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The Effectiveness of Incentivized and Non-Incentivized Vessel Speed Reduction Programs: Case Study in the Santa Barbara Channel

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Introduction:

Shipping is an important industry to southern California, with the Ports of Los Angeles (POLA) and Long Beach (POLB) experiencing steady, substantial growth over the last 20 years. Currently, these ports facilitate over 470 billion $US in trade annually (Port of Long Beach and Port of Los Angeles websites). However, this lucrative and expanding industry is associated with a number of environmental impacts, including ocean noise pollution, air pollution and whale ship strikes (Redfern *et al.* 2013; McKenna *et al.* 2012; National Research Council of the US National Academies 2003; Andrew *et al.* 2002). The level at which shipping adversely impacts local ecosystems has often been linked to ship speed, with conventional wisdom being that faster ships lead to increased pollutant emissions (Psaraftis et al. 2009), increased noise pollution and higher whale mortality risk (Wiley et al., 2011; Vanderlaan and Taggart 2007; Wang et al., 2007; Laist et al 2001). Ocean noise is important to track as it has been associated with increased stress, reduced feeding, and potentially increasing susceptibility of whales to ship strikes (Redfern et al Forthcoming; Gedamke et al. 2016, McKenna et al 2015; Clark et al. 2009).

While the industry is global in scale, some regions of the world have significantly higher concentrations of ship traffic. Via POLA and POLB, the Southern California Bight contains approximately 50% of seaborne cargo into the US (Louttit, pers comms.) but is also home to The Channel Islands National Marine Sanctuary (CINMS) serves as a federal designated marine protected area in an otherwise heavily urbanized Southern California Bight marine ecosystem. In Santa Barbara County alone (one of the counties surrounding the sanctuary), emissions from ships account for over 50% of the total NOx emissions (SBCAPCD 2016). Ship emissions contribute to worsening air quality and can even increase the prevalence of lung-related disease rates (Bone et al 2016; Corbett et al 2007; Bailey and Solomon 2004). In addition, the Santa Barbara Channel ranks among some of the noisiest ocean regions worldwide, with just 6% of the Sanctuary experiencing noise pollution levels below estimated pre-industrial conditions (Gedamke et al. 2016).

Beyond contributing to ambient noise pollution, ships commonly collide with whales in the SCB; leading to injury or mortality. Whale ship strikes have been in the public spotlight in the SCB after four blue whales (*Balaenoptera musculus*), an ESA-designated endangered species, washed ashore and were ruled as likely to be ship strike mortalities in 2007 (Berman-Kowalewski 2010). While managers can not be sure of the exact numbers of ship strikes per year due to the low chances of discovering an event, this number greatly exceeded recorded confirmed or presumed ship strike fatalities in previous years. This prompted the National Oceanic and Atmospheric Administration (NOAA) to declare an Unusual Mortality Event (UME). Given that the Eastern Tropical Pacific Blue Whale stock has been slower to recover than other large baleen whale populations (Irvine 2014) and that recent research has indicated that blue whales do not exhibit rapid avoidance behavior to avoid ship strikes (McKenna et al. 2015), a number of policy actions taken by NOAA have been focused on their recovery. Ship strikes are known to also affect fin (*Balaenoptera physalus*) and humpback (*Megaptera novaeangliae*) whales as well in southern California at relatively consistent rates annually (Calambokidis 2011; Vanderlaan & Taggart 2007). Based on a review of NMFS marine mammal stranding data there has been on average 1-3 large baleen whales likely struck by ships along the California coast. All of these species are afforded the same protections by the Marine Mammal Protection Act (50 C.F.R. Part 218) and when in sanctuary waters the National Marine Sanctuaries Act (Title 16, Chapter 32, Sections 1431 et seq. United States Code).

Local, state and federal agencies are working together to mitigate impacts of the shipping industry on air quality and whale populations in Southern California through a number of spatial exclusion and speed reduction efforts. In 2008, the California Resources Board (CARB) adopted fuel regulations that required the use of cleaner fuels out to 24 nm from the coast to reduce the amount of shipping emissions nearshore. Later, in 2010, the United States Environmental Protection Agency (EPA) enacted the North American Emission Control Area (referred to ECA for the remainder of this manuscript), which limited the sulfur content of shipping fuels within 200 nm of the coastline (EPA 2010). Both regulations had unintended consequences of altering the spatial patterns of traffic in SCB, with over 50% of the ships deciding to not use the nearshore shipping lanes in the SBC when the CARB rule went into effect. The establishment of the ECA likely pushed ships to slow down to improve fuel economy as they had to use more expensive cleaner fuels. This created a somewhat scattered pattern of shipping traffic, with a lot of the traffic going south of the Northern Channel Islands; an area with a scarcity of available cetacean habitat data compared to other parts of the SBC. In 2014 and 2015, 34% and 40%, respectively, of arrivals to POLA and POLB used the SBC Traffic Separation Scheme (TSS), a designation used to organize shipping traffic into lanes. Comparatively, 28% (2014) and 21% (2015) of transits approach the ports from a western approach south of the sanctuary, which has no shipping lane (Loutitt, unpublished data). While these efforts have likely reduced air pollution in Santa Barbara and Ventura coastal communities, a high density of traffic and its respective level of impacts remains in the greater SCB.

In response to the highly variable traffic patterns, there have been a number of efforts to understand how re-routing ship traffic and changing placement of shipping lanes in the SCB could reduce risk to whales from ship strikes. Based on recommendations from NOAA, the International Maritime Organization (IMO) shifted the TSS in the SBC in 2013 following a US Coast Guard Port Route Access Study to determine alternate routes for shipping lanes (Segee 2010; US Coast Guard 33 CFR Part 167). In 2008 and again in 2015, the Channel Islands National Marine Sanctuary Advisory Council (SAC) investigated potential management alternatives to better protect whales in the CINMS region. The SAC's

2015 Marine Shipping Working Group proposed a number of alternatives, including adjustments to the TSS, an extension of the IMO-declared Area To Be Avoided (ATBA) around the islands, a new western route transiting south of the sanctuary into the POLA and POLB, a seasonal VSR zone, and an expanded VSR incentive-based trial (Marine Shipping Working Group Final Report 2016). With available whale distribution data and increasingly sophisticated population and habitat modeling, managers are considering to what degree the SAC's recommendations would reduce ship strike impact (Marine Shipping Working Group Final Report 2016).

Given the high density of traffic in the SCB, fuel regulations alone do not directly reduce ship strike risk. Even though the existing TSS had recently been adjusted to reduce the co-occurrence of ships and whales, overlap of shipping activities and critical whale habitat still occurs. Because of the remaining overlap, agencies and conservation groups are still pursuing VSR programs to further reduce risk to large cetaceans and decrease air emissions. Large vessels that travel at slower speeds burn less fuel as long as they remain above a specific speed threshold. Thusly, these slow-going vessels emit fewer pollutants compared to those traveling at greater speeds (Psaraftis et al. 2009). In addition to these air quality benefits, evidence also shows a decrease in cetacean mortality risk in ship collision events with decreases in speed (Wiley et al. 2011; Vanderlaan and Taggart 2007; Wang et al., 2007; Laist et al 2001).

VSR programs have been instated in other areas with success. Both POLA and POLB use monetary incentives to slow ships coming into the ports through dockage fee reimbursements (POLA 2009; POLB 2009). The program has been widely deemed a success with large reductions in emissions around the port and surrounding areas (POLB 2013). However, emissions measurements still exceed state and federal standards outside of the program's incentive areas (40 nm) and it is possible that ships will increase speed to make up time lost from participating in a VSR. This speed adjustment could spatially alter where impacts are the greatest and simply pass along increased ship strike risk farther along the coast.

Voluntary VSR (e.g. non-incentivized) programs have never been compared to incentivized VSR approaches in the same spatial area and under identical emissions regulations. Comparing these approaches is important because while voluntary incentivized programs may come at a cost to conservation groups or taxpayers, they may have improved efficacy over voluntary measures without incentives. In response to regional shipping issues in the Santa Barbara Channel, Channel Islands National Marine Sanctuary (CINMS) and Santa Barbara County Air Pollution Control District (SBCAPCD) implemented a trial incentivized VSR Program in the Santa Barbara Channel TSS in the summer of 2014. Since 2008 the National Marine Fisheries Service and CINMS have implemented a voluntary speed reduction program in this same area. This allows CINMS and SBCAPCD to test the efficacy of an incentivized approach to vessel speed reduction along an open coastline and compare that approach to a voluntary measure under similar conditions.

Materials and Methods:

Study Area: The Santa Barbara Channel and the northern Channel Islands are a biological hotspot for cetaceans and are known for high cetacean density during summer months (Gedamke et al 2016; Calambokidis et. al. 2015; Calambokidis and Barlow 2004; Mate et al 2009). There is an existing Traffic Separation Scheme (i.e. north and south bound shipping lanes) between the mainland coast and the Channel Islands as well as an Area To Be Avoided (ATBA) around the Channel Islands National Marine Sanctuary (Fig 1). The ATBA effectively keeps large traffic outside of the majority of sanctuary waters and the Sanctuary has additional regulations prohibiting large vessels over 300 gross tons from within 1 nm of the islands. Over the last few years shipping traffic has split around the ATBA with approximately 2400 transits going through the shipping lane and approximately 1400 transits traveling south of the islands annually.

Incentivized VSR trial (IVSR): The IVSR area extended from POLA and POLB's incentive area (40 nm from the port entrance) to the end of the shipping lane around Point Conception (Fig 1) creating a trial area that spans approximately 100 nm. The trial was conducted from July-November 2014 as this is the time when whale abundance and air pollution is highest in the region. In order to participate, ships must have had an average speed over 14 knots in the 4 months leading up to the trial period and must also participate in POLA/POLB's VSR program. Seven shipping companies (i.e. COSCO, Hapag-Lloyd, K Line, Maersk Line, Matson, Mitsui O.S.K. Lines, and United Arab Shipping Company) enrolled in the trial and agreed to slow a total of 35 individual transits down to an average speed of 12 knots or less through the IVSR zone for an incentive purse of $2,500 per transit. Twelve knots was chosen as this was the speed believed to maximize emission reduction, reduce the lethality of ship strikes on whales, and it matched the speed required by the neighboring Port's speed reduction program.

Vessel speed data were collected from an Automatic Identification System (AIS) receiver that CINMS maintains on Santa Cruz Island (33° 59.667' N, 119° 37.941' W). CINMS maintains and owns this data stream to monitor ship traffic around the sanctuary and implement management strategies for vessel traffic. Vessels 300 gross tons or more are required by law to carry AIS transmitters that emit a VHF radio signal to a series of land-based receiving stations containing a variety of data, including the ship's position and speed. CINMS' receiver on Santa Cruz Island has coverage as far north as Point Conception and has coverage on the south side of the islands to approximately 33° N. The program shipplotter is used to store AIS transmissions as log files which were then stored in a SQL database. Data was extracted from the SQL database and analyzed in ESRI's ArcGIS or R (R Core team 2012).

Ship speeds during incentivized transits were calculated by averaging the speeds from the transmission data (a datum point transmitted every 2-15 seconds) from all the detections that occurred in the IVSR zone. CINMS and SBCAPCD independently computed average transit speeds for vessels and cross-checked to verify calculations. Ships that maintained an average speed of 12 knots or less qualified for the incentive payment, while those traveling at speeds greater than 12 knots did not qualify (Table 1). Ship trips and speeds from the IVSR trial and qualifying period were also plotted in ArcGIS to identify if a spatial trend in speeds existed along the route. Speeds were averaged within 5 km^2 blocks along the IVSR route and compared among blocks with a Chi-square.

Also of interest to resource managers was whether ships that participated in the IVSR were speeding up just northwest of the IVSR zone to compensate for the slower than historical transit in the TSS. As our IVSR zone ran against POLB and POLA's IVSR to the south east, we did not have the same concern for the area south of the IVSR. For analysis outside of the SCB area, we used satellite collected AIS data (sAIS) and subset it to the area shown in Fig 2A. This satellite AIS data has spatial and temporal gaps compared to terrestrial AIS data but provided data from beyond the extent of our terrestrial receiver. Because of the sizable temporal gaps in sAIS, we needed to select data from a large area. The area we drew ensured that ships traveling north along the coast to other west coast ports as well as those moving west along the "Great Circle Route" (aka the route from the US west coast to Asian ports) would be included with the temporal gaps of sAIS data in mind. We received data from SpaceX for the 24 ships that participated in the trial as well as 24 randomly selected vessels (to match the number of vessels participating in the IVSR) that did not participate in the IVSR. SpaceX maintains a series of satellites that collect AIS data and they shared this data with SBCAPCD. The satellite data coverage lasted from June to early October 2014, but did not include all incentivized transits in the IVSR. In the sAIS datset, there were 17 incentivized transits and 136 non-incentivized transits. We compared vessel speeds in the post IVSR area of interest (Fig. 2A) between non-incentivized and incentivized transits with Wilcoxon rank sum test (Figure 2B).

Non-Incentivized VSR: From 2008 to the present, CINMS and the National Marine Fisheries Service (collectively NOAA) have enacted a seasonal voluntary Whale Advisory Zone (WAZ) similar to the one described in McKenna et al. (2012). For the purposes of this study, we have chosen to analyze the WAZ in 2015 because it was under the same emission standards, similar economic conditions and similar overall traffic patterns to 2014. Also, we chose not to use 2014 as an example year because the implementation of the IVSR may have altered traffic patterns in the SBC. Via the Coast Guard's Notice to Mariners, NOAA Weather Channel broadcast, and direct communications to shipping agents, NOAA recommended ships over 300 gross tons reduce speed to 10 knots in the shipping lane between Point Conception to San Pedro Point, Santa Cruz Island (Fig 1). We used AIS data from the Santa Cruz Island Station to assess speed compliance within the WAZ zone in the Santa Barbara Channel TSS. We calculated daily average speeds of each cargo ship in the WAZ from June to November and noted how many of those ships had average speeds below 10 knots on a given calendar day. We compared the number of WAZ compliant daily average ship speeds among months to see if compliance changed through time with a Chi Square. We also compared average speeds by vessel for pre-WAZ (Jan 1, 2014-May 30, 2014), WAZ (June 1, 2014-Nov 15, 2014) and post WAZ (Nov 16, 2014-Dec 31, 2014) time periods. To see if the WAZ was effective, we compared these average speeds among these time periods with a Kruskal Wallis Chi-Square with Campell and Skillings multiple comparisons. Finally, we compared annual average ship speeds in the SBC between 2014 and 2015 test whether overall ship speeds were not largely different between years to ensure that behavior was not different.

Results:

Participation with IVSR was high with 27 of the 35 transits that were enrolled qualifying for an incentive by having a mean transit speed at or below 12 knots. We calculated an average of a 5.1 knot reduction from ship's average baseline speeds for the prior 4 months. The maximum speed reduction from a baseline speed was 8.6 knots (Table 1). Seven enrolled transits were not eligible to receive an incentive due to average speeds in excess of 12 knots, although we calculated a 0.48 knot average speed reduction for these failed transits. One additional transit failed because its route was modified and it did not transit through the SBC. Five vessels with failed transits had speeds during intended IVSR transit that were higher than their baseline average speeds with the highest increase in speed being 3.5 knots over that ship's baseline.

The average speed of all non-incentivized transits in the post IVSR area of interest (Fig 2A) was 16.8 knots and the median speed was 17.3 knots. Transits incentivized by the IVSR had significantly lower speeds in the same area north of the IVSR zone with an average speed of 12.64 knots and a median of 12.9 knots (Wilcoxon rank sum test, $W=1276900$, $p < .0001$, Fig 2). Only one incentivized transit sped up above the 16.82 knot average. Even though the continued slow speed was not required, 3 transits of the 17 transits covered in the satellite data continued the required IVSR slow transit speed of 12 knots or below; however, the majority of IVSR transits maintained speeds just slightly above 12 knots.

In the IVSR zone, both incentivized and non-incentivized transit speeds appear to be spatially homogeneous. This means that speeds appear to be consistent throughout the IVSR zone and ships are not making large changes in speed during their transit. During the qualifying period, ships participating in the IVSR did not have significant differences in average speeds across 5 km^2 blocks along the IVSR area (X^2= 1.545, df=67, p=1). Incentivized transits maintained a relatively consistent speed across all blocks during their incentivized transits as well (X^2= 6.15, df=67, p=1).

During the 2015 WAZ, vessel traffic had a mean daily average ship speed of 14.18 through the WAZ area, approximately 4 knots over the recommended WAZ speed. Of the 1334 daily average ship speeds, only 174 daily average ship speeds were below 10 knots for about a 13% compliance rate. Out of 383 ships detected, 85 ships had daily average speeds below 10 knots at some point during the WAZ. However, only 19 ships appeared to have consistently participated with WAZ and never had a daily average speed over 10 knots in the dataset Participation did not differ by month and remained consistent from June to November (Chi-square, X2= 6.73399, df=5, p=0.15). Average ship speeds during the WAZ (13.5 knots) were significantly faster compared to pre-WAZ (13.0 knots) and post-WAZ speed (13.1 knots; Kruskal-Wallis chi-squared = 33.503, df = 2, p-value < 0.005); albeit differences were less than 0.4 knots. About 13.3% of ships Pre-WAZ and 12.2% Post-WAZ traveled below 10 knots. During the WAZ however, ships only 7% of ships had speeds below 10 knots.

Cargo ship speeds in the SBC do not appear to be different between years. In 2014, ships had a median speed of each ship's average speeds was 12.62 knots with a mean speed of 12.92 knots and a standard deviation of 2.44 knots. Speeds were similar in 2015 with an average speed of 13.20 knots, median speed of 12.79 knots, and a standard deviation of 2.98 knots.

Discussion:

We found that our voluntary incentivized approach had a higher percentage of participation when compared to voluntary measures without incentives applied in the SBC. Shipping companies are constantly trying to find the economic balance between fuel costs, operational costs and scheduling, which could be a large reason why incentivized approaches are more effective. The cash incentive in the trial IVSR likely helps spur particpation; however, a number of factors may influence these results. One example is that the industry itself is beginning to push for self-imposed slow speed measures to improve fuel efficiency for maximizing financial gains (McKenna et al. 2012). Despite this increased interest in the benefits of speed reduction, the data show that most large vessels typically travel at a speed that incurs significant risks to whales and at faster rates than the optimum speed for pollution minimization (Rodrigue 2017; Laist et al. 2014, Conn and Silber 2013, Notteboom and Carriou 2009).

The non-incentivized WAZ had low participation overall but there appears to be some improvement over time. McKenna et. al. (2012) found that the ship speeds were not affected by a voluntary speed reduction scheme broadcast over the Notice to Mariners from 2007-2009. While McKenna et al showed 0% participation in a non-incentivized VSR, the WAZ in our study showed 13% of daily average ship speeds traveling at the requested speed or below appear to signal greater participation. Participation may have improved due to increased attention on ship strikes after VSR implementation and effective outreach to the shipping industry. This is difficult to understand however, as other factors like scheduling issues at POLA and POLB, cost benefits of reduced speeds, and other external economic drivers are likely to have a big role in the speed reduction as well. Another confounding factor could be the difference in maximum speed set by the two efforts (12 knots for IVSR and 10 knots for the WAZ). Ten knot speeds may decrease large vessel maneuverability, and this could have affected percentage of vessels able to or willing to comply with the WAZ.

Additionally, compliance with the IVSR is biased, as ships agreed to participate and demonstrated buy-in to the effort prior to their incentivized transit. The trial IVSR generated participation demand that exceeded expectations (with over 7 shipping companies seeking to enroll 80+ transits in the pilot effort), but the available funding could cover only 35 transits in 2014. Recognizing this demand, we do believe the IVSR could be scaled up to incorporate a larger percentage of the faster transits taking place. However, it is important to note that it is unknown whether these participating transits are representative of the majority of vessel activity; it is possible that faster ships, or those on tighter schedules, may be more difficult to motivate to travel at reduced speeds. Future work should focus on what other potential issues may hinder scaling up IVSRs in the SCB, and potentially along the whole California coast.

Programs like IVSR and POLA and POLB's VSR require relatively small incentive purses per transit compared to total operational costs for these major shipping lines. CINMS paid out $2,500 US per transit for the IVSR in 2014. By providing this financial incentive and providing positive public relations benefits, agencies and conservation groups can influence shipping companies to meet best environmental practices and improve cooperation with non-regulatory conservation efforts. However, the financial burden of scaling up and sustaining these programs may also be prohibitive for non-profits or agencies with tight budgets in areas where traffic is dense like the SCB. Future work should investigate different payout schemes, such as paying for a season of compliance (e.g. summer), to test their efficacy and drive down costs of running a larger scale IVSR. Additionally, positive publicity from participating in these programs may be a stronger incentive for shipping companies to participate.

One of the major questions for all VSR programs is if the localized mitigation of environmental impacts caused increased air pollution and ship strike risk in other areas if ships speed up once they exit the prescribed VSR zone to meet static schedules. The IVSR program here did not appear to have this issue as the majority of ships either returned to approximately the average speeds of other transiting vessels or continued to steam at reduced speeds. Only one ship went a full knot over the average speed of other vessels transiting in the area once it exited the IVSR zone. The results from our program suggest that ships are building in the increased transit times of participation to their respective routes instead of trying to increase speed to make up for lost time.

It is important to consider that the limited sample of ships of the VSR may not be an accurate representation of the entire fleet that transit in the SCB. Depending on the cargo type, schedule limitations and other schedule factors, a number of ships may not opt to participate in VSR programs. We also saw a few compliance failures in the IVSR. A number of potential reasons for this were found from follow-up conversations including: the shipping company failed to communicate to the captain, the captain failed to comply, or scheduling issues superseded participation for a particular transit. Given the limited number of vessels involved in the IVSR, it is possible that this subset of ships is biased towards ships that can easily participate. If true, scaling up a VSR to the majority of the fleet or more may be difficult. That being said, the ports have extremely high compliance with 90% or more of ships participating in their VSR programs.

Conclusion:

Cooperation with non-incentivized vessel speed reductions appears to be limited. Although cooperation with the WAZ did appear to improve compared to prior examinations, relative participation was still low compared to incentivized approaches and it is unclear whether the slight improvement in slower speeds in the WAZ reflects true participation with the effort. Financial rewards, even minimal ones, and positive publicity in a structured program appears to be more effective at achieving industry buy-in and slowing down vessel traffic. Scaling up an IVSR program to capture a significant portion of the transits taking place could be expensive. However, future work should attempt to discover the “floor” of what the shipping companies are willing to accept and adjust payout schemes based on how much money will be required to achieve desired behaviors.

With the implementation of the CARB and ECA rulings, more ships are traveling south of the Channel Islands and not using the TSS. The general thought was that ships traveled outside of boundaries where expensive cleaner fuels were required, like the TSS, to reduce operational costs. Getting ships to slow down outside of a designated route may be more difficult as dispersed traffic patterns could lead to unforeseen transit issues. For example, slower speeds may decrease maneuverability, increase risk and could increase costs or cause scheduling issues at ports.

While whale sightings data are concentrated in a geographically smaller region than the study region, and sparse in much of the region due to lack of effort, modeling does suggest that there is high quality potential whale habitat south and west of CINMS (Becker et al. 2016; Marine Shipping Working Group Final Report 2016; Redfern et al 2013) and this habitat is not covered by the current ATBA. In fact, the current ATBA may not be as effective at protecting large cetaceans in the region because important habitats are spread out throughout the SCB and beyond the ATBA boundaries. To add to the challenge, data on ships strikes are limited: the number of strikes per year, conditions that increase strike risk, potential cetacean avoidance behavior and the impact of strikes on population recovery all require additional research. For this reason, it is difficult to quantify exactly how this IVSR trial minimized risk to local whales. However, a number of cetacean populations (namely blues, fins, and the Central American humpback population segment) are still in recovery and despite the data gap, managers are treating ship strikes as a major impediment to recovery. The reduction in air pollution with speed decreases has been documented in other studies (Psaraftis et al. 2009) and has been used to justify other speed reductions in the region. To estimate air emissions reduction, future IVSR-type programs could require a fuel log from participating vessels. To date, the most utilized management tools for addressing these conservation concerns are limiting spatial over lap and reducing speed. Testing an incentive program in this southern region will be critical to effective management of whales in the SCB, due to the fact that approximately 25-30% of traffic to the ports use this area.

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Table 1: Table of VSR Transits and Speeds

Ship	Planned Transit Date	Min.	Median	NOAA Mean VSR	Max.	NOAA Baseline	Post-VSR Speed
Mahi Mahi	7/11/2014	11.2	11.7	11.78	12.6	18.62	No Data
Verrazamo Bridge	7/13/2014	6.8	7.6	7.587	8.5	16.16	10.5375
Xin Da Yang Zhou	7/23/2014	9.3	10.2	10.39	12	15.01	17.23333
Cosco Indonesia	7/25/2014	10.5	11.5	11.45	12	15.13	13.05887
Matrix	8/1/2014	11.6	17.1	17.69	20.5	15.3	No Data
Cosco Thailand	7/25/2014	10.7	11.4	11.45	12.4	15.58	13.59313
Vincent Thomas Bridge	8/4/2014	10.9	11.4	10.07	12.5	13.98	No Data
Gerd Maersk	8/7/2014	10.9	11.4	11.56	12.5	17.55	15.72471
Seaspan Hamburg	8/7/2014	2.9	8.5	9.44	11.5	15.34	13.02857
Mahi Mahi	8/8/2014	11	11.6	11.61	12.5	18.62	No Data
Cosco Indonesia	9/6/2014	10.4	11.2	11.16	11.7	14	11.75909
Cosco Asia	8/26/2014	9.9	10.6	10.62	11.3	15.58	14.05362
Maersk Altair	8/27/2014	10	10.8	10.78	11.6	17.13	13.23333
Mol Modern	8/29/2014	8.7	11.3	11.26	12	15.08	10.50594
Xin Da Yang Zhou	9/3/2014	8.5	9.2	9.154	10	15.01	7.45

Santa Ricarda	8/13/2014	8.7	9.7	9.72	11.2	16.89	12.13415
Vincent Thomas Bridge	9/7/2012	9.3	10.6	10.48	11.4	13.98	5.480864
Grete Maersk	9/10/2014	12	12.6	12.58	13.3	17.55	12.5
Rio de Janeiro Express	9/10/2014	1.3	11.6	10.7	12.3	14	12.52875
Cosco Thailand	9/13/2014	10.2	11.3	11.18	11.8	15.58	14.31301
Seaspan Chiwan	9/20/2014	16.1	16.9	16.8	17.5	16.77	No Data
Verrazamo Bridge	9/21/2014	6.4	7.5	7.51	8.7	16.16	No Data
Seaspan Chiwan	10/3/2014	10.9	12.3	12.2	12.9	16.77	17.75
Seaspan Hamburg	10/11/2014	9.9	10.7	10.65	11.2	15.34	No Data
Vincent Thomas Bridge	10/12/2014	11.7	18.1	17.49	19.3	13.98	No Data
Xin Da Yang Zhou	10/18/2014	9.6	11.1	10.93	12.3	15.01	No Data
Cosco Indonesia	10/18/2014	10.3	10.8	10.83	11.5	15.13	No Data
Santa Ricarda	10/18/2014	10	11.2	11.16	11.9	16.89	No Data
Seaspan Hamburg	10/22/2014	10.4	11.1	11.1	11.6	15.34	No Data
Gerner Maersk	10/20/2014	10.9	15.8	14.5	16.7	15.19	No Data
Seaspan Felixstowe	10/25/2014	9.6	10.4	10.4	11	15.69	No Data
Cosco Thailand	10/26/2014	11.7	11.9	11.9	12.1	15.58	No Data
Verrazamo Bridge	10/29/2014	11.6	17.4	16.31	18.1	16.16	No Data

Figure 1: A map of the region, the CINMS boundary and spatial extents of both the WAZ and IVSR.

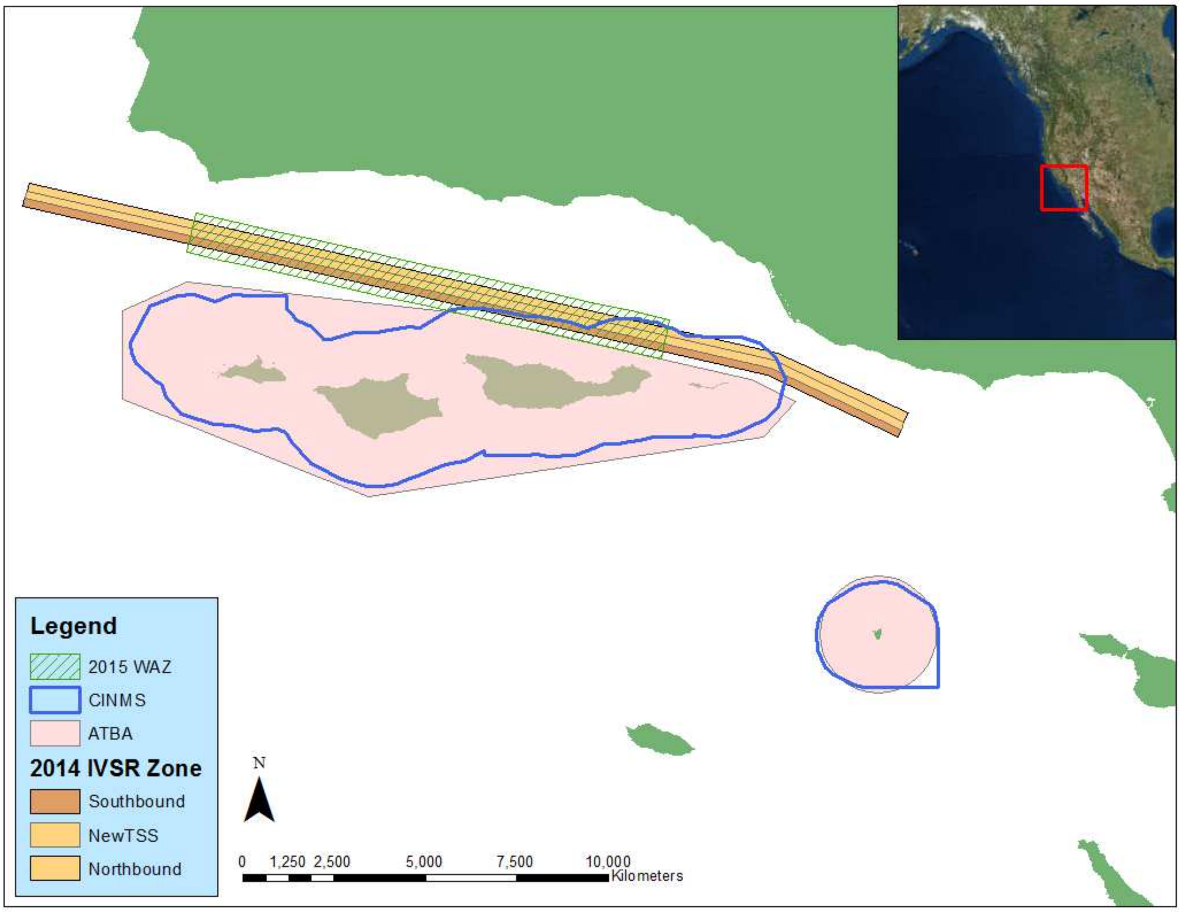
Figure 2: A. Map of the area of interest north east of the IVSR. This area was selected to be large enough to capture vessels traveling north to other west coast ports and those traveling across the "Great Circle Route" to Asian ports B) Boxplot of transit speeds in this area of interest for vessels incentivized by our VSR and vessels not participating in our VSR.

Figure 3: Average speed across 5km2 blocks are shown for A) IVSR participating transits and B) transits not incentivized by our IVSR. Ships appear to maintain relatively consistent speeds and are not making large changes in speed throughout the IVSR zone regardless of participation in the program.

Figure 4: Speeds density plots between the 2015 Pre-WAZ, WAZ and Post-WAZ time periods. The speeds during WAZ was found to be statistically faster compared to Pre-WAZ and Post WAZ time periods (13.1 knots; Kruskal-Wallis chi-squared = 33.503, df = 2, p-value < 0.005)**; however the mean speed was only approximately a half knot faster during the WAZ.**

Figure 5: Density Plot shows the annual average speeds of vessels in 2014 and 2015. Qualitatively, distributions are very similar. In 2014, ships had a median speed of each ship's average speeds was 12.62 knots with a mean speed of 12.92 knots and a standard deviation of 2.44 knots. Speeds were similar in 2015 with an average speed of 13.20 knots, median speed of 12.79 knots, and a standard deviation of 2.98 knots.

Figure 1:



Legend
2015 WAZ
CINMS
ATBA
2014 IVSR Zone
Southbound
NewTSS
Northbound
N
0 1,250 2,500 5,000 7,500 10,000
Kilometers

Figure 2A

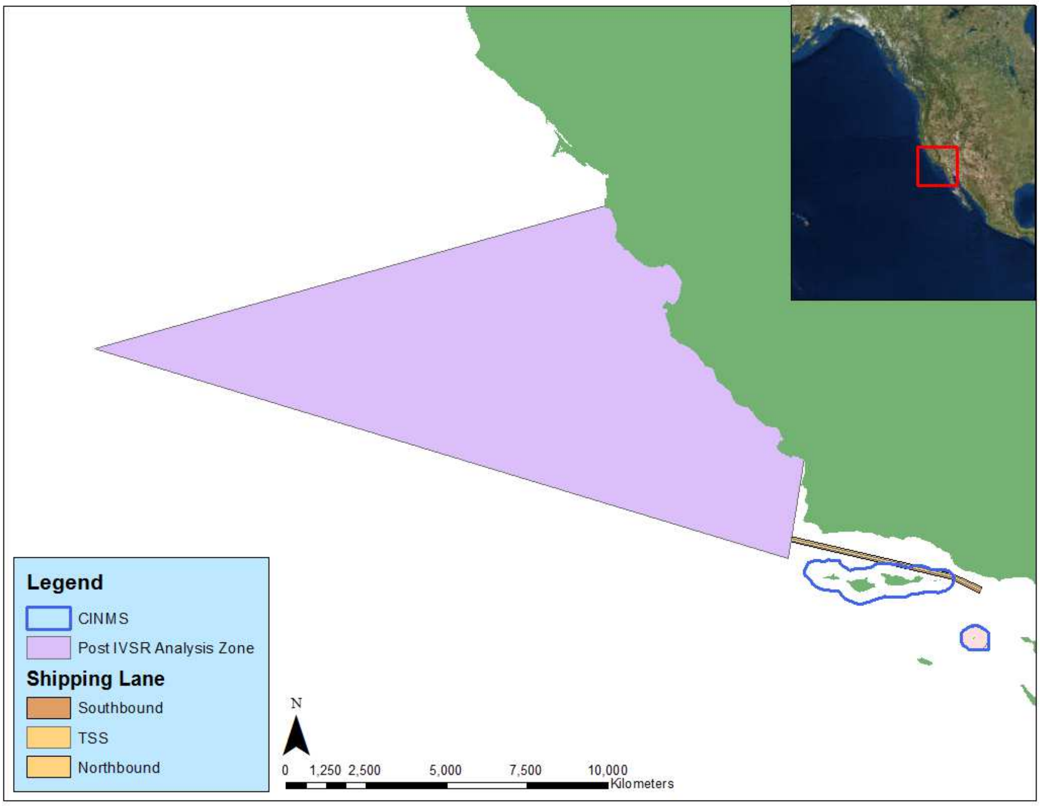


Figure 2b:

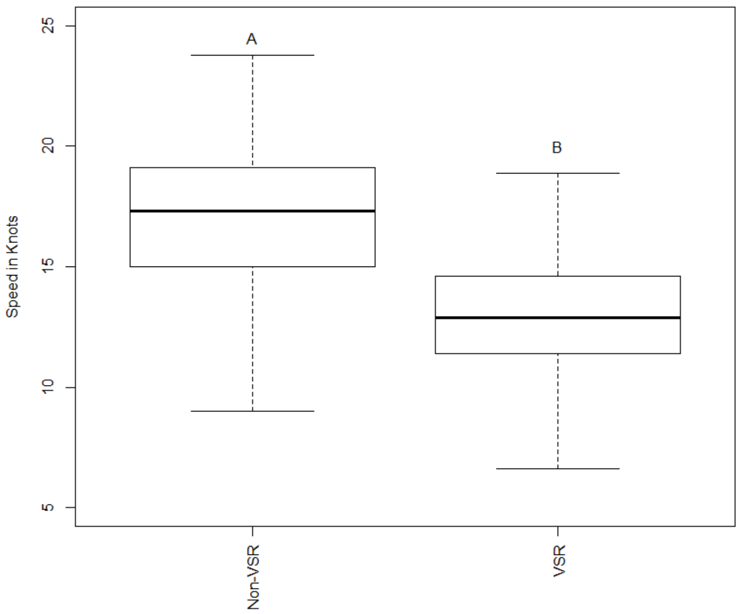
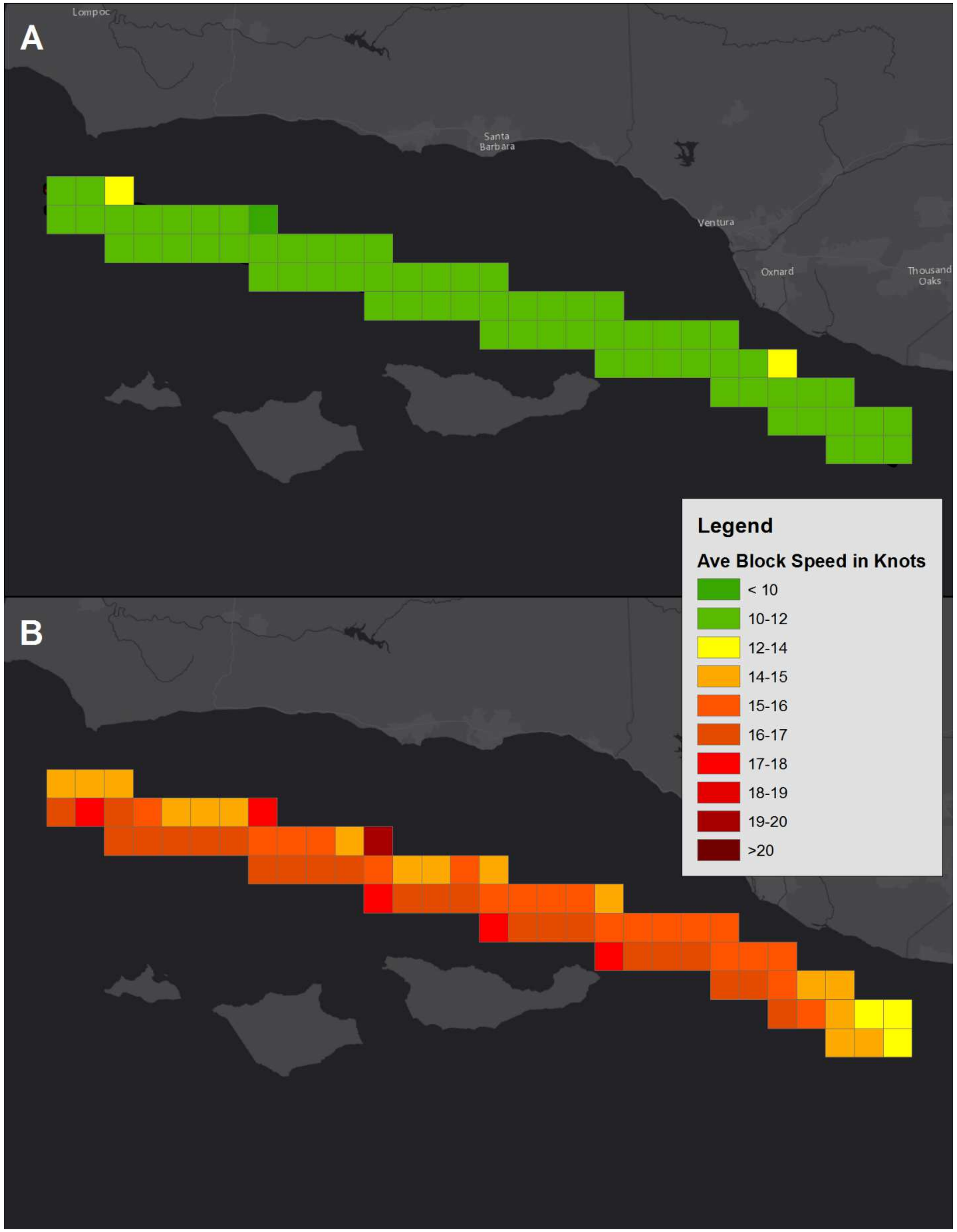
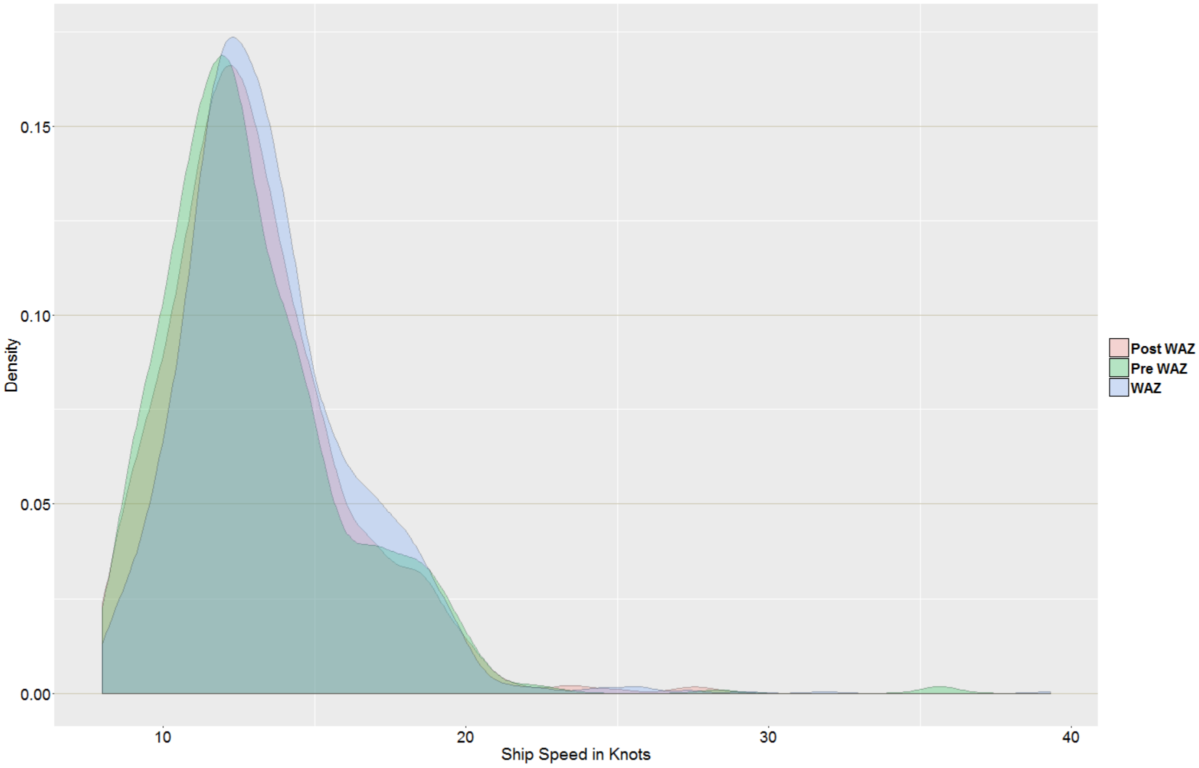


Fig 3:



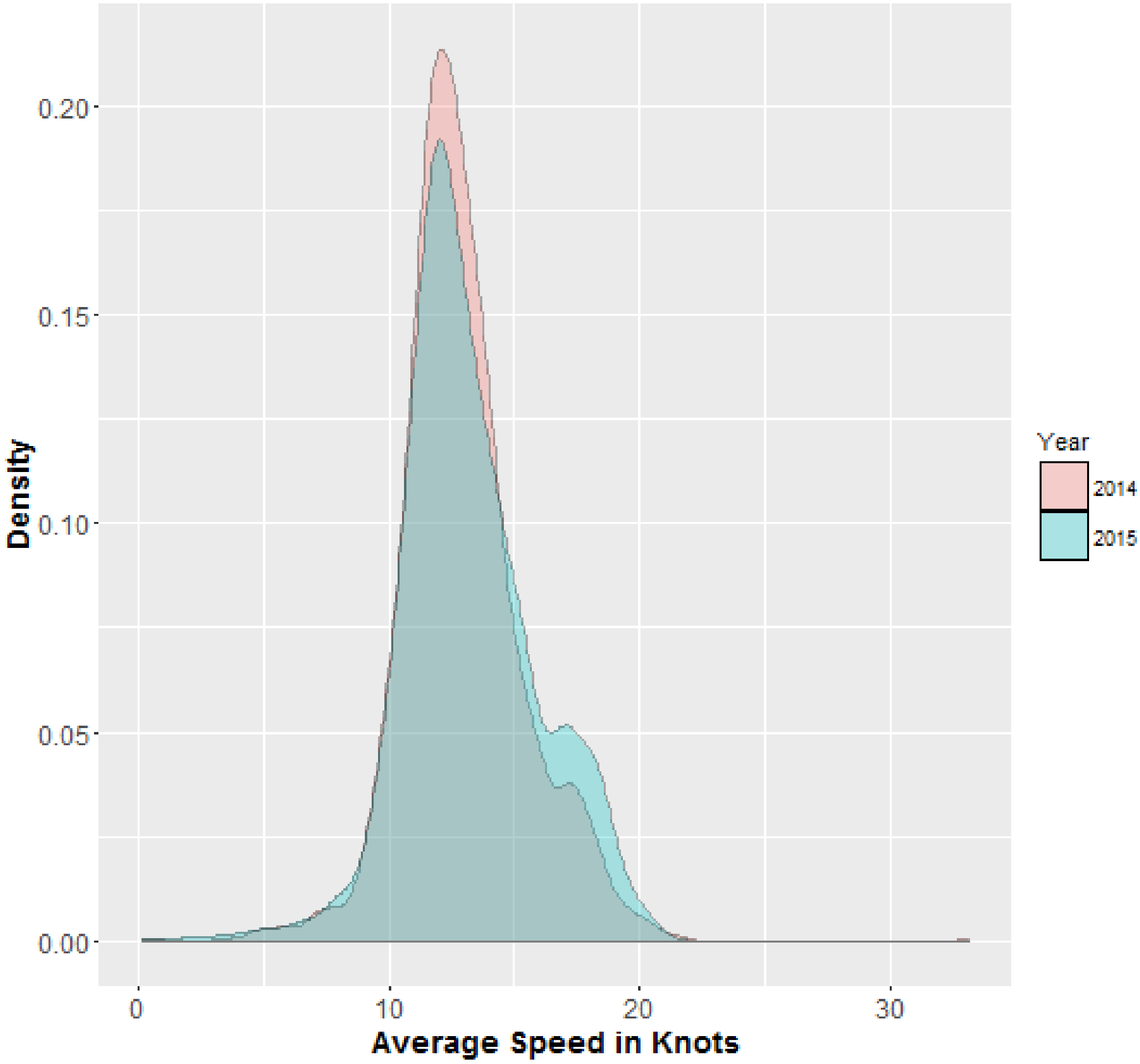
A
Lompoc
Santa Barbara
Ventura
Oxnard
Thousand Oaks
B
Legend
Ave Block Speed in Knots
< 10
10-12
12-14
14-15
15-16
16-17
17-18
18-19
19-20
>20

Figure 4:



0.15
0.10
0.05
0.00
Density
10
20
30
40
Ship Speed in Knots
Post WAZ
Pre WAZ
WAZ

Fig 5:



0.20
0.15
0.10
0.05
0.00
Density
0
10
20
30
Average Speed in Knots
Year
2014
2015