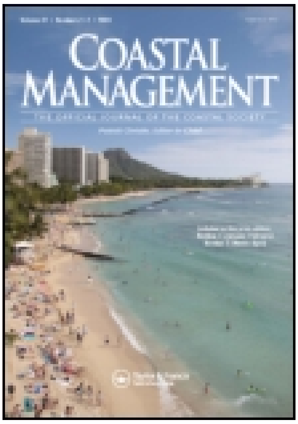

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Response of Commercial Ships to a Voluntary Speed Reduction Measure: Are Voluntary Strategies Adequate for Mitigating Ship-Strike Risk?

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*Collisions between ships and whales are an increasing concern for endangered large whale species. After an unusually high number of blue whales (*Balaenoptera musculus*) were fatally struck in 2007 off the coast of southern California, federal agencies implemented a voluntary conservation program to reduce the likelihood of ship-strikes in the region. This initiative involved seasonal advisory broadcasts requesting vessel operators to voluntarily slow to 10 knots or less when transiting a 75 nm stretch of designated shipping lanes. We monitored ship adherence with those speed advisories using Automatic Identification System data. Daily average speed of cargo and tanker ships and the average speed of individual ship transits before, during, and after the notices were statistically analyzed for changes related to the notices. Whereas a small number of individual ships (1%) traveled significantly slower during the requested periods, speeds were not at or below the recommended 10 knots, nor were daily average speeds reduced during the notices. Voluntary conservation measures are established in a variety of contexts, and may be preferable to regulatory action; in this case, a request to make voluntary changes appeared largely ineffective. Reducing collision risks for whales in this area will require consideration of the various factors that likely explain the lack of adherence when developing an alternative strategy.*

Keywords Automatic Identification System, baleen whales, commercial ship traffic, Local Notices to Mariners, scale mismatch, ship-strike, voluntary conservation

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Introduction

Collisions between ships and whales are regularly reported throughout the world's oceans (Laist et al. 2001; Berman-Kowalewski et al. 2010; Jensen and Silber 2003). At-sea collisions result in serious injury or fatality to some whales and for some endangered large whale populations, ship-strikes are identified as a major threat to survival and recovery (Clapham, Young, and Brownell Jr. 1999; Kraus et al. 2005). The global occurrence and severity of vessel-strikes combined with the predicted growth in maritime traffic (Corbett and Winebrake 2007) has made ship-strikes an emerging conservation issue, particularly in coastal regions where high vessel traffic density intersects with important large whale habitat.

In fall 2007, five blue whale (*Balaenoptera musculus*) mortalities due to ship-strikes occurred off the coast of southern California, a region near one of the largest ports in the world, the combined ports of Los Angeles/Long Beach (Berman-Kowalewski et al. 2010). Blue whales are listed as Endangered under the Endangered Species Act (ESA) and Depleted under the Marine Mammal Protection Act (MMPA) and the northeast Pacific stock is slowly recovering from commercial whaling over the last two centuries (Calambokidis and Barlow 2004; Barlow and Forney 2007).

Compared to previous years, the fatalities in 2007 represented an abnormally high number of ship-strike incidents for such a small region and short period of time (Berman-Kowalewski et al. 2010). This region is an important foraging habitat for blue whales; they aggregate annually from mid-June to late October in the region's cold, up-welled coastal waters to feed on euphausiid shrimps (Croll et al. 1998). Regional whale surveys in fall 2007 found a record high count of individual whales in the Santa Barbara Channel (SBC) with more whales distributed in the vicinity of the shipping lanes than previous years (Berman-Kowalewski et al. 2010). The blue whale mortalities that year raised concern that such deaths could continue or escalate, threatening the population's recovery. In response, government agencies and other groups took action to avoid the re-occurrence of these events (Figure 1).

Various whale-conservation initiatives have been proposed to reduce the threat of whale–ship collisions, including both mandatory and voluntary vessel speed reductions to reduce the lethality (Silber and Bettridge 2012) and vessel route changes to reduce the spatial co-occurrence (Vanderlaan et al. 2008, 2009; Silber et al. 2012b). Previous modifications of vessel routs to avoid whale habitat were implemented through either changes in Traffic Separation Schemes (TSS) or establishment of Areas To Be Avoided. Both options require a U.S. Coast Guard (USCG) port access route study and a review by the International Maritime Organization (IMO), an agency of the United Nations charged with developing a consistent international code of operations for maritime shipping (Silber et al. 2012b). This process can take several years. Reducing ship speed is another option thought to reduce whale mortalities from ship-strikes (Laist et al. 2001; Vanderlaan and Taggart 2007). Although collisions may still occur at any speed, previous studies have shown reduced speed decreases the risk of serious injury or mortality in the event of a collision (Vanderlaan and Taggart 2007; Vanderlaan et al. 2009; Laist et al. 2001).

As an initial response to the fall 2007 events, ocean resource managers in southern California designed a voluntary plan of action to reduce the threat of whale–ship fatal collisions. The plan called for the USCG, in coordination with the National Marine Fisheries Service (NMFS), to issue Local Notices to Mariners (LNM) requesting vessels in the SBC shipping lanes to take steps to avoid collisions with whales. LNM are an established vehicle for the USCG to communicate information to professional mariners on changes to

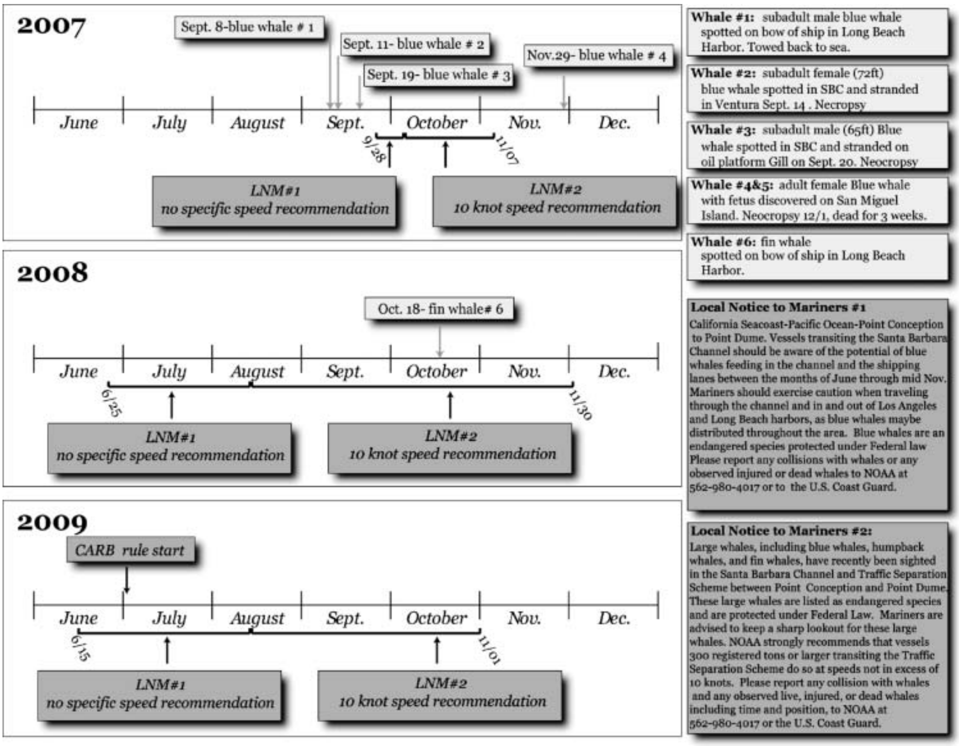

Figure 1. Timeline of events in 2007, 2008, and 2009. During the LNM period, notices were broadcast two times per day. In all years, initial notices did not include a specific speed recommendation, but were subsequently modified to include a 10 knot speed recommendation. In 2007, the notices were sent out in response to the fatalities of whales. In 2008 and 2009 notices were broadcast based on a precautionary approach through an agreement between USCG and NMFS. The start of the California Air Resources Board (CARB) rule in 2009 is shown.

navigation rules and aids to navigation as well as the presence of local hazards (46CFR Ch1 §35.20–1—Federal Register 2010). LNM are published once a week and the LNM in this study were broadcast twice a day on marine band radio. The USCG is the relevant authority for managing large vessel traffic and the NMFS is the regulatory authority for protection and recovery of whales under both the ESA and MMPA. Both the USCG and NOAA (via the NOAA Office of Law Enforcement) are authorized to enforce violations of relevant Federal statutes protecting whales in the SBC. Voluntary conservation agreements are an alternative to this level of enforcement that allows for immediate and cost-effective implementation (Khanna 2001), greater flexibility in the design and implementation process and are sometimes adopted as a first-tier approach (Silber et al. 2012a).

We evaluated the effectiveness of the LNM in reducing vessel speeds. Ship speeds in the SBC were monitored using Automatic Identification System (AIS) data and analyzed before, during, and after the LNM. Because carriage of AIS transponders and adherence to the use of the system is mandatory on ships greater than 300 gross tons (68 FR 39353—Federal Register 2003) and the AIS signal can be obtained from shore-based stations, AIS amounts to a cost-effective compliance monitoring system that provides a census sample of the vessels encountering the LNM. Analyses of ship speeds in the management region included a comparison of average daily ship speed related to the notice periods and individual ship speeds before, during and after the LNM.

Materials and Methods

Local Notice to Mariners and Study Region

Local notice to mariners are the vehicle for the USCG to communicate to professional mariners up to date information on changes to navigation rules and aides to navigation as well as the presence of local hazards. LNM are published on line and in print once per week, and in this study LNM notices were also broadcast on International marine-band radio twice per day. The Code of Federal Regulations states that failure to be aware of them constitutes neglect of duty for licensed officers operating large vessels (46CFR Ch1 §35.20–1—Federal Register 2010). Thus, a reasoned basis exists for believing that vessel masters were aware of it.

The conservation area identified in the LNM was a 75 nm segment of the shipping lanes in the SBC established by the USCG as a TSS. The area covered 366 nm^2 including northbound and southbound lanes, the traffic separation zone, and one mile buffers outside the TSS. The bounded coordinates of the region, identified as the "Whale Advisory Zone (WAZ)," were to the northeast 34°5.9′N 119°15.4′W, southeast 34°0.4′N 119°18.8′W, southwest 34°16.4′N 120°28.3′W, and northwest 34°22.3′N 120°28.3′W (Figure 2).

Beginning in late September 2007 and continuing in subsequent years, each year's LNM notice broadcast period began with messages requesting mariners exercise caution, but offering no specific speed recommendation, when transiting the WAZ within the SBC. The boundaries of the WAZ, as well as the specific language of the LNM, were determined in the course of a multi-sector negotiation of the regional response to the whale fatalities of 2007 (CINMS 2009). The negotiation of WAZ boundaries was informed by observed whale distributions (Berman-Kowalewski et al. 2010). As each season progressed, LNM messages were changed to include a specific speed recommendation of 10 knots or less in response to interests and needs expressed by the parties to the voluntary agreement process. Ocean resource managers working with representatives of the shipping industry and local stakeholders determined 10 knots as an appropriate speed based on its use in a 2008 rule limiting vessel speed to protect North Atlantic right whales from ship collision risks along the east coast (Silber and Bettridge 2012). During the first three years of operation LNM were broadcast from September 28 to November 7 in 2007, from June 25 to November 30 in 2008, and from June 15 to November 1 in 2009 (Figure 1).

The dimensions and locations of the WAZ boundaries, as well as the timing and languages used in the LNM were negotiated in a forum provided by the Channel Islands National Marine Sanctuary Advisory Council. The parties to the negotiation included State, Tribal, and Federal agencies, representatives from the shipping industry and local and regional environmental advocacy groups. Industry representation was provided by the Marine Exchange of Southern California, secretariat of the Los Angeles/Long Beach Harbor Safety Committee, with occasional supplementation by representatives of individual shipping lines and trade advocacy groups. The Channel Islands National Marine Sanctuary Advisory Council maintains a historic record of this group's process (CINMS 2009).

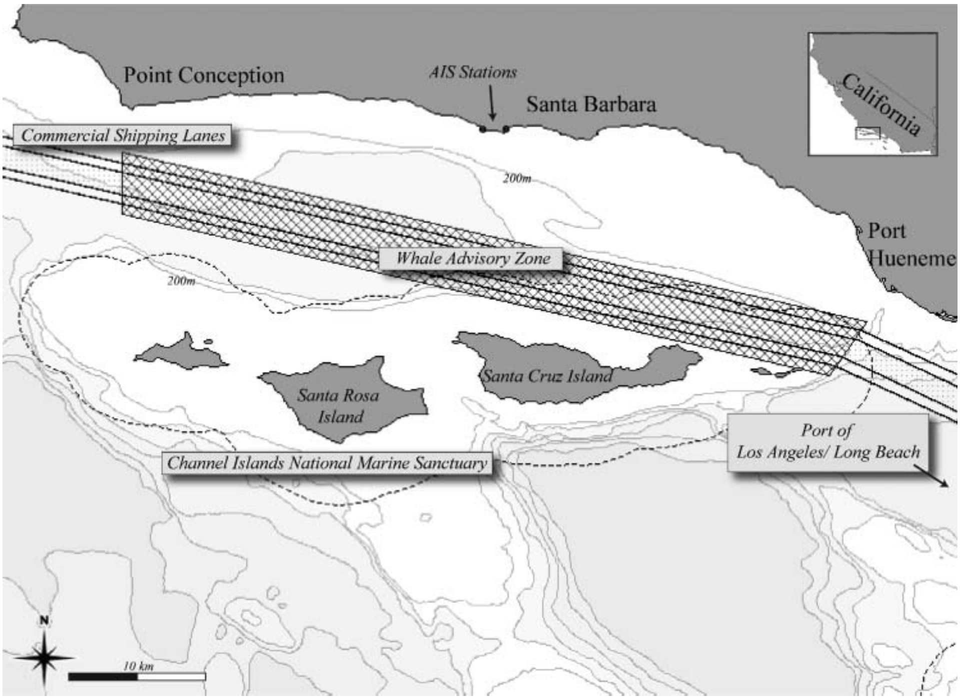

Figure 2. Map of the study region and targeted management area. Cross-hatched region designates the WAZ. The solid black lines denote the north and southbound commercial shipping lanes with a shaded separation zone. The dashed black line represents the boundaries of the Channel Islands National Marine Sanctuary. The AIS shore stations, represented as the black dots, were located on the campus of UCSB, and at Coal Oil Point (COP), west of Santa Barbara.

Automatic Identification System Data

Vessel traffic within the management area was monitored using AIS. The system was designed to enhance ship-to-shore and ship-to-ship communication for ships greater than 300 gross tonnage (GT) (Tetreault 2005). AIS transponders transmit very high-frequency (VHF) radio signals containing dynamic ship information (e.g., speed over ground, latitude, longitude) up to twice per second when the vessel is in transit. Static information (e.g., vessel name, ship type, dimensions, and destination) transmits every six minutes when the vessel is in transit. The transmitted signals were received at a shore station located on the University of California, Santa Barbara campus (UCSB; 34°24.7′N 119°50.5′W) from August 23, 2007 until September 15, 2008. After September 15, 2008, AIS transmissions were collected at an AIS receiving station located at Coal Oil Point (COP; 34°24.5′N 119°52.7′W). The change to COP site did not change the spatial coverage of the region analyzed in this study, but had improved remote communication for data management.

Spatial coverage of AIS is similar to other VHF applications and depends on the range to the horizon from the position of the receiving VHF antenna in addition to atmospheric conditions (Eriksen et al. 2006). A typical range for our AIS station was 73 nm and maximum ranges from the WAZ to our shore stations were 37 nm to COP and 36 nm UCSB. The received AIS signals were decoded using *ShipPlotter* (ver. 12.4.6.5) and archived as daily logs of all AIS transmissions. A Coordinated Universal Timestamp was added to the received signal at the shore station. AIS data were downloaded remotely and imported into a *PostgreSQL* (ver. 8.4, 2009) database. We designed spatially explicit queries to extract information on individual ship speeds within the WAZ.

Spatial Analysis of Ship Traffic and Speed

Ship traffic patterns were spatially analyzed to evaluate the likelihood of ships being in the WAZ during the LNM. A 0.5 mile by 0.5 mile grid was generated and for each LNM period, the number of unique ships within each grid cell was summed for each LNM period in 2007, 2008, and 2009. In addition, average ship speed per grid cell was calculated by averaging the mean speed of each unique ship within a given cell.

Daily Average Ship Speed

Daily average speed (DAS) for tankers and container ships transiting within the WAZ was treated as the unit of comparison, or statistical sample of the population of ships, to test for changes in ship speeds. Tankers and container ships are not only the most frequent ship types transiting this region but also the largest; therefore these ships present the highest risk to whales inhabiting the region. The AIS data required processing to appropriately treat each ship's contribution to the sample. For example, each ship's transit through the WAZ was treated as independent. Although individual ships may transit more than once, the WAZ was a small portion of a larger transit and there was no rational basis for discounting specific transits by individual ships.

The number of AIS positions transmitted by a given ship within the WAZ will vary, depending on the speed of the ship and signal transmission conditions; a ship traveling at 14 knots over a 63 nm region would transmit AIS information approximately 536 times; compared to 326 times if a ship was traveling at 23 knots. On the one hand, these transmissions are highly auto correlated and it would be statistically inappropriate to treat them as independent. On the other hand, it is possible ships change speeds over the course of a 75 nm transit. Therefore, we calculated a "distance-weighted" average speed for each ship's transit through the WAZ. This was estimated by first determining the total distance traveled by the ship as the sum of distances between each AIS point. The speed between each AIS point was then multiplied by the fraction of the total distance traveled and then summed to produce an average speed weighted by the speed contribution of each distance segment. Both the average speed reported by AIS and the distance-weighted average speed were estimated for each ship. Ships were eliminated from the analysis if less than two AIS points were recorded. The DAS was then calculated by averaging all unique distance-weighted average ship speeds for a given ship-type on a given day.

To test for statistical differences in DAS, general linear models (GLM) were performed in *R* (ver.2.7.1, 2008). The GLM provided a statistical tool for testing our hypothesis that DAS varied among the nine time periods, and an estimate of the regression estimator for the change in speed with time. The nine time periods were defined as pre-LNM, within-LNM, and post-LNM in 2007, 2008, and 2009. "Time" served as the continuous independent variable and the "time period" represented the categorical level. An effect of the LNM was evaluated as a significant time-level interaction term and results were deemed significant when $p < .05$. There were a number of possible predictors of DAS and interactions among them; the best performing GLM's were selected using Akaike's Information Criteria (AIC) with the lowest AIC deemed the best performing statistical model of the data (Burnham and Anderson 2002).

In addition to the GLM, we performed a simple *t*-test to determine if the DAS during the notices differed from the recommended 10 knots. Because some of the notices included a non-specific speed reduction recommendation, we also asked the question: Did ship speeds change during LNM relative to speeds in the preceding period? To compare the daily ship speed averages before the notices to speeds during the broadcast of the notices we performed a *t*-test in *MATLAB* (ver. 2011b). Multiple *t*-tests required that we perform a Bonferroni correction and adjust the level of significance for individual tests to $p < .004$.

Change in Individual Ship Speeds

We identified cargo and tanker ships that transited the management region during all defined time periods (before, during, after) in a given year. This provided a sub-set of ship transits to examine individual behavior by operators who should have been most familiar with the LNM messages and collision risks. These ship transits were analyzed to determine if their speeds during the notice were at or below the 10 knot recommended speed limit. In addition, ships that transited the WAZ at slower speeds during the LNM, compared to pre- and post-periods were identified and statistically compared using an ANOVA performed in *MATLAB* (ver. 2011b).

Results

During our study period, a total of 10,132 unique cargo and tanker transits occurred in the management region, WAZ (Table 1). Spatial coverage within the WAZ was adequate for all LNM periods; however, outside the WAZ both west SBC and south of the islands had more complete coverage in 2008 and 2009, after data from the second AIS station became available. The spatial gaps outside the WAZ did not impact the results of this study; however, when interpreting Figures 3 and 4 it is important to note that in 2007 the AIS receiver position resulted in some regions being shadowed from VHF signals.

The majority of ship transits of the WAZ were by cargo vessels (93%), which were observed transiting the region all days of the analysis. In 2007 and 2008 most cargo ships (89% and 79%, respectively) traveled within the designated TSS (Figure 3a–b). During the 2009 LNM, only 54% of the cargo ships traveled through the TSS and cargo ship traffic south of the islands increased (Figure 3c) resulting in a sharp decrease in the number of cargo ships transiting the WAZ beginning in mid-2009 period (Table 1). This occurred coincident with a new state air quality improvement rule implemented by the California Air Resources Board (CARB) and apparently displaced ships further off shore beyond the State's regulator air emission zone (CARB 2011; McKenna et al. 2012). Some cargo ships also transited inshore of the TTS in all three years; these vessels tended to be smaller ships servicing offshore oil platforms that are distributed through the SBC.

In a spatial comparison of all regional tanker traffic, about 50% of all tankers transited within the WAZ in 2007 and 2008, with a decrease to 32% in 2009 (Figure 3d–e). The reason some tankers transited south of the islands instead of through the SBC (i.e., WAZ) relates to regulations what tankers are allowed to carry within the SBC. Within the WAZ, tanker ships were present on 56% of the days and on the days tankers were present traffic remained fairly constant in the WAZ with an average of 1.5 ships per day (Table 1).

Relevant spatial and temporal patterns also emerge with regard to ship speeds. In particular, ships traveled slower as they approached and left the port of Los Angeles/Long Beach (Figure 4). In 2009 vessels in the southbound lane of the TSS within the SBC (i.e.,

Table 1
Summary of vessel transits and speeds in the management area

				CARGO					TANKER				
		Start Date	*End Date*	*No. days*	*No. unique transits*	$\bar{x}$ *speed* ($m\ s^{-1}$)	*SD speed*	$\bar{x}$ *ships* d^{-1}	*No. Days*	*No. unique transits*	$\bar{x}$ *speed* ($m\ s^{-1}$)	*SD speed*	$\bar{x}$ *ships* d^{-1}
2007	Pre	23-Aug	27-Sep	36	509	10.1	0.6	14.1	32	52	7.4	0.7	1.6
	LNM	28-Sep	07-Nov	41	571	9.9	0.5	13.9	34	53	7.1	0.7	1.6
	Post	08-Nov	18-Dec	41	510	10.0	0.6	12.4	23	27	7.4	0.7	1.2
2008	Pre	17-Jan	24-Jun	160	1,984	9.9	0.6	12.4	89	131	6.8	1.1	1.5
	LNM	25-Jun	30-Nov	159	2,024	9.8	0.7	12.7	92	140	7.2	0.9	1.5
	Post	01-Dec	05/08/2009	159	1,931	9.6	0.6	12.1	107	183	7.0	0.8	1.7
2009	Pre	09-May	14-Jun	37	448	9.7	0.5	12.1	22	32	7.1	0.6	1.5
	LNM	15-Jun	01-Nov	138	874	8.8	1.0	6.3	61	86	7.2	0.7	1.4
	Post	02-Nov	31-Dec	59	220	8.4	1.1	3.7	11	11	6.4	1.2	1.0

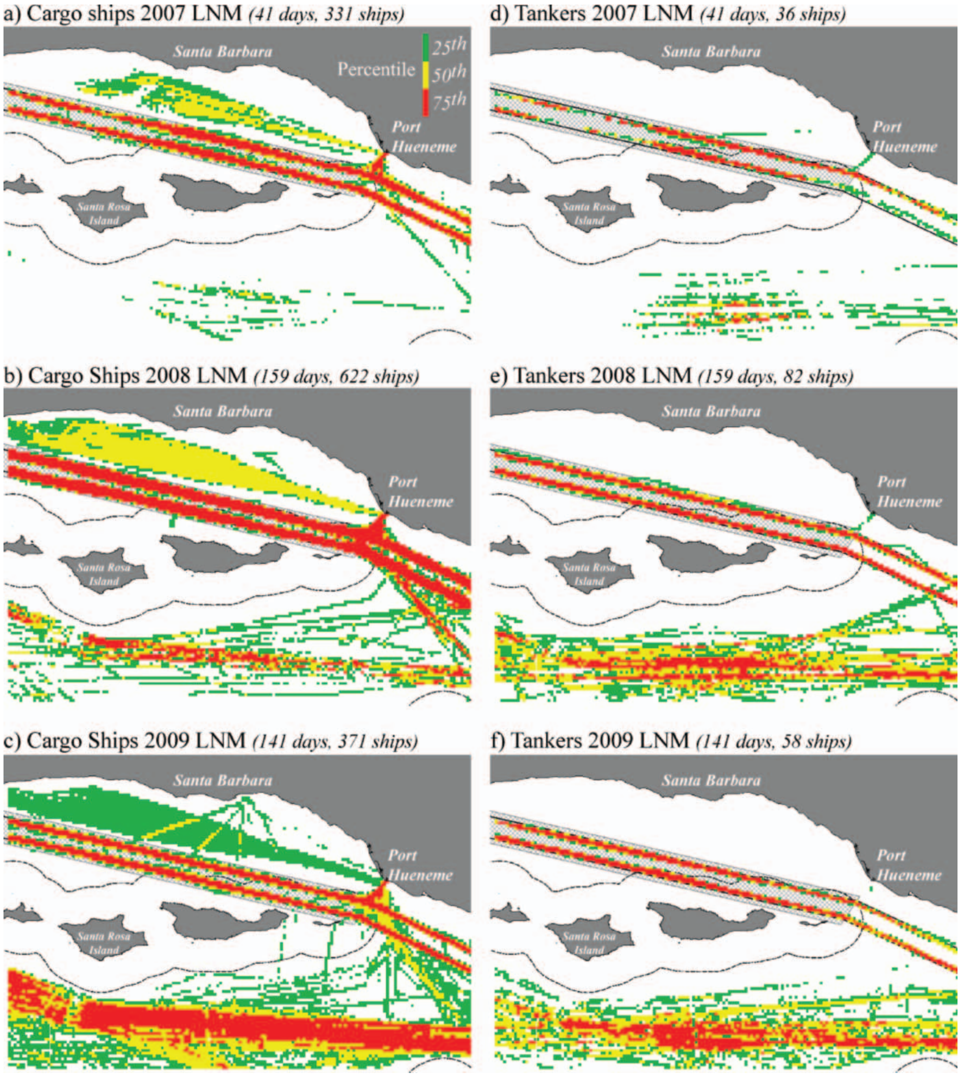

Figure 3. Spatial distribution of ship traffic in the region during the LNM: (a–c) Cargo traffic in 2007, 2008, and 2009, (d–f) Tanker traffic in 2007, 2008, and 2009. Ship density was calculated as the number of unique ships in each 0.5 mile grid cell over the given time period. The WAZ is shown as the gray shaded area. The number of days corresponds to the days during the notice and the number of ships corresponds to unique ships in the WAZ (color figure available online).

heading to port) also averaged slower speeds than in previous years and at speeds slower than those transiting south of the islands.

Change in Daily Average Speed Related to the LNM

We began this analysis by examining DAS within each of the three advisory seasons during the periods when LNM contained no specific speed recommendation and when they

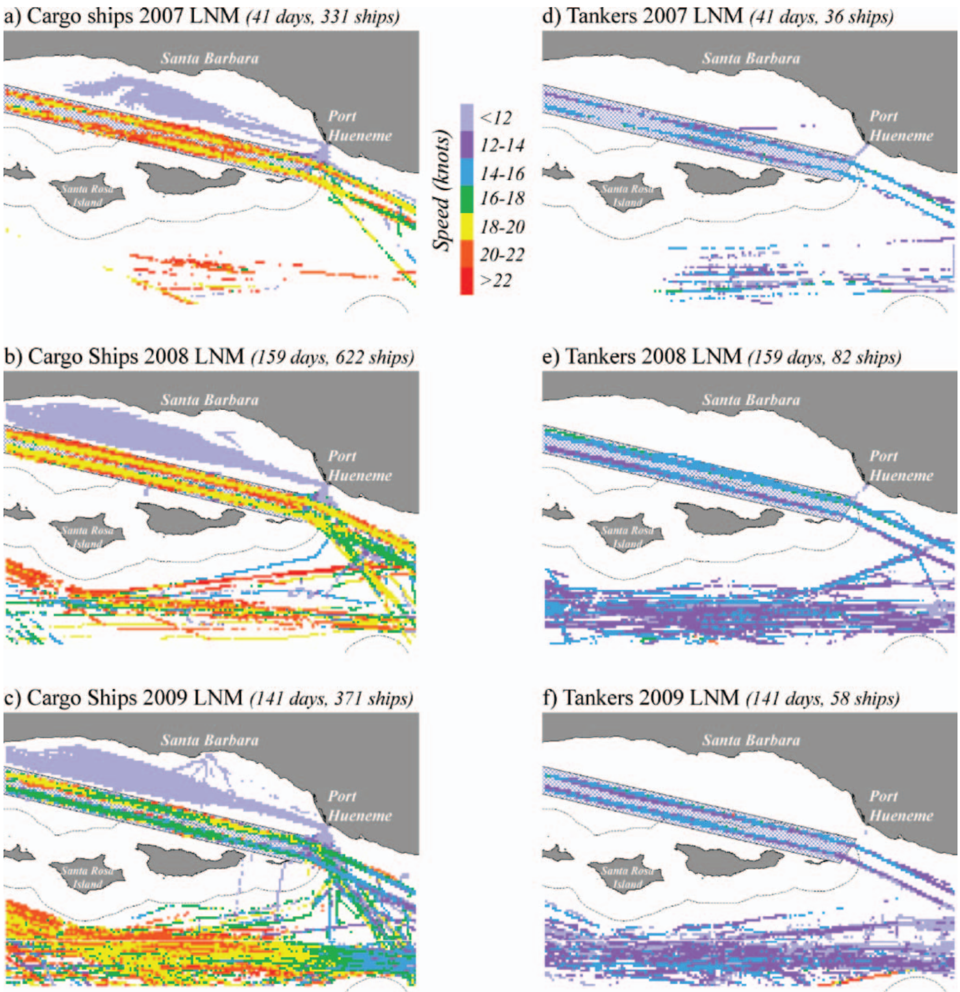

Figure 4. Spatial representation of average ship speed in the region during the LNM: (a–c) Cargo traffic in 2007, 2008, and 2009, (d–f) Tanker traffic in 2007, 2008, and 2009. The WAZ is shown as the gray shaded area. The number of days corresponds to the days during the notice and the number of ships corresponds to unique ships in the WAZ (color figure available online).

contained the specific 10 knot or less recommendation (Figure 1). We found that there were no significant differences in average vessel speeds between the periods when the different messages were broadcast (Table 2). The only statistically significant difference was in 2009 when the speeds of cargo ships declined in mid-July shortly after the LNM was changed to recommend the 10 knot standard. This decrease, however, was coincident with the implementation of the new State air quality requirements for ships in July of that year, as discussed above, and potentially related to ship operators intentionally slowing ships to cut fuel costs (Notteboom and Vernimmen 2009). Based on these results, we decided to pool each year's advisory season data together rather than subdivided it according to periods when slightly different LNM messages were broadcast.

Table 2
Summary of statistical results for daily average ship speeds

I. Is there a difference between LNM slow down period and LNM 10 knot period (t-test)

Cargo			Tanker		
year	*t-stat*	*pval*	*year*	*t-stat*	*Pval*
2007	0.11	0.916	2007	–0.03	0.98
2008	1.66	0.101	2008	–0.98	0.33
2009	7.11	< 0.001*	2009	–0.60	0.55

II. Did ships travel below 10 knots during the LNM periods? (t-Test)

Cargo				Tanker			
year	*t-stat*	*pval*	*SD*	*year*	*t-stat*	*pval*	*SD*
2007	63.70	< 0.001*	0.48	2007	16.81	< 0.001*	0.67
2008	87.60	< 0.001*	0.67	2008	20.19	< 0.001*	0.93
2009	43.16	< 0.001*	1.00	2009	23.05	< 0.001*	0.67

III. Was ship speed different before, during, after LNM? (Analysis of Variance)

Cargo

							Bonferroni post hoc test	
year	*ss*	*df*	μ^2	*Fs*	*pval*	R^2	*before–during*	*during–after*
2007	0.59	2	0.30	0.94	0.392	0.02	0.590	0.930
2008	4.51	2	2.26	5.80	0.003*	0.02	1.000	0.021*
2009	36.20	2	18.09	19.29	< 0.001*	0.14	0.001*	0.022*

Tanker

							Bonferroni post hoc test	
year	*ss*	*df*	μ^2	*Fs*	*pval*	R^2	*before–during*	*during-after*
2007	1.55	2	0.78	1.71	0.188	0.04	0.280	0.500
2008	5.38	2	2.69	3.16	0.044*	0.02	0.040*	0.950
2009	5.72	2	2.86	5.38	0.006*	0.11	1.000	0.005*

IV. Did ship speed change relative to LNM and over time? (Generalize Linear Model: speed = time + (period * time))

Cargo

		LNM 2007			LNM 2008			LNM 2009		
term	*time*	*before*	*during*	*after*	*before*	*during*	*after*	*before*	*during*	*after*
pval	0.803	0.373	0.804	0.634	0.710	0.848	0.736	0.806	0.583	0.275

Tanker

		LNM 2007			LNM 2008			LNM 2009		
term	*time*	*before*	*during*	*after*	*before*	*during*	*after*	*before*	*during*	*after*
pval	0.167	0.167	0.331	0.171	0.302	0.153	0.148	0.175	0.165	0.032*

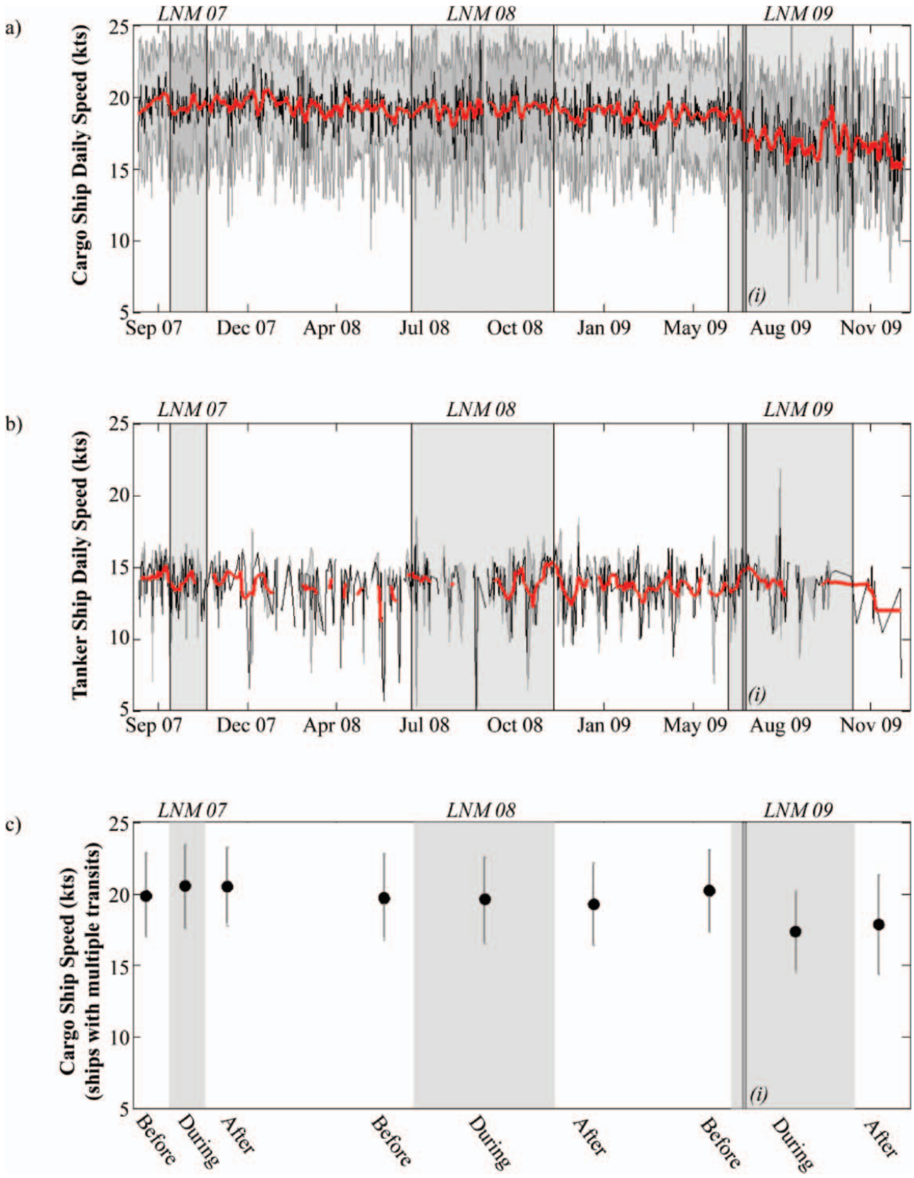

Figure 5. Daily average speed for (a) cargo and (b) tanker ships transiting the management area. Solid red lines are a 7-day running average. (c) Average cargo speeds for ships with multiple transits ($n = 395$). Data are binned into before, during and after the LNM, the LNM periods are shaded in gray. Gaps in tanker running average are an artifact of days without ship present in the SBC. (*i*) indicates the date the CARB rule when into effect, July 1, 2009 (color figure available online).

When we compared DAS through the WAZ before, during, and after the LNM advisory seasons, we found few statistically significant differences in the speeds of either cargo ships or tankers over the three-year study period (Table 2, Figure 5a–b). In all comparisons we found DAS speeds to be significantly different from a mean speed of 10 knots. In 2008 a slight reduction in the speed of cargo ships was recorded during the advisory season that was statistically significant, but then their average speed remained 8 to 10 knots faster than the recommended 10 knot standard. A more substantial decline that was also statistically significant was recorded for cargo ships in 2009; however, that occurred coincident with the new air quality requirements. A linear regression indicated that this declining speed trend related to the air-quality rule was significant for cargo ships ($F_s = 291.85$, $pval < 0.001$).

Tankers also showed little evidence of responding to the LNMs over the study period. Overall they maintained average speeds 3 to 5 knots higher than the 10-knot standard throughout both the advisory and non-advisory seasons (Figure 5b). In 2008, there was a slight increase in average tanker speed during the advisory season that was statistically significant. There was also a slight decline in tanker speeds during the 2009 advisory season that was again coincident with the new air quality requirements. However, the slowing trend for tankers after the air quality requirements went into effect were not significant ($F_s = .962$, $pval = 0.327$).

The non-significant DAS reductions during the LNM were further supported by the results of the GLM (Table 2). The best model selected (lowest AIC) for cargo ships included time-period interaction variable, but no terms were deemed significant. The best model selected (lowest AIC) for tanker ships only included the period term, but only the last period was significant, again coincident with the air quality improvement rule. Following the air quality improvement rule, the faster moving container ships (a type of cargo ship) traveled outside the WAZ leaving the slower vessels (bulk carriers, another type of cargo) within the WAZ. AIS does not distinguish between types of cargos, so we combined the AIS information with Lloyd's register of ships to distinguish the types of cargo ships (IHS Fairplay 2009). Thus, the reduction in DAS represents a change in population of ships, rather than a change in the behavior of individual ships.

Change in Individual Ship Speeds

A total of 405 individual ships ($n = 395$ cargos, $n = 10$ tankers), representing 23% of unique vessels over the three-year study period, had transits in the WAZ before, during, and after LNM in a given year. These included 132 in 2007, 241 in 2008, and only 32 in 2009 because of the shift in traffic mentioned in the previous section. In 2007, 36% of these ships traveled detectably slower during the LNM period compared to before and after, but only two of these ships traveled at significantly slower speeds ($pval = 0.001$, $pval = 0.010$), and none below 10 knots. In 2008, 24% of the ships traveled detectably slower during the LNM period compared to before and after, but only three ships showed a significant reduction ($pval = 0.019$, $pval = 0.028$, $pval = 0.041$); again with none below 10 knots. In 2009, 5% reduced their speeds during the LNM period, although none significantly, and none reduced their speed to 10 knots or less. Thus, for 405 individual repeating transit ships, 1% showed recognition of the speed reduction measure by significantly reducing their speed during the LNM period, and 0% fully adhered with the 10 knot recommendation.

The average speeds of the more frequent travelers (i.e., those ships that traveled through the channel before, during and after at least one of the LNMs and therefore most likely aware of the LNM) were averaged and then compared to the larger sample of ships (Figure 5c). As found with the larger sample, no reduction in speed related to the LNM periods was found for the frequent travelers.

Discussion

Our analysis of ship speed during the LNM suggests there was no change in average daily ship speeds related to the LNM periods, that few ships reduced their speeds significantly on an individual basis, and none fully cooperated with the voluntary conservation measure in any of the three years studied. This result comes despite the use of a voluntary conservation agreement (VCA) (Karamanos 2001).VCAs are voluntary agreements developed across industry or private sectors to improve environmental conditions (Karamanos 2001). In this case, the decision to issue the LNM rather than resort to regulatory action was reached through a series of public meetings and discussions involving relevant government agencies (USCG and NMFS), industry representatives, and nongovernmental, environmental agents (see http://channelislands.noaa.gov/sac/wgsub.html for historical record of agreement process).

Low compliance to a voluntary measure, as found in this study and previous studies (Wiley et al. 2008; Jett and Thapa 2010; Silber et al. 2012a), likely relate to factors such the cost advantage, or lack thereof, offered by voluntary agreements, the availability of assurances or incentives (Langpap and Wu 2004), and scales of the agreement (Cumming, Cumming, and Redman 2006). Economic costs associated with increased transit time likely exist. For example, slowing a cargo ship from an average of 19 to 10 knots for 75 nm (length of the WAZ), adds almost four hours to a ship's transit time. Although slower speeds may result in savings in per mile fuel consumption, other costs (e.g., added crew wages or ship rental fees or other costs that cannot be accounted for through proper voyage planning) may exceed fuel savings (Notteboom and Vernimmen 2009).

Although not a component of this conservation strategy, incentive programs can be employed to offset the indirect costs to the industry. Coincidentally, these same ships were managed by another voluntary conservation program, The Green Flag Program (http://www.polb.com/environment/air/vessels/green_flag.asp). Under this program, the Port of Long Beach created a voluntary speed reduction program in 2005, requesting vessels to travel at or below 12 knots within 40 nm of the entrance to the harbor to decrease harmful air emissions. Compliance with the measure has increased steadily, particularly since 2010 when the Port committed $2.5 million to reward vessel operators with lower dockage fees and recognition for participating in the program. Because this measure has resulted in high levels of vessel compliance, the program provides a reference point for the magnitudes of incentives recognized by the industry.

Another disincentive for adhering with voluntary measures may be a scale mismatch (Cumming, Cumming, and Redman 2006); in this case, a mismatch in the spatial scale of the management area (WAZ) and the spatial scale of the industrial activity. It is possible that the conservation benefits perceived by the local nongovernmental stakeholders and Federal agency authorities may not balance the economic benefits of a trans-global shipping company and their multinational market. Operators of ships transiting the WAZ must balance the operating costs and willingness to accept the risk of collision with a whale within the 75 nm WAZ against transits that may be as long as 5,500 nm from the Asian Far East. Furthermore, shipping company managers directing ship transits from offices in foreign countries might not receive or be aware of the LNM, although interestingly they were aware of the regulated zones for the air quality rule and Green Flag program. If the ship company managers fail to factor time for slowing down in the WAZ into their ship schedules, vessel masters could be pressured to avoid unplanned delays to respond to LNM. Whatever costs or incentives exist, vessel operators have intrinsic scales that may or may not match management initiatives on scales such as the WAZ in this study.

The consequences of scale mismatches between local-scale resource management on the one hand and large-scale commercial activity on the other include unmanaged outcomes (as seen in this study), management decisions that lack continuity and consistency, or even no viable solutions that satisfy parties to the VCA (Cumming, Cumming, and Redman 2006). Long-term solutions to scale mismatch problems depend on the development of flexible institutions that can adjust and reorganize in response to changes. In this case, effective conservation strategies for large whales in the presence of high density commercial shipping must address the scales at which the ships are making decisions and being managed.

Avoiding a recurrence of collision events similar to those in 2007 in the SBC likely will require a more comprehensive conservation plan that considers tradeoffs between conservation benefits and cost to the shipping industry. Alternative strategies in this regard may include vessel re-routing to avoid co-occurrence of ships with whales or mandatory speed reductions in regions of predictable whale habitat; although this strategy only works when alternative routes are both geographically feasible and incur minimal costs to the industry (Silber et al. 2012b). Recent assessments of regional vessel re-routing options, however, have identified conflicts with other users (i.e., military operations) as well as a potential for increasing ship-strike risk with blue whales and other endangered whales along alternative routes (Redfern et al. in review). Mandatory ship speed regulations are also possible and could increase compliance rates. Such rules were implemented by the NMFS in late 2008 to protect endangered North Atlantic right whales near port entrances along the U.S. east coast (Silber and Bettridge 2012). Studies to monitor the effectiveness of those rules have revealed that compliance with mandatory speed reduction measures was low at first, but improved significantly within a few years (Silber and Bettridge 2012). In the case of the North Atlantic right whale, mandatory management actions were only undertaken after voluntary actions proved unsuccessful over the 1990s (see CINMS 2009 for a more complete case study of the North Atlantic right whale case). It is possible that lack of immediate response on the part of the industry to mandatory actions following a protracted period of voluntary actions may have resulted in some ambiguity as to the binding nature of the mandatory actions. If low rates of adherence continue in the presence of voluntary agreements, regulatory measures are one option that could be reconsidered, but if deployed would likely benefit from clear messaging in outreach to the affected industries.

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