throughout the year from across the world and often under difficult circumstances. We are all inspired by your activism and courage.

We would like to recognize that the University of California, Los Angeles resides on the traditional home belonging to the Tongva, Chumash, Tataviam, and Acjachemen Nations. We recognize all of the Honuukvetam (Ancestors),'Ahiihirom (Elders), and 'eyoohiinkem (our relatives/relations) past, present, and emerging.

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9. APPENDIX

A. Whale Watching Revenue

Whale Watching Revenue

Inflation Calculations

Year	Price
2016	50$
2022	56$

Assumptions

Post Pandemic, whale watching numbers will return to those in 2018

Studies Indicate 2016 charges of a minimum of 50$ per person, we use average world inflation to find 2022 prices

Industry Growth (Sri Lanka participants)

2012	2013	2014	2015	2016	2017	2018
22000	58500	86100	113700			150000

Predicting linear growth from 2013 to 2015, and then a slowdown using a polynomial trend afterwards, we estimate that by 2018 there were over 150,000 annual whale watchers in Sri Lanka. To not overestimate, this is the number we used.

3 Scenarios

1: Continue As Is

2. Shipping lane best case

3. Shipping lane worst case

Scenario 1: Total Whale Watching Revenue

Participants	Avg. Price	Total Revenue	Additional Direct Revenue	Tourism Revenue from International Whale Watchers	Additional Indirect Revenue
150,000	56	8400000	0	175500000	0

Scenario 2: Shipping Lane Change Best Case

Participants	Avg. Price	Total Revenue	Additional Direct Re	Tourism Revenue from Whale Watcher	Additional Indirect Revenue
180,000	56	10080000	1680000	193050000	17550000

Scenario 3: Shipping Lane Change Worst Case

Participants	Avg. Price	Total Revenue	Additional Direct Re	Tourism Revenue from Whale Watcher	Additional Indirect Revenue
165,000	56	9240000	840000	184275000	8775000

B. Cost of Carbon To Sri Lankan Shipping Industry

Cost of Carbon to Sri Lanka from Shipping

World Average Ship EEOI Calculation

Ship Type	EEOI (gCO2/t-nm	# of ships analyzed	world fleet	verage EEOI * Total Categorical Fleet Si:	Average EEOI of All Ships
Ro-ro ship	113.3	128	0.51	28436.07843	Sum of EEOI of all ships divided by sample size of ships analyzed
General Cargo Ship	29.8	503	0.5	29978.8	
Vehicle Carrier	80.2	211	0.515	32858.64078	
Container Ship	21.5	831	0.51	35032.35294	
Other Ship Types	110.7	29	0.475	6758.526316	
Gas Carrier	68.6	163	0.566 --		
Bulk Carrier	8.4	1927	0.647	25018.23802	
Chemical Tanker	21.1	713	0.652	23074.07975	
Refrigerated Cargo Carrier	125.1	95	0.704	16881.39205	
Oil Tanker	10.2	1144	0.714	16342.85714	
Combination Carrier	19.2	2	0.4	96	
LNG Carrier	27.5	104	0.542	5276.752768	
Total		9659	0.606		**22.75118731**

Average Dwt Calculations

World fleet Dwt	Total Ships	Avg. Dwt
2100000000	53000	39622.64151

Scenario 1: Keep Current Shipping Lane

Average EEOI all ships	22.75118731
Shipping lane length (nm)	418.466675
gCO2/cargo_ton (Sri Lanka)	9520.613705
Ships passing annually	32,000
Average Ship Cargo Tonnage	39622.64151
gCO2 released annually	12071419640563
tons CO2	12071419.64
SCC (per ton)	9
SCC of shipping lane	108642776.8
Amount of Emissions Reaching Sri Lanka	60.00%
SCC to Sri Lanka	**$ 65,185,666.06**

Scenario 2: Keep Current Shipping Lane Best Case (50% reduction in Emissions making landfall)

Average EEOI all ships	22.75118731
Shipping lane length (nm)	430.076675
gCO2/cargo_ton (Sri Lanka)	9784.754989
Ships passing annually	32,000
Average Ship Cargo Tonnage	39622.64151
gCO2 released annually	12406330854286
tons CO2	12406330.85
SCC (per ton)	9
SCC of shipping lane	111656977.7
Amount of Emissions Reaching Sri Lanka	30.00%
SCC to Sri Lanka	**$ 33,497,093.31**

Scenario 3: Keep Current Shipping Lane Worst Case (30% reduction in Emissions making landfall)

Average EEOI all ships	22.75118731
Shipping lane length (nm)	430.076675
gCO2/cargo_ton (Sri Lanka)	9784.754989
Ships passing annually	32,000
Average Ship Cargo Tonnage	39622.64151
gCO2 released annually	12406330854286
tons CO2	12406330.85
SCC (per ton)	9
SCC of shipping lane	111656977.7
Amount of Emissions Reaching Sri Lanka	42.00%
SCC to Sri Lanka	**$ 46,895,930.63**

9. APPENDIX

C. Hourly Cost for Shipping Industry Crew

Cost of Crewmembers on OGV Yearly Estimations

Assumptions to be made for the data:

Typical crew size is 20 - 25 people.

Using data from International Vessel Report.

A crew consists usually of the following:

Average Salary of Seafarers on Different Types of Tankers per Month

Rank/Members		**Product**	**Chemical**	**VLCC**	**LPG/LNG**
Deck Crew:					
Master		$12,000.00	$13,000.00	$11,277.50	$14,100.00
Chief Mate		$9,625.00	$10,972.00	$9,531.00	$11,450.00
2nd Mate (x2) Value per 2nd Mate ->		$4,400.00	$4,500.00	$5,005.00	$5,005.00
3rd Mate		$3,550.00	$3,960.00	$3,450.00	$4,000.00
Bosun		$2,225.00	$2,300.00	$2,225.00	$2,400.00
4 Sailors		$830.00	$940.00	$828.00	$968.00
Engineers:					
Chief Engineer		$11,600.00	$13,340.00	$11,850.00	$13,720.00
2nd Engineer		$9,500.00	$10,800.00	$10,400.00	$11,100.00
3rd Engineer		$4,400.00	$4,730.00	$4,400.00	$5,005.00
4th Engineer		$3,550.00	$4,100.00	$3,450.00	$4,000.00
Pumpman		$2,375.00	$2,575.00	$2,375.00	$2,500.00
3 Oilers		$1,700.00	$1,775.00	$1,700.00	$1,900.00
Electrician		$3,400.00	$5,250.00	$4,755.00	$7,050.00
Fitter		$2,225.00	$2,300.00	$2,225.00	$2,250.00
Wiper		$1,100.00	$1,275.00	$1,100.00	$1,550.00
Catering					
Chief Cook		$3,767.00	$4,595.74	$3,767.00	$4,595.74
Crew Cook		$1,700.00	$2,188.00	$1,700.00	$2,150.00
Steward (x2)		$1,012.00	$1,775.00	$1,012.00	$1,600.00
	SUM:	$78,959.00	$90,375.74	$81,050.50	$95,343.74
Adding an additional 5 nm (5.75 miles) depends on how fast the vessel is going in terms of time.	Math for Average Hourly Spend (20 crew)	$54.83	$62.76	$56.29	$66.21
Ports typically ask that cargo vessel operators entering or leaving ports observe a 10-knot speed limit.	**Additional Cost with Adjustment (20 Crew)**	**$708.68**	**$811.17**	**$727.55**	**$855.76**
	SUM for 25 Crew Members:	$84,371.00	$96,650.74	$87,067.50	$101,948.74
Calculations:					
10 knots is equal to 11.5078 mph	Math for Average Hourly Spend (25 Crew)	$58.59	$67.12	$60.46	$70.80
Conversion to additional time:	**Additional Cost with Adjustment (25 Crew)**	**$757.28**	**$867.53**	**$781.45**	**$915.09**
12.925					
Additional Hours added					

9. APPENDIX

D. Shipping Industry Gas Cost

Current estimate of $738 per metric ton with today's rates.

Fuel costs represent as much as 50-60% of total ship operating costs, depending on type of ship and service needed.

Assumptions Made:

1. Average ship travels at 20 nautical miles
2. Ships, depending on size, carry anywhere from 1.5 to 3.5 million gallons of fuel
3. Efficiency depends entirely on size of ship, amount of cargo, and ship speed.

For this, we will use gallons per hour/gallons per day since that's the typical measurement for large ocean going vessels.
Average ship traveling at cruising speed (defined as 20 - 25 mph) will burn an estimated 60 - 100k gallons of fuel per day.
Simplifying this, this will yield around 2500 - 4000 gallons per hour or approximately 125 - 200 gallons per mile

Expanding the shipping lane out by based off of the GIS map will result in an additional 12.925 hours of transit (13.0488 miles added)
One metric ton of fuel is approximately 300 gallons
Using the range of 125 to 200 gallons per mile we get the following math:

125 GPM	200 GPM
$4,012.51	$6,420.01

These numbers represent the approximate increase in cost for the vessel by increasing the distance.

Expected Gallons/Miles	Calculated Tonnage Used	Additional Cost by Moving 13 nm	Cost of fuel per metric ton:	Addition Miles:
125	0.416667	$4,012.51	$738	13.0488
130	0.433333	$4,173.01	$738	13.0488
135	0.450000	$4,333.51	$738	13.0488
140	0.466667	$4,494.01	$738	13.0488
145	0.483333	$4,654.51	$738	13.0488
150	0.500000	$4,815.01	$738	13.0488
155	0.516667	$4,975.51	$738	13.0488
160	0.533333	$5,136.01	$738	13.0488
165	0.550000	$5,296.51	$738	13.0488
170	0.566667	$5,457.01	$738	13.0488
175	0.583333	$5,617.51	$738	13.0488
180	0.600000	$5,778.01	$738	13.0488
185	0.616667	$5,938.51	$738	13.0488
190	0.633333	$6,099.01	$738	13.0488
195	0.650000	$6,259.51	$738	13.0488
200	0.666667	$6,420.01	$738	13.0488

E. Ecosystem Impact Estimate

Ecosystem Impact of Whales (Carbon Sink)

Ecosystem Impact of Whales (As Element of Ecosystem)

Carbon capacity (metric tons) for whales as carbon sinks	--->	33 tons of CO2
Carbon footprint of Sri Lankan Shipping Industry	--->	2 million tons
Carbon emissions of Sri Lanka (2020)	--->	21.11 million tons of CO2

Number of metric tons of Carbon saved under condition (A)	33 tons x (10,160 years lost/80 year life span) = -4191 saved	**4191 lost**	
Number of metric tons of Carbon saved under condition (B)	33 tons x (520 years lost/80 year life span) = -214.5 saved	**215 lost**	net gain of 3976 ton potential !*
Number of metric tons of Carbon saved under condition (C)	33 tons x (5430 years lost/80 year life span) = -2239.8 saved	**2240 lost**	net gain of 1951 ton potenial from current

If cost to remove 1 ton of carbon = $600 - $800, assume $700

*		**Context: Collision as functional unit of lane change**	NUMBER
B	Best Case Scenario: = (3976 x $700) = $2,783,200	Sri Lankan Whale Population Estimate	37
A	Current: = ($0)	Annual Whale Collisions	1016
C	Conservative: = (1951 x $700) = $1,365,700	Fatal (reported) collision proportion of total whale population	11
		Whale collision proportion of total whale population	

condition (A) — Current collision numbers
--> disables whales from being able to reach level of 33 metric tons at time of death
--> say collision = 10 years lifespan decrease or fatal
upper = 80 - 70 = 10 lower = 80 - 10 = 70
assumption = fatal collision at peak maturity (at 10 years), lifespan = 80 year.*

Proportion of Sri Lankan Carbon Emissions under condition (A)
Proportion of Sri Lankan Carbon Emissions under condition (B)
Proportion of Sri Lankan Carbon Emissions under condition (C)

In a sample year, of ___X__ whales
11 fatalities = 11 NULL Carbon Offset Capability
1016 - 11 = 1005 losses of 10 years = 10,050 years lost in carbon offsets
PLUS
fatalities 11*(80-70 = 10) = 110 110
10, 160 years lost in carbon offsets

Economic Value of Whales (Individual)

Number of Whale sighting required for blue whale tourism excursion	5% of current collisions	condition (B)	Projected decrease in collisions (low estimate, 15 nm)	--> *52 collisions, no deaths	10*52 = **520 years lost**
Number spent by tourists in tandem with ecotourism economy	50% of current collisions	condition (C)	Projected decrease in collisions (high estimate, 15 nm)	--> *508 collisions, 5 deaths	(10*500) + (70*5) = **5430 years lost**

Current Scenario

Net impact per whale	1848000
Total Whales	37
Total Impact Currently	68376000

If shipping lanes were to move 15 nm to the south and fishing activity remained unchanged, the number of fishing vessels encountered in the shipping lanes would be around 33% of the current situation
Not all collissions are fatal: 1016 per year
Shipping density = highest in "the main eastwest shipping lanes close to the TSS (Traffic Separation Scheme)
slightly greater total volume of westbound traffic overall.

9. APPENDIX

F. Coastal Fisheries

COASTAL FISHERIES MODEL

GDP of Marine Fishing = 169,976 x 1 million rupees

1 USD = 359.66 rupee

Total Marine Fishery GDP (USD) $472,601,901.80

As of 2019, the number of different types of fishing vessels is shown below

Year	High Seas IMUL	Other IMUL	IDAY	OFRP	MTRB	NTRB	NBSB	Total	Coastal Fishing Boats
2019	1189	3696	948	23404	2140	16312	1287	48976	44091

Estimated based on the monthly reports submitted by the Fisheries Inspectors of DFAR for their FI Divisions and log book information (1) 1995-2014 High seas IMUL boats included (2) 1995-2000 Beach Seine Crafts included Note : IMUL - Inboard Multi-day Boats, IDAY - Inboard Single-day Boats, OFRP - Out-board engine Fiberglass Reinforced Plastic Boats, MTRB - Motorized Traditional Boats, NTRB - Non-motorized Traditional Boats

Port	IMUL	IDAY	OFRP	MTRB	NTRB	NBSB	Total	TOTAL EFFECTED BOATS
Colombo	58	28	447	1	292	25	851	
Kalutara	400	4	390	12	240	40	1,086	
Galle	664	20	368	194	222	49	1,517	
Matara	920	74	756	232	603	7	2,592	
Tangalle	722	13	853	120	682	105	2,495	
Total	2764	139	2814	559	2039	226	8541	5777

These 5 areas are the districts who's coastal fisheries would be effected by a change in shipping lanes. We will not consider Inboard Multi Day Boats as they likely were not previously effected by the closer shipping lane, and will not be effected by father out shipping lanes as their routes are long ranging. The total amount of effected boats is 5777.

Coastal Catch (Mt)	Deep Sea Catch (Mt)	% Coastal
242580	172910	58.38%

Assuming that most of the deep sea catch in Sri Lanka comes from Multi Day vessels, we can infer that all other vessels account for coastal catch. Using total marine fishery revenues, we can estimate total GDP from coastal catch. We then use the % of coastal vessels in the areas effected by a shipping lane change to find the GDP of shipping lane effected fishing boats.

Total Coastal Fishery GDP	% of coastal fishing boats effected by shipping lane	Total Effected Boat GDP
$275,924,256.51	13.10%	$36,152,830.05

Referencing "Reducing the Probability of Ship-Strike Risk to Blue Whales in Sri Lanka Waters", we can aknowledge that a shipping lane shift will allow for safer travels of local fisherman (effected boats). We can thus estimate at least a 5% increase in effected boats fishing, assuming the fish supply is not already stretched to thin, we can use this number to predict possible increases in GDP from an increase in fishing vessels.

Base Case

Total Effected Boat GDP	% Change in Fishing Revenues	Marginal Effect	Total
$36,152,830.05	5.00%	$1,807,641.50	$37,960,471.56

Best Case

Total Effected Boat GDP	% Change in Fishing Revenues	Marginal Effect	Total
$36,152,830.05	10.00%	$3,615,283.01	$39,768,113.06

15 NM SHIPPING LANE SHIFT

IMPACT ASSESSMENT BRIEF

2022

Bella Alvarado | Ruthie Glauber | Matt St. Germain | Qin He | Aiden Metzner | Coltyn Steinheimer

Background

Ocean blue whales, Balaenoptera musculus indica. These whales are currently under threat from collisions in heavily trafficked shipping routes hugging the Sri Lankan coast. Shifting these shipping routes a further 15 nautical miles (nm) offshore to a total of 20 nm may reduce blue whale mortality with other added economic benefits. In this scenario, ship traffic would be rerouted by shifting the location of the eastward and westward Dondra Traffic Separation Scheme (henceforth referred to as TSS) on Sri Lanka's southern coast.

Methodology

To analyze the impacts of moving the TSS 15 nm south of their current position along the Sri Lanka southern coast, a cost-benefit analysis (henceforth referred to as CBA) and a geographic information system analysis (henceforth referred to as GIS) were conducted.

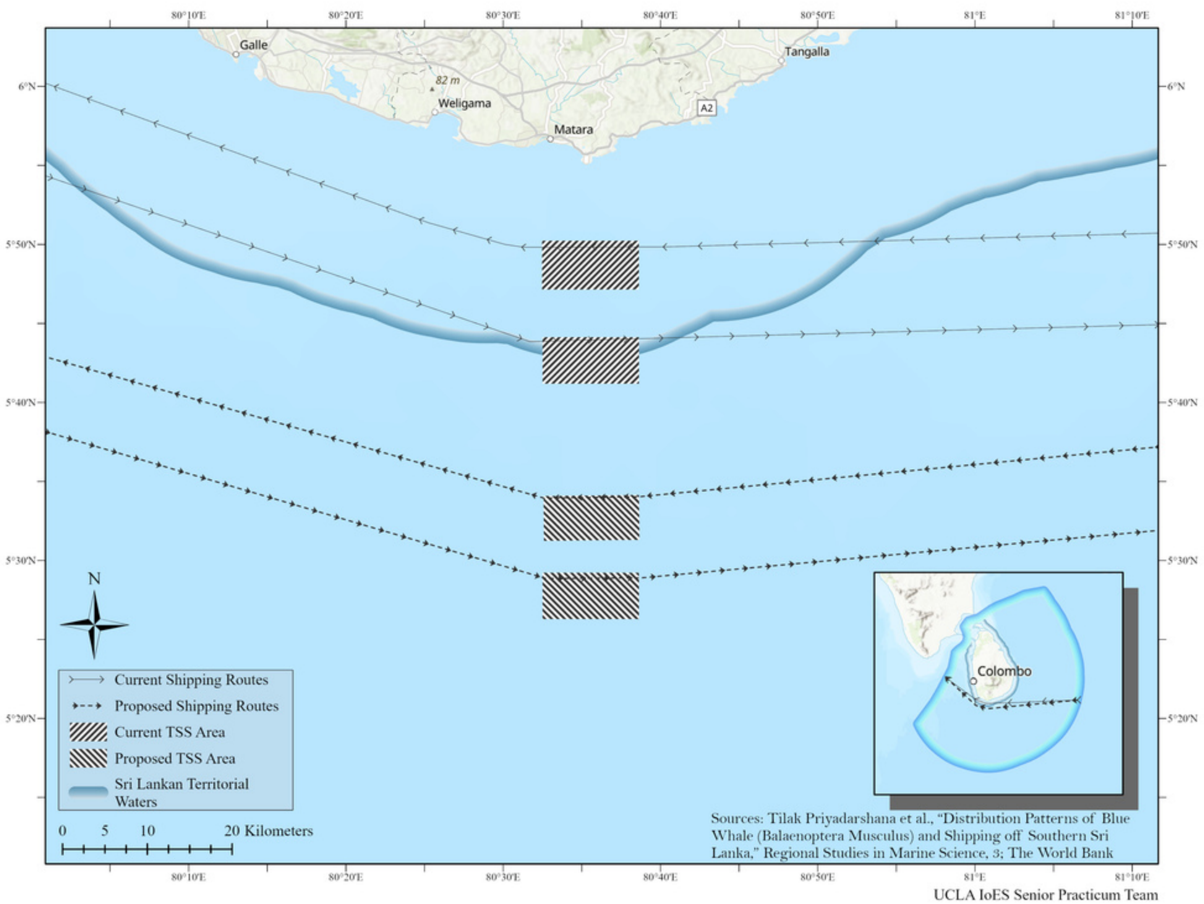

Figure 1. Current and proposed shipping routes and Traffic Separation Schemes (TSS) off of Sri Lanka's southern coast. This is showing the average route a vessel passing through the current Sri Lanka TSS but not calling at a Sri Lanka port makes in light gray. In addition, it visualizes the vessel passing through Sri Lanka if the TSS were to be moved 20 from the coastline as the proposed shipping routes.

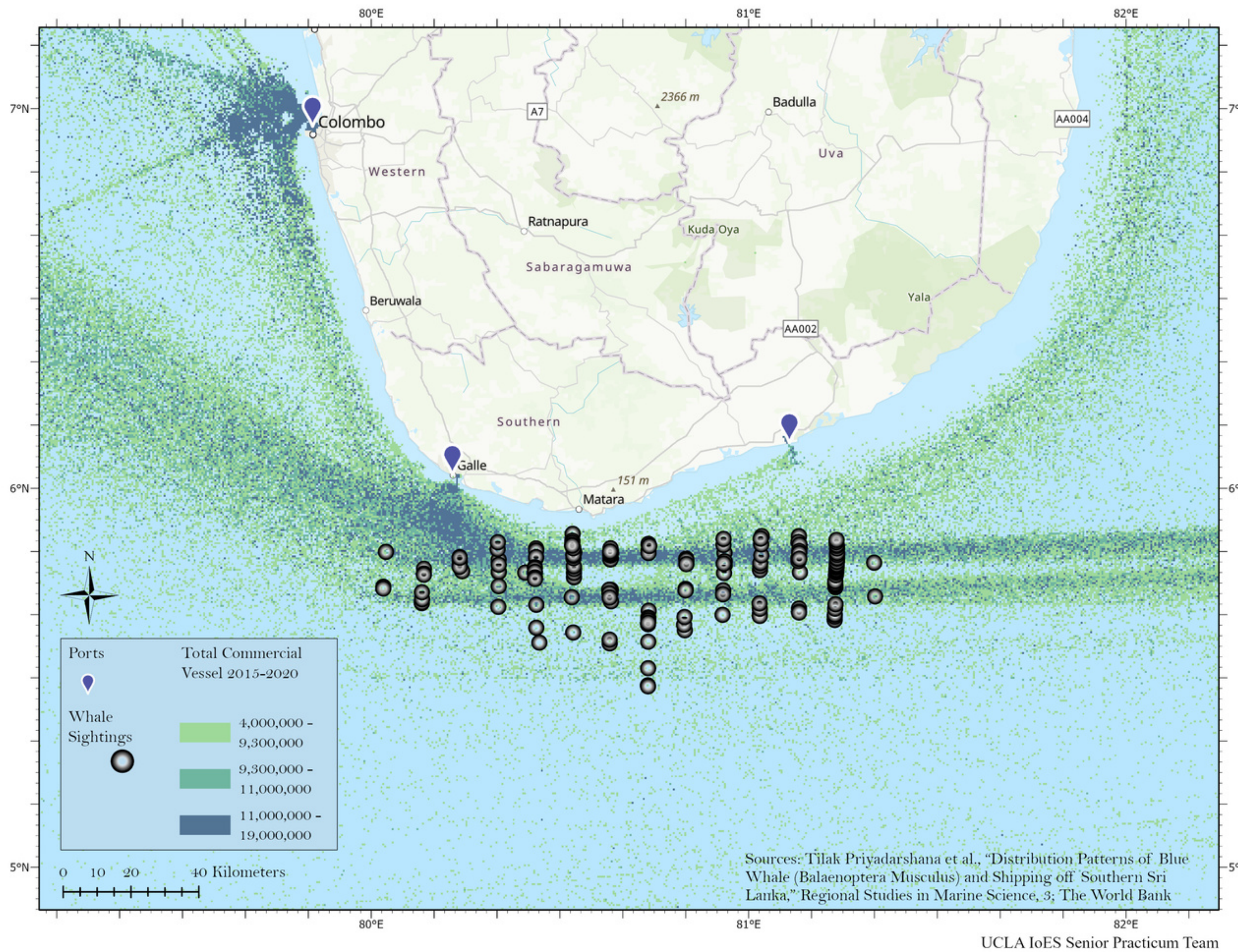

Figure 2. Whale Sightings and Commercial Ship Density off of Sri Lanka's Southern Coast. Global commercial ship density from 2015 to 2020 is represented in green to blue dots in comparison with the transect locations of whale sightings found in a 2015 study in Sri Lanka.

Key Findings

Across the submodels of Ecosystem Impact Estimate, Shipping Industry Impact, Coastal Fisheries Impact, and total Sri Lankan economy impact, results indicate a base case net positive gain of $31,321,984.64 USD across all categories. This reflects the conservative impact of a shipping lane change, and a best case scenario is also included, indicating a total projected increase in revenues of $59,316,999.99 across the submodels. This represents a 4.77% change in USD and an 8.67% change with regards to the total percent change from current values. It is important to note that this percent change does not show the percent impact on Sri Lanka's economy as a whole, but just for the variables analyzed within these four submodels.

This report recommends that the shipping lane be shifted 15 nm to the proposed 20 nm offshore in order to achieve:

- Ecosystem Impact Estimate: Scenario B, corresponding to a 3976 metric ton net carbon sequestration and $2,783,200 USD in savings.
- Cost of Carbon to Sri Lanka from Shipping: Scenario C, resulting in a decrease of impact of carbon emissions to Sri Lanka valued at $19,933,980 USD in savings.
- Shipping Industry Gas Cost: roughly $4,012.51 to $6,420.01 increase.
- Coastal Fisheries Impact: A 5% increase in fishing industry revenues resulting in a marginal increase of over $1,800,000 USD in industry GDP.
- Impact to Tourism Industry: Leveraging the shipping lane shift to promote Sri Lanka as a popular ecotourism destination which would lead to an increase in both direct and indirect tourism revenues from whale watching, resulting in a total increase in tourism revenues of $9,615,000 USD to Sri Lanka.
- Port Revenues: No substantial change to port revenues.

Indicator	Result
Ecosystem Impact Estimate	$1,365,700 USD saved due to 1951 tons of carbon not released.
Cost of Carbon to Sri Lanka from Shipping	$19,933,980.24 USD saved due to a 30% decrease in emissions from ships reaching Sri Lankan shores
Shipping Industry Gas Cost	Approximate increase in fuel costs ranging from $4,012.51 to $6,420.01.
Coastal Fisheries Impact	Increase in fishing revenues of $1,807,641.50 due to safer passage on Sri Lankan coast.
Impact to Tourism Industry	Total yearly tourism industry GDP increasing by $9,615,000 as a result of direct and indirect pathways.
Port Revenues	Port revenue will remain around the same at $28,991,831.86. Slight year-over-year variance expected.

"Your strength becomes someone else's inspiration... Be courageous, believe in yourself, support one another, take time to understand each other."
- Dr. Asha de Vos