NOAA Ocean Noise Strategy Implementation Case Studies

INTRODUCTION

Fulfilling NOAA's role as an ocean steward will require the agency to effectively manage a range of ocean noise effects. Chapters 1-3 of the NOAA Ocean Noise Strategy Roadmap present recommendations to guide the agency's management and science actions towards understanding and managing noise impacts to (1) protected, endangered and commercially managed species and (2) acoustic habitats for sound-sensitive and sound-producing marine life and (3) the development of enhanced NOAA capacity to characterize marine soundscapes of concern. Risk assessment provides a scientific framework for integrating information regarding the impacts of noise on high priority, acoustically sensitive and active marine animals and their habitats. As such, it is a decision support tool that aids effective management.

Risk assessment is part of an iterative process containing five components when used to make management decisions:

1) Formulate the problem
2) Assess risk
3) Evaluate potential management actions
4) Implement selected management actions
5) Monitor the effects of management actions

Problem formulation seeks to identify sources of risk, species that may be impacted, timing and location of impacts, and mandates for managing risk. Stakeholder participation in formulating the problem can increase the success of management actions.

Risk assessment requires spatially explicit characterizations of human activities, management jurisdictions, species distributions, methods for estimating the co-occurrence of these factors, metrics for estimating the consequences of co-occurrence, and explicit consideration of sources of uncertainty (Hope 2006). The framework for assessing risk from ocean noise described below synthesizes frameworks suggested in Ellison et al. (2012), Moore et al. (2012), Thompson et al. (2013) and Francis and Barber (2013). A spatially explicit characterization of the soundscape (Chapter 3) is required to assess the risk of ocean noise to marine species. Spatially explicit characterizations of species distributions may range from densities predicted by habitat models to formal critical or essential habitat to boundaries of biologically important areas based on expert opinion (Chapter 1, Appendix B). Places to be protected for their holistic value, including their acoustic quality, include marine protected areas such as National Parks and National Marine Sanctuaries (Chapter 2). The types of representations that are available to depict species distributions and soundscape variables, as well as the types of management jurisdictions that are available to support implementation of evaluated management options, will determine the methodologies that are applied to assess risk.

Soundscape and species distributions can be integrated to estimate co-occurrence using selected frequencies referencing presumed or known hearing sensitivity or audiogram weighting (Erbe et al., 2014) across a range of frequencies. To date, most attention has focused on short-term consequences of the co-occurrence between marine mammals and single, high-intensity noise sources. Dose-response relationships can be used to assess the likelihood of mortality and injury (including hearing loss) from loud noise (Ellison et al., 2012) or behavioral disruption from a single noise source (Moretti et al., 2014).

However, the effects of chronic noise, multiple noise sources, and the context in which noise is experienced (e.g., the activity state of an animal and the spatial relationship between the noise source and an animal; Ellison et al., 2012) must also be considered. Estimates of the loss of acoustic communication space can be a valuable tool for assessing risk caused by chronic noise (Hatch et al., 2012). Risk can be also be defined as the number of individuals estimated to be impacted by noise. Alternatively, areas of elevated risk may be identified where noise overlaps with high species densities (Erbe et al., 2014), biologically important areas or protected areas. Risk to populations can be derived by linking individual impacts to vital rates (Thompson et al., 2013).

Uncertainty occurs in each stage of risk assessment. Uncertainty caused by lack of knowledge can be addressed through further data collection and analysis, while uncertainty caused by stochastic variability cannot (Hope 2006). To correctly interpret the results of a risk assessment and use the results to evaluate potential management actions, all sources of uncertainty must be clearly identified. Documenting the assumptions used in the assessment and data availability and quality are powerful tools for identifying sources of uncertainty (Thompson et al., 2013). Sensitivity analysis can also be used to understand the relative importance of assumptions and data gaps. Explicitly identifying uncertainty helps managers understand the degree of confidence they can place in the risk assessment and helps to prioritize future data collection efforts (Hope 2006).

Risk assessments can be used to evaluate potential management actions, such as the removal or modification of a noise source (e.g., sonar or shipping lanes) or avoiding species habitat. Barlow and Gisner (2006) provide a good discussion of the challenges in applying these management actions to activities that may impact beaked whales. When selected management actions are implemented, monitoring may be required, such as visual or acoustic surveys conducted prior to, during, and after specific events (e.g., use of military sonar or seismic exploration) or changes to a noise source. It is important to design these monitoring efforts to address identified data gaps as much as possible. The location and timing of activities, as well as potential long-term changes in noise associated with the activities (e.g., increases in shipping traffic resulting from vessels servicing offshore energy developments), should also be documented to improve soundscape characterizations and our understanding of acoustic habitat. The results of these efforts should be incorporated in the risk assessment to reduce uncertainty, update evaluations of potential management actions, and inform selection of future management actions.

Using the proposed risk assessment framework can assist NOAA in identifying areas that require noise management and the degree to which current (e.g., Marine Mammal Protection Act, Endangered Species Act and National Marine Sanctuaries Act) and latent (e.g., Magnuson Stevens Act) tools are sufficient to achieve successful noise impact management. It can also assist NOAA in identifying data gaps and prioritizing the allocation of resources to address those gaps. Application of the risk assessment framework is explored here in two case studies that are used to explore methodologies that can be used with different types of data and potential application of NOAA mandates to address noise.

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Case Study 1:
Assessing the Risk of Chronic Noise from Commercial Ships to Large Whale Acoustic Habitat[6]

Introduction

Ocean noise produced by human activities has significantly increased since the beginning of the industrial era and is likely to continue to increase and expand its footprint. For example, noise measurements made during the 1960s and in the 1990s off Point Sur (central California, Figure 4-1) and through the early 2000s west of San Nicolas Island (southern California, Figure 4-1) show approximately 10dB increases, representing nearly a doubling in acoustic power at low frequencies every decade (e.g., 20-80Hertz; Andrew et al., 2002, McDonald et al., 2006). Southern California waters host a diverse stakeholder community, including the military, oil and gas companies, shipping, fishing, research, and ecotourism (Crowder et al., 2006). Some stakeholders produce noise that is infrequent, but is high intensity when it occurs (e.g., seismic surveying associated with fault line research). Other stakeholders produce high intensity noise more frequently because of their long-term presence in the region (e.g., low- and mid-frequency sonar used in military training exercises). However, the increase in chronic, background noise in this region has been predominantly caused by increases in commercial shipping (McDonald et al., 2006), including both increases in the number of ships and increases in their gross tonnage and horsepower.

A large component of the underwater noise generated by commercial ships comes from propeller cavitation, which is known to peak at 50–200 Hertz (Hz) (Ross 1976). This noise occurs in frequencies used by baleen whales for communication and behavioral responses to shipping noise have been documented for several species. For example, the probability of blue whale (*Balaenoptera musculus*) D calls was found to increase with increasing shipping noise (Melcón et al., 2012). This increase may be a vocal response by individuals to overcome increased noise or it may be the result of an increased number of callers during periods of higher shipping noise (Melcón et al., 2012). McDonald et al. (2009) suggest that changes in blue whale tonal frequencies may be related to changes in population density, modified by increasing shipping noise, and trade-offs between long and short distance communication. Fin whales (*B. physalus*) have also been documented to change their song characteristics under increased shipping noise (Castellote et al., 2012). Finally, Sousa-Lima and Clark (2008) found a negative relationship between the number of humpback whale (*Megaptera novaeangliae*) singers and noise from whale watching vessels on a breeding ground. While studies have not been conducted on feeding grounds, humpback whales are known to sing on feeding grounds (Clark & Clapham 2004).

Southern California waters include seasonal feeding populations of blue and humpback whales (Calambokidis & Barlow 2004, Calambokidis et al., 2009) and year-round aggregations of fin whales (Forney et al., 1995). These waters also contain Biologically Important Areas (BIAs) for blue and humpback whales, which represent areas of high concentrations of feeding animals (Calambokidis et al., 2015). Fin whale BIAs have not yet been identified (see Calambokidis et al., 2015 for a discussion of the difficulties associated with identifying fin whale BIAs). All three species are currently listed as Endangered under the Endangered Species Act (ESA 1973) and as Depleted and Strategic in the Marine Mammal Protection Act (MMPA 1972). Although populations of fin and humpback whales along the California coast have been increasing since at least 1991 (Calambokidis & Barlow 2004, Moore & Barlow 2011) and Monnahan et al. (2014) suggest that blue whales may have reached carrying capacity, these species still face threats from ship strikes, fisheries entanglements, and anthropogenic noise. Increases

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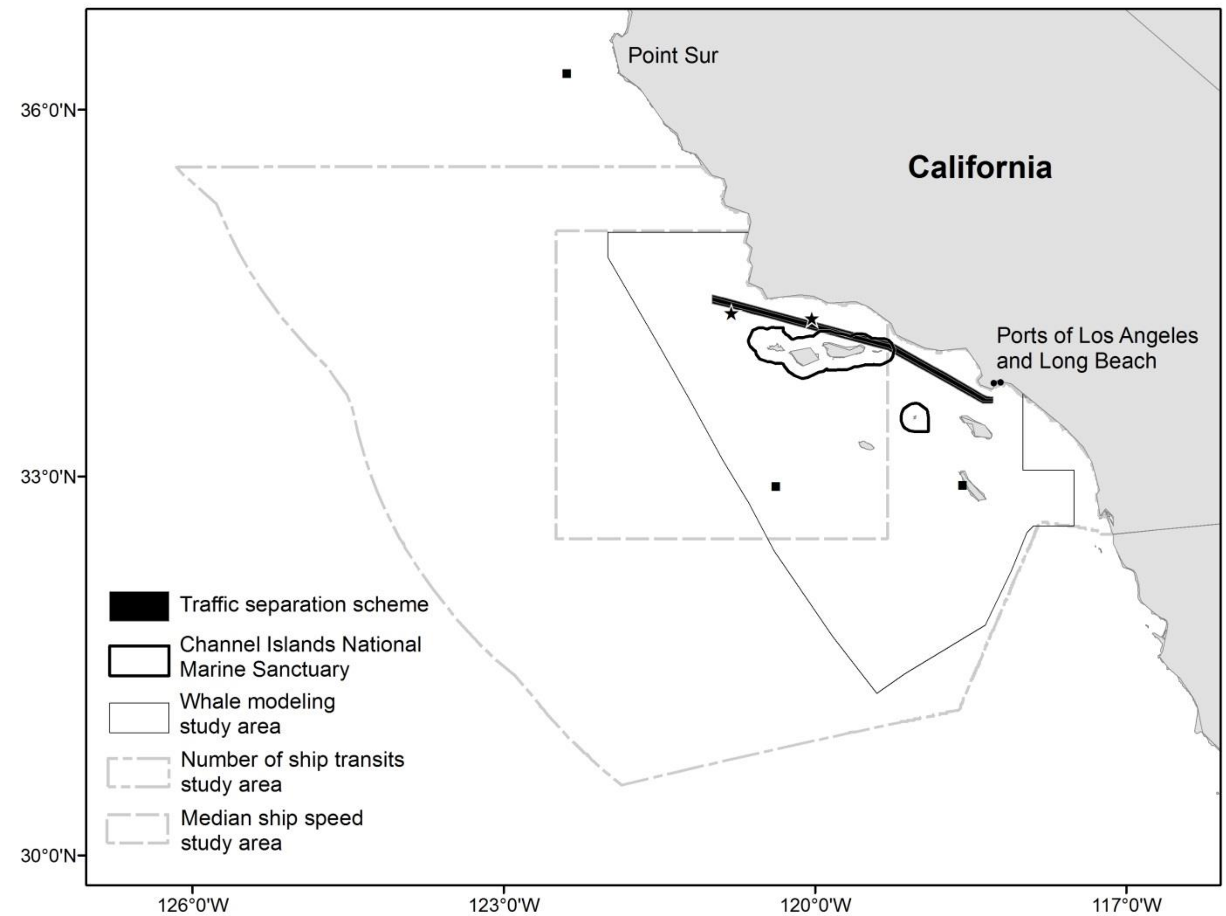
in low frequency noise in this region have occurred within the lifetimes of these long-lived animals. This noise has the potential to mask a variety of acoustic signals, including sharing information among individuals, cues predicting prey availability (e.g., motion in water column, features associated with upwelling), and predator avoidance (e.g., the presence of killer whales).

Figure 4-1. Waters off the southwestern United States are shown, including the Channel Islands National Marine Sanctuary, a Traffic Separation Scheme adopted by the International Maritime Organization, and three study areas used in our analyses: the whale modeling, number of ship transits, and median ship speed study areas (see text for details). The two largest ports (Los Angeles and Long Beach) are shown as black circles. The locations of the HARPs are shown as black stars and locations associated with historic noise monitoring referenced in this study (i.e., off Point Sur, west of San Nicolas Island, and off San Clemente Island) are shown as black squares.



Current U.S. regulation of noise under the Endangered Species Act and Marine Mammal Protection Act does not include impacts associated with chronic noise from shipping. Consequently, the possibility of place-based regulation has been explored. The Channel Islands National Marine Sanctuary (CINMS) is located within these waters (Figure 4-1) and was established to protect the rich community of marine life, including blue, fin, and humpback whales. It was among the first areas identified in national and international discussions of management techniques to reduce chronic underwater noise impacts because the Ports of Los Angeles and Long Beach (Figure 4-1) are ranked among the nation's largest for both the number of port calls and cargo capacity (MARAD 2014). An evaluation of noise impacts in the CINMS was completed in partnership with the Office of National Marine Sanctuaries (Polefka 2004) and was followed by a formal presentation of CINMS as a policy case study to examine methods for reducing shipping noise impacts (Haren 2007). Haren concluded that pursuit of sanctuary authority to regulate noise would face significant jurisdictional obstacles and would not address the influence of shipping noise beyond the boundary of the CINMS. However, the National Marine Sanctuary Act's provision for federal agency consultation (16 U.S.C. 1434, sec. 304 (d)) can be used to recommend methods to reduce or eliminate noise created by federally-authorized activities. Haren also noted that it is possible for the U.S. to request that the International Maritime Organization (IMO) designate the CINMS and surrounding areas as a Particularly Sensitive Sea Area (PSSA) and require ships to operate in a manner that reduces noise (e.g., travel at slower speeds or use alternative shipping routes). However, these operating conditions are difficult to specify without a better understanding of the risk of noise to marine species in the region.

The need to understand noise risk is particularly important in this region because shipping traffic is dynamic. A decrease in the number of ship transits off southern California was observed as a result of the "great recession" that occurred between December 2007 and June 2009 (McKenna et al., 2012a). Traffic patterns also changed when the California Air Resources Board implemented the Ocean-Going Vessel Fuel Rule (hereafter, fuel rule) in July 2009. The fuel rule was intended to reduce air pollution by requiring large, commercial ships to use cleaner-burning fuels when traveling within 24 nautical miles of the mainland coast (Soriano et al., 2008). A majority of ships traveled through the Santa Barbara Channel in the traffic separation scheme (TSS) adopted by the IMO before implementation of the rule. Following implementation, a higher proportion of ships began traveling south of the northern Channel Islands to reduce the time spent using more expensive, cleaner fuels (McKenna et al., 2012a). Shipping traffic in this region is expected to continue to change as fuel costs vary and new regulations take effect (for example, the IMO adopted and the U.S. Environmental Protection Agency codified the North American Emission Control Area recently, which requires the use of lower sulfur-content fuel).

Assessing the risk of noise requires spatial representation of underwater noise generated by human activity and species' habitat. Noise levels and species' habitat can be integrated to estimate co-occurrence using selected frequencies or audiogram weighting (Erbe et al., 2014) across a range of frequencies. Dose-response relationships can be used to assess the likelihood of mortality and injury (including hearing loss) from loud noise (Ellison et al., 2012) or behavioral disruption from a single noise source (Moretti et al., 2014). However, the effects of chronic noise, multiple noise sources (Moore et al., 2012), and the context in which noise is experienced (e.g., the activity state of an animal and the spatial relationship between the noise source and an animal; Ellison et al., 2012) must also be considered. Estimates of the loss of acoustic communication space can be a valuable tool for assessing risk caused by chronic noise (Hatch et al., 2012). Risk can also be defined as the number of individuals estimated to be impacted by noise. Risk to populations can be derived by linking individual impacts to vital rates (Thompson et al., 2013). Finally, risk can be scaled up to communities and ecosystems by understanding population responses among multiple species and interactions among these species (Francis & Barber 2013).

We conducted a spatially explicit assessment of the risk of noise from commercial shipping to blue, fin, and humpback whale acoustic habitats in Southern California waters. Specifically, 50 and 100Hz noise was modeled using shipping traffic patterns derived from Automatic Identification System (AIS) data. Predicted noise was compared to noise measurements at two sites within the study area. Whale habitat was defined using three sources of distribution data that capture different habitat elements. Risk is defined as the co-occurrence of 50Hz noise percentiles and blue and fin whale habitat and the co-occurrence of 100Hz noise percentiles and humpback whale habitat. The noise and risk characterizations allow managers and stakeholders to identify areas where chronic noise may impact the acoustic habitat of these three species and provides an opportunity to re-examine noise management options in Southern California waters.

Methods

Characterization of noise from commercial shipping

The noise modeling approach that we used is described in Porter and Henderson (2013) and is briefly reviewed here. Noise modeling requires environmental information, such as bathymetry, bottom type, and sound speed. These data are used to calculate transmission loss for noise sources distributed on a grid of the study area. Noise level is then calculated by convolving the transmission loss with source level densities estimated for specific activities (e.g., shipping, pile driving, or sonar). This two-stage approach provides a mechanism for quickly updating noise predictions to reflect changes in source level densities.

Our model used depth from the SRTM30_PLUS data set (http://topex.ucsd.edu/WWW_html /srtm30_plus.html; Smith & Sandwell 1997, Becker et al., 2009). The seafloor bottom was categorized using sediment thickness (http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html; Divins 2003) and seabed properties from Pacific States Marine Fisheries Commission (http://marinehabitat.psmfc.org /physical-habitat.html). These data sources only differentiate between “hard” and “soft” bottom types. We used Bottom Sediment Type (Anonymous 2003) to define hard as cobbles to very coarse pebbles (phi = -6) and soft as fine silt (phi = 7.9). Basalt lies below the depth of the sediments as given by the NOAA sediment-thickness database. Sound speed was calculated by averaging “summer” and “fall” temperature and salinity climatologies from the World Ocean Atlas (Levitus et al., 2013). Finally, the scattering loss of sound due to sea surface roughness was incorporated in the model using significant wave height for a 10-knot wind speed (e.g., H. Zhang at ftp://eclipse.ncdc.noaa.gov/pub/seawinds/SI/uv /monthly/ieee).

The source level densities used in our model were obtained from measurements of shipping traffic. Specifically, we used AIS data collected between August and November in 2009 to calculate the number of ship transits in approximately 1km x 1km grid cells. The low-frequency noise produced by ships has the potential to propagate long distances. Consequently, the number of ship transits was calculated in an area larger than the whale modeling study area (Figure 4-1) to ensure the model included noise from as many ships affecting the study area as possible. AIS data were downloaded from NOAA Fisheries’ Coastal Services Center’s Marine Cadastre website (www.marinecadastre.gov). We only used data that had valid Maritime Mobile Service Identity (MMSI) values (201000000 and 775999999), speed over ground > 0 knots, and a navigational status of under way using engine, restricted maneuverability, under-way sailing, or undefined. The AIS data points were joined in chronological order to form a line if both points had the same MMSI and the elapsed time between points was less than one hour. If the elapsed time was greater than one hour and less than six hours, points that had less than a 30° change in heading were joined. If two successive points failed to meet these criteria, the current line ended and another was started. The total number of transits in each grid cell was calculated using the Line Statistics Tool in ArcGIS (Environmental Systems Research Institute 2014. ArcGIS Desktop: Release 10.2.2. Redlands, CA) for four length-based ship categories: (1) ≥ 18m and ≤ 120m; (2) > 120m and ≤ 200m; (3) > 200m and ≤ 320m and (4) > 320m. A search radius of approximately 0.5642km was used in the calculations because the area of the resulting circle is the same as the area of the grid cells.

The number of ship transits per cell was converted to source level densities using the source levels in Carey and Evans (2011) for the four length-based ship categories. The source levels in Carey & Evans (2011) are based on a worldwide shipping noise model known as the Ambient Noise Directionality Estimation System (ANDES), which references vessels active during the 1970s and 1980s. As reported in Carey and Evans, source levels vary from 130dB for the smallest length category ("small tanker", 18-120m) and highest frequency (400Hz) to 180dB for the largest length category ("super tanker", >320m) and lowest frequency (50Hz). Ships in all four categories were modeled using a propeller depth of 6m. The source level densities (dB re 1μPa^2 / Hz at 1 meter) are reported by frequency in 1-Hz bands.

Noise levels produced by ships are influenced by ship size and speed (McKenna et al., 2013). We modeled noise associated with four ship length categories that provide estimates appropriate to the purpose of large-scale and long-term noise predictions. However, variability among individual ships within a category was not incorporated in the noise model. The average speed for each length category was estimated to determine within-cell residency times for each transit and the associated accumulation of source levels. We obtained ship speeds from point-based AIS data collected by the U.S. Coast Guard between August and November in 2009 (accurate speed data cannot be obtained from the 2009 Marine Cadastre data). Specifically, we calculated the median speed for all ships in each size category within the bounding box shown in Figure 4-1. We limited our analyses to this smaller box, rather than using all shipping data, to avoid ships traveling into and out of the main ports in our study area. Ship speeds close to ports are slower and do not represent speeds throughout the broader area. Although reduced noise has been measured for some ships when traveling at slower speeds (McKenna et al., 2013), this reduction may be offset by the increased time spent in an area when traveling at slower speeds. The median speed used to model noise was 6.40 knots for ships ≥ 18m and ≤ 120m, 13.50 knots for ships > 120m and ≤ 200m, 17.20 knots for ships > 200m and ≤ 320m, and 21.00 knots for ships > 320m.

The KRAKEN Normal Modes model (Porter & Reiss 1984, Porter & Reiss 1985) was used to model the transmission loss. Normal modes of the ocean are calculated at the center of each grid cell and the sound field is calculated along a fan of radials around the center of each grid cell using adiabatic mode theory (Kuperman et al., 1991). Resulting source level densities were convolved with transmission loss to estimate noise received levels for each cell at a discrete depth (30m) for two specific 1Hz frequency bands (50 and 100Hz). Predicted levels are expressed as equivalent, unweighted sound pressure levels (Lzeq), which are time-averaged across a specified duration, in this case the 122 days for August through November. Noise was summarized using the 10th, 50th (median), and 90th percentiles. The percentile values were compared to time series of noise measurements to assess their correspondence to different volumes of shipping traffic. Modeled noise was also compared to pre-industrial noise levels, which are associated with little to no shipping traffic. McDonald et al. (2008) estimated that pre-industrial noise levels were 55dB at 40Hz at a site near San Clemente (Figure 4-1). Assuming a 10dB offset in mean dB relative to mean intensity, we estimate that pre-industrial noise levels are 65dB at 50Hz. We also use 65dB as the pre-industrial noise level at 100Hz.

Predictions from the noise model were compared to empirical underwater acoustic data collected at two sites in the region (McKenna 2011), one north of the Santa Barbara TSS between Santa Rosa and Santa Cruz Islands and one on the southwestern edge of the TSS (Figure 4-1). Acoustic data were collected using High-frequency Acoustic Recording Packages (HARPs) developed at Scripps Institution of Oceanography (Wiggins & Hildebrand 2007). The HARP hydrophones were deployed approximately 10m above the seafloor. Acoustic data for November 2009 were decimated to a sampling frequency of 2kHz and processed to determine monthly sound spectrum averages. For each 225s interval, the time series was processed using a fast Fourier transform (FFT) and a Hanning window with a FFT length of 2000 samples and 0% overlap, resulting in a 1Hz frequency resolution of sound pressure levels. Samples of 225s were chosen for consistency with previous ambient noise measurements and allowed us to minimize contributions from any transient signals, if present. We calculated the mean of intensities for November 2009 at 40 and 99 Hz to capture the dominant frequency of ship noise, while avoiding transient signals from blue and fin whale calls at 50Hz and known system noise at 100Hz. These frequencies were assumed to represent measurements of background noise that could be directly compared to 50 and 100Hz model predictions. Mean of intensity and the 90th percentile of sound pressure levels in dB were found to correspond closely for HARP measurements. Consequently, the mean of intensities for measured noise was used in the comparison with modeled noise. Comparisons were made between the HARP data and predicted noise received levels in the cell containing the HARP.

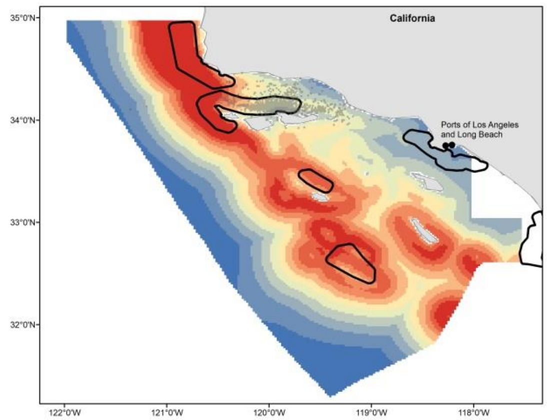
Co-occurrence of whale habitat and noise

Whale distribution data were available from three sources that capture different elements of whale habitat. Redfern et al. (2013) developed habitat models for blue, fin, and humpback whales in waters off southern California using seven years of data (1991, 1993, 1996, 2001, 2005, 2008, and 2009) collected by NOAA Fisheries' Southwest Fisheries Science Center on systematic marine mammal and ecosystem assessment surveys. These surveys were conducted throughout the U.S. EEZ from August to November; consequently, model predictions of species density (Figure 4-2) capture large-scale patterns in species distributions during a single season, but do not capture fine-scale patterns, particularly near the coast, or seasonality. Calambokidis et al. (2015) developed boundaries for Biologically Important Areas in these waters (Figure 4-2). These boundaries primarily encompass known feeding areas and do not necessarily capture areas of highest densities (Calambokidis et al., 2015). Finally, the CINMS has been collecting opportunistic sightings (primarily from whale watching vessels) in the Santa Barbara Channel since 1999 (Figure 4-2). These data provide information about where whales were present, but do not provide information about relative densities or absences.

We used all three sources of whale distribution data to estimate the co-occurrence of each species' habitat with noise. Noise levels at 50Hz were used for blue and fin whales because they produce infrasonic pulsed calls at approximately 15-25Hz. Noise levels at 100Hz were used for humpback whales because they produce song-like and non-song sounds across a range of lower frequencies (approximately 100-5,000Hz) in feeding areas. Predictions from the habitat models were made in a 2km x 2km grid covering the study area; they were extracted at the center of each 1km x 1km cell in the noise grid. Cells in the noise grid with one or more opportunistic sightings were categorized as a presence and other cells were treated as missing data. We calculated the number of cells within noise percentiles associated with varying volumes of shipping traffic that overlapped with the highest 20% of predicted densities, BIAs, and presence cells.

Figure 4-2. Habitat representations for (A) blue, (B) fin, and (C) humpback whales from three data sources. A habitat model was developed from seven years of line-transect data and used to predict density throughout the study area. Predicted densities are shown in 10 approximately equal area categories (highest densities are shown in red and lowest in blue). Biologically Important Areas (BIAs), which represent areas of high concentrations of feeding animals, are outlined in black (BIAs have not yet been defined for fin whales). Opportunistic sightings collected in the Santa Barbara Channel are shown as transparent, gray dots (the size of the dots is larger for fin whales, than blue and humpback whales, because there were so few fin whale sightings in the Channel).

(A)



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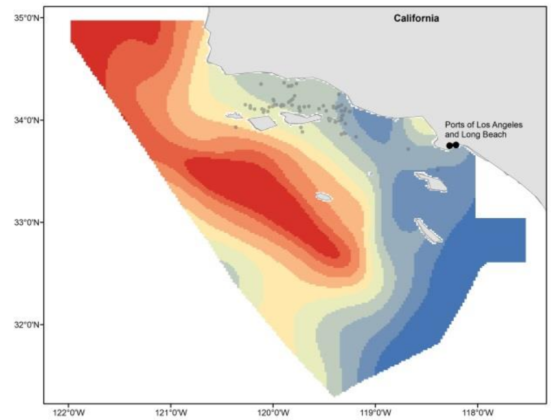

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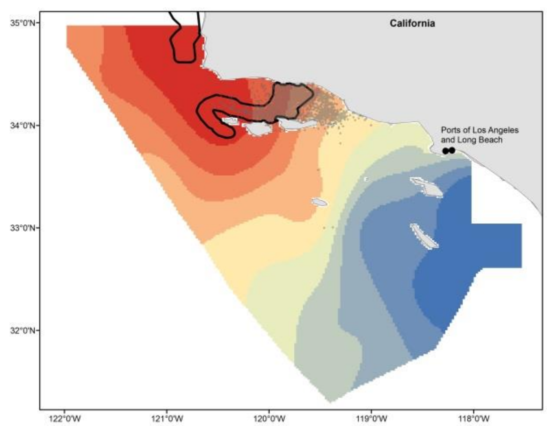


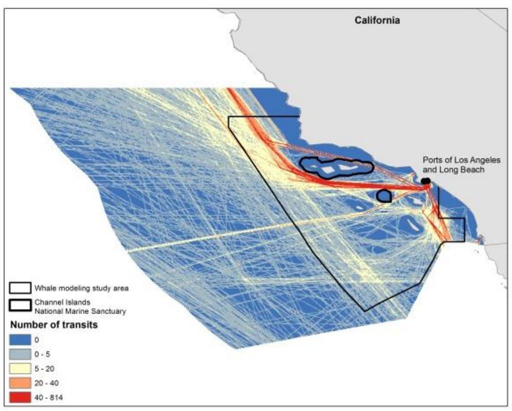
Results

Characterization of noise from commercial shipping

The 1km x 1km grid summarizing the number of ship transits between August and November 2009 shows that ships travelled in a broad area south of the northern Channels Islands and in the TSS within the Santa Barbara Channel (Figure 4-3a). Predicted 50 and 100Hz noise received levels at 30m depth reflected these shipping traffic patterns. However, predicted noise also reflects longer-distance, low-frequency propagation from distant shipping traffic in some regions, such as the center of the northern edge of the whale modeling study area, west of San Miguel, and south of the Channel Islands. In contrast, the Santa Barbara Channel is not exposed to noise from distant shipping traffic. Mean and median predicted noise received levels were 88dB at 50Hz and 77dB at 100Hz (Figure 4-4). At the HARP north of the Santa Barbara TSS between Santa Rosa and Santa Cruz Islands, predicted 50 and 100Hz noise received levels were between 5-12dB higher than measured noise (Table 4-1). At the HARP on the southwestern edge of the TSS, predicted 50 and 100Hz noise received levels were closer to measured noise (within 3dB) (Table 4-1). Thresholds for the 10th, 50th (median), and 90th percentiles of predicted noise received levels at both frequencies (Table 4-2) corresponded to low, moderate, and heavy levels of shipping traffic in a time series of measurements made off Point Sur (Urick 1984). We used a 65dB threshold to assess prevalence of pre-industrial noise conditions at both 50 and 100Hz (McDonald et al., 2008). Only 0.4% and 6% of the whale modeling study area contained predicted noise received levels below this pre-industrial noise threshold at 50 and 100Hz, respectively (Table 4-3).

Figure 4-3. (A) The number of transits by ships >200m and <=320m between August and November in 2009 was calculated in an area larger than the whale modeling study area to capture the influence of ships in surrounding waters in the noise predictions. (B) 50Hz predicted average noise received levels at 30m depth; (C) 100Hz predicted average noise received levels at 30m depth. Noise predictions at both frequencies are categorized by thresholds representing pre-industrial noise levels (65dB) and the 10th, 50th, and 90th percentiles of the predictions at each frequency.

(A)



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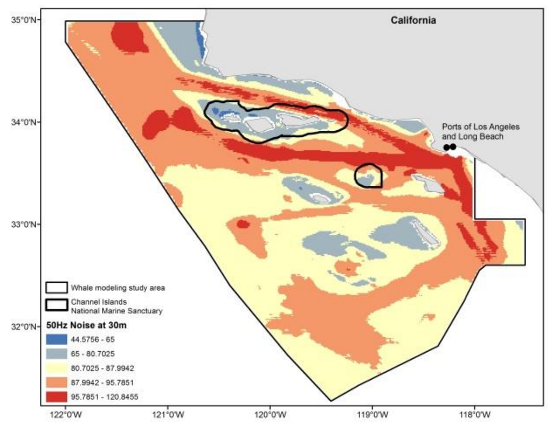

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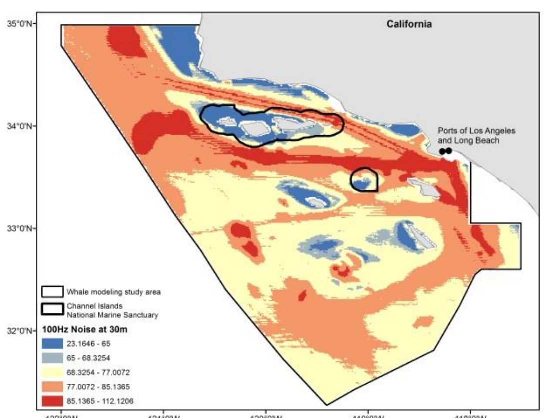


Figure 4-4. Histograms of 50 and 100Hz predicted noise received levels within the whale modeling study area. The x-axis and summary statistics are in decibels (dBs). Thin gray lines mark the noise levels used in our analyses: pre-industrial noise below 65dB for both frequencies and the 10th, 50th (median), and 90th percentiles of predicted noise received levels (exact values are reported in Table 4-2).

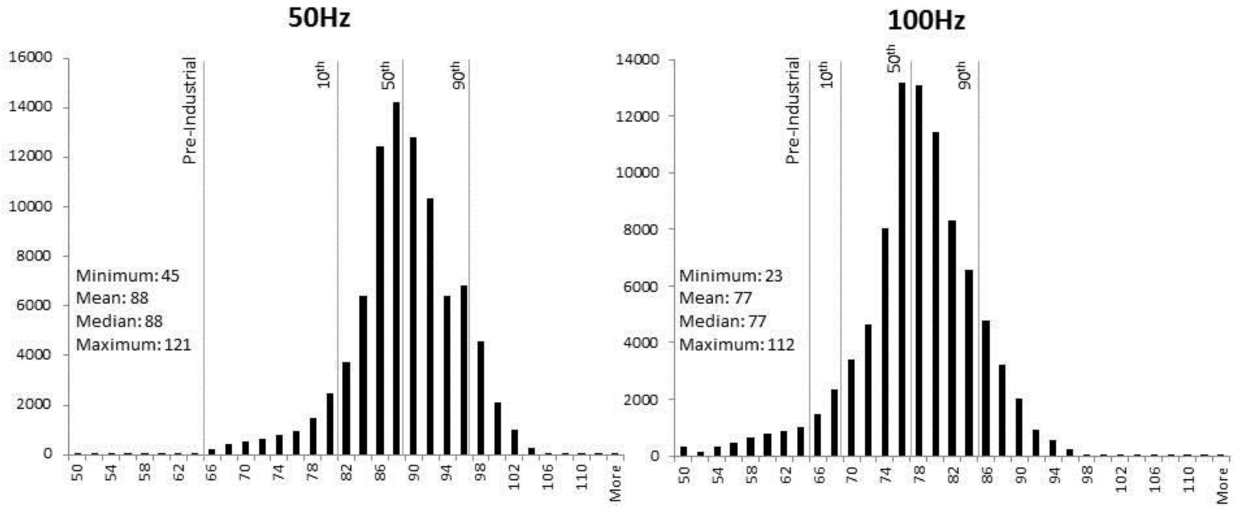


Table 4-1. Comparison of predicted 50 and 100Hz noise received levels (averaged from August to November 2009) to mean intensity of noise measured at two HARPS in November 2009.

Location	Sea Floor Depth	Mean Predicted Noise at the HARP (dB)	Noise Measured at the HARP (dB)
50Hz			
North of the TSS between Santa Rosa and Santa Cruz Islands	578	91	80
southwestern edge of the TSS	777	89	86
100Hz			
North of the TSS between Santa Rosa and Santa Cruz Islands	578	80	75
southwestern edge of the TSS	777	75	78

Table 4-2. Values for the 10th, 50th (median), and 90th percentiles of predicted noise received levels (reported in decibels) in the whale modeling study area compared to empirical measurements that are associated with different volumes of shipping traffic. Percentiles are reported to four decimal places to reflect the exact thresholds used in our analyses. The empirical estimates of pre-industrial noise used in our analyses are also shown.

	50Hz	100Hz	Volume of Shipping Traffic	Empirical Reference
Pre-industrial	65	65	Pre-industrial	Reviewed in McDonald et al. (2008)
10th percentile	80.7025	68.3254	Lower	Wenz (1962) “usual traffic deep”; Point Sur ~1960
50th percentile	87.9942	77.0072	Moderate	Urick (1984) "moderate traffic"; Point Sur ~1980
90th percentile	95.7851	85.1365	Heavy	Urick (1984) "heavy traffic”; Point Sur ~1995

Table 4-3. Proportion of the whale modeling study area and Channel Islands National Marine Sanctuary below thresholds for the 10th, 50th (median), and 90th percentiles of predicted noise received levels associated with different volumes of shipping traffic (Table 4-2). For example, predicted noise received levels less than the threshold for the 90th percentile were assumed to represent noise below the level associated with heavy shipping. These percentiles were compared to the proportions of the Channel Islands National Marine Sanctuary (CINMS) that experienced predicted noise received levels below the thresholds. For example, predicted 50Hz noise received levels were less than 87.9942dB (the threshold for 50th percentile of predicted noise received levels in the whale modeling study area) in 76% of the CINMS, suggesting that a larger proportion of the CINMS, compared to the whale modeling study area, experiences noise below the threshold associated with moderate volumes of shipping traffic.

	Whale Modeling Study Area		Channel Islands National Marine Sanctuary	
	50 Hz	100Hz	50Hz	100Hz
Below pre-industrial noise threshold (<65dB)	0.004	0.06	0.04	0.43
Below lower shipping traffic threshold (0dB to the 10th percentile threshold)	0.10	0.10	0.52	0.57
Below moderate shipping traffic threshold (0dB to the 50th percentile threshold)	0.50	0.50	0.76	0.78
Below heavy shipping traffic threshold (0dB to the 90th percentile threshold)	0.90	0.90	0.89	0.93

The CINMS contained lower predicted noise received levels than the whale modeling study area (Table 4-3). At 100Hz, 43% of the CINMS contained predicted noise received levels below the pre-industrial noise threshold. Higher percentages of the CINMS, compared to the larger region, also contained predicted 100Hz noise received levels below thresholds associated with lower and moderate volumes of shipping traffic. Specifically, 57% of the CINMS contained noise below the threshold associated with lower shipping compared to 10% of the whale modeling study area and 78% of the CINMS contained noise below the threshold for moderate shipping compared to 50% of the whale modeling study area. Only 4% of the CINMS contained predicted 50Hz noise received levels below the pre-industrial noise threshold. However, higher percentages of the CINMS contained predicted 50Hz noise received levels below thresholds associated with lower and moderate volumes of shipping traffic (Table 4-3), similar to the results at 100Hz.

Co-occurrence of whale habitat and noise

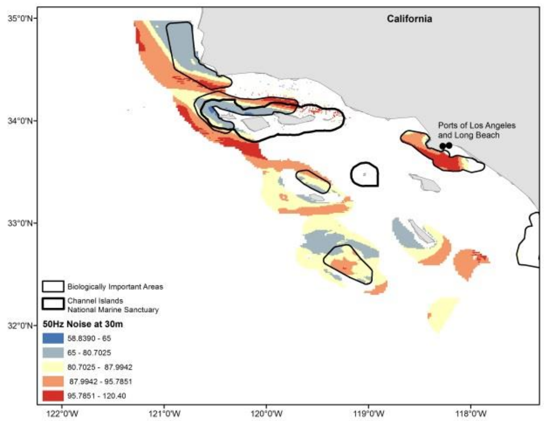
Blue whale habitat was associated with the 200-m isobath (Redfern et al., 2013), which represents the shelf break in this region. The blue whale BIAs and the predictions from the habitat model capture offshore patches of blue whale habitat, although the BIAs and sightings suggest higher densities of blue whales in the Santa Barbara Channel than the habitat model (Figure 4-2a). Almost no blue whale habitat, regardless of the data source used to define habitat, contains predicted noise received levels below the 50Hz threshold associated with pre-industrial noise (Table 4-4 and Figure 4-5a). However, a higher percentage of blue whale habitat, compared to the larger region, contained predicted 50Hz noise received levels below thresholds associated with lower and moderate volumes of shipping traffic (Table 4-4 and Figure 4-5a). Specifically, 24-38% of blue whale habitat contained noise below the threshold associated with lower shipping compared to 10% of the whale modeling study area and 62-65% of blue whale habitat (excluding habitat in the Channel, which is captured by opportunistic sightings) contained noise below the threshold for moderate shipping compared to 50% of the whale modeling study area.

Table 4-4. The proportion of whale habitat, defined using three data sources, that experiences predicted 50Hz (blue and fin whales) and 100Hz (humpback whales) noise received levels below thresholds for the 10^{th}, 50^{th} (median), and 90^{th} percentiles of predicted noise received levels in the whale modeling study area (Table 4-2). These thresholds are associated with different volumes of shipping traffic (Table 4-2). Fin whale BIAs have not yet been defined.

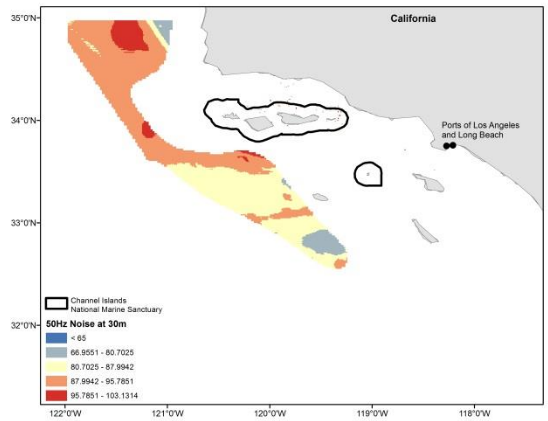
	Blue Whales			Fin Whales			Humpback Whales		
	Density	BIA	Sightings	Density	BIA	Sightings	Density	BIA	Sightings
Below pre-industrial noise threshold (<65dB)	0.003	0.01	0.001	0.00		0.00	0.19	0.52	0.25
Below lower shipping traffic threshold (0dB to the 10^{th} percentile threshold)	0.24	0.38	0.28	0.06		0.25	0.24	0.63	0.39
Below moderate shipping traffic threshold (0dB to the 50^{th} percentile threshold)	0.62	0.65	0.48	0.43		0.43	0.37	0.84	0.67
Below heavy shipping traffic threshold (0dB to the 90^{th} percentile threshold)	0.94	0.88	0.76	0.93		0.76	0.83	0.97	0.91

Figure 4-5. Noise at 50Hz is shown within categories (< 65dB and the 10th, 50th, and 90th percentiles of predicted noise received levels in the whale modeling study area) for (A) blue and (B) fin whale habitat (i.e., the highest 20% of predicted densities, within BIAs, and in cells with sightings). Categorized noise at 100Hz is shown for (C) humpback whale habitat. Fin whale BIAs have not yet been defined.

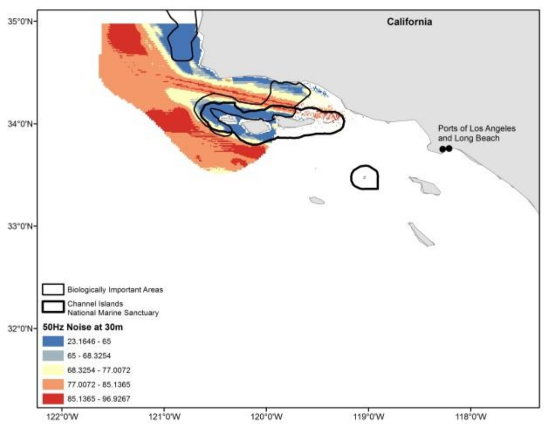
(A)



(B)



(C)



Fin whale habitat (Figure 4-2b) occurred in offshore waters and had the least overlap with predicted noise received levels associated with pre-industrial, lower, and moderate volumes of shipping traffic (Table 4-4 and Figure 4-5b). In particular, no fin whale habitat contained predicted noise received levels below the 50Hz threshold associated with pre-industrial noise. Additionally, only 6% of fin whale habitat (defined as the highest 20% of fin whale densities predicted by the habitat model) contained noise below the threshold associated with lower shipping compared to 10% of the whale modeling study area and 43% of fin whale habit contained noise below the threshold for moderate shipping compared to 50% of the whale modeling study area.

Humpback whale habitat occurred in the northernmost portion of our study area (Figure 4-2c). The humpback whale BIAs overlap with the highest densities predicted by the habitat model, although the habitat model also predicts higher densities offshore. All humpback whale habitat, regardless of the data source used to define habitat, had the highest overlap with predicted 100Hz noise received levels associated with pre-industrial and lower volumes of shipping traffic noise (Table 4-4 and Figure 4-5c), compared to the percent overlap with frequency-specific noise for blue and fin whales. In particular, 19-

52% of humpback whale habitat contained predicted 100Hz noise received levels below the threshold associated with pre-industrial noise. Additionally, 24-63% of humpback whale habitat contained noise below the threshold associated with lower shipping compared to 10% of the whale modeling study area.

Discussion

Predicted noise received levels in southern California waters suggest high, region-wide exposure to shipping noise. For example, only 0.4% of the whale modeling study area contains predicted 50Hz noise received levels below the 65dB threshold used to estimate pre-industrial ocean noise conditions. Additionally, only 6% of the area contains predicted 100Hz noise received levels below the pre-industrial noise threshold. The predicted noise received levels were broadly comparable to times series of ocean noise measurements made in central and southern California (Urick 1984, McDonald et al., 2008). The agreements and differences between predicted noise received levels at the HARP locations and the HARP measurements highlight many sources of variability that influence predicted noise received levels at a particular location, at particular frequencies, and within specific time periods.

In southern California waters, the differences between predicted and measured noise are likely strongly influenced by changes in shipping traffic. The volume of shipping traffic in the Santa Barbara Channel decreased after implementation of the fuel rule in July 2009 (McKenna et al., 2012a). Our noise model was developed using the number of ship transits between August and November 2009 and shows higher predictions for the HARP north of the Santa Barbara TSS between Santa Rosa and Santa Cruz Islands (i.e., the HARP that occurs within the Santa Barbara Channel) compared to the HARP on the southwestern edge of the TSS. In contrast, the HARP measurements were made in November 2009 and show higher noise at the southwestern, compared to the northern, HARP. The differences in predicted versus measured noise are likely strongly influenced by the reduced shipping traffic in the Santa Barbara Channel during the shorter and later period of HARP measurements compared to the longer time period used in the noise model. Specifically, differences between predicted and measured noise were much higher (5-12dB) at the northern HARP because this HARP measured the reduced traffic in November, compared to the higher traffic estimates obtained between August and November that were used in the model. Differences were smaller (less than 3dB) at the southwestern HARP because it occurs farther from the TSS and in a location that receives more influence from ships traveling south of the Northern Channel Islands, resulting in less change between the time periods used to measure and model noise.

The differences in predicted versus measured noise may also be the result of ship source levels. The noise model used ship source levels that were estimated from data collected in the 1970s and 1980s (Carey & Evans 2011); these source levels may overestimate the noise produced by the modern fleet. The 1 Hz-band ship source levels used in the noise model are approximately 10-15 dB higher than some more recent, broader-band estimates of source levels for newer ship designs (e.g., McKenna et al., 2012b). Improvements in the noise model could also be made by incorporating ship speed in predicted ship source levels. High-resolution, spatially explicit maps of vessel speed can be derived from AIS data. However, algorithms to estimate changes in source level from speed exist for a small number of vessel types and length classes (e.g., container ships; McKenna et al., 2013). Finally, the noise model could be improved by increasing the resolution of bottom-type data for waters off Southern California because sound propagation is influenced by bottom type.

Our risk assessment suggests that fin whale habitat occurs in noisier waters than blue and humpback whale habitat. The habitat models developed by Redfern et al. (2013) predicted that higher fin whale densities occurred farther offshore than higher blue whale densities, resulting in a higher overlap between fin whale habitat and predicted 50Hz noise received levels. Blue and fin whale habitats in the

Santa Barbara Channel, as represented by opportunistic sightings collected primarily from whale watching vessels, were similar. Consequently, both species experienced similar noise levels in this smaller area. Humpback whale habitat generally occurred in waters less influenced by noise than blue and fin whale habitat because humpback whales occur closer to shore, where predicted 50 and 100Hz noise received levels were lower. In general, predicted 100Hz noise received levels were less than 50Hz levels because large ships produce less noise at 100Hz than 50Hz (Carey & Evans 2011). Additionally, 100Hz can be considered a lower bound for assessing risk of masking to humpback vocalizations. For humpback whales, BIAs and areas with sightings are less noisy than the area defined by the highest 20% of predicted densities because the predicted densities expand farther offshore where predicted 100Hz noise received levels were higher.

The co-occurrence of blue and fin whale habitat and predicted 50Hz noise received levels raises concerns about the quality of their acoustic habitat and how it supports their communication at low frequencies. These long-lived animals evolved to take advantage of acoustic conditions that this study estimates have been entirely (fin whales) to near entirely (blue whales) eliminated within the habitats most important to sustaining their presence in Southern California waters. Place-based management in the CINMS has resulted in CINMS containing a higher percentage of quieter areas than the larger region. Specifically, 52% and 57% of the CINMS contained predicted 50 and 100Hz noise received levels, respectively, below the threshold associated with lower shipping compared to 10% of the whale modeling study area. This noise protection is likely an ancillary benefit of the area to be avoided (ATBA) that was created around the CINMS by the IMO in 1991 to reduce groundings and pollution risks. Ships over 300 gross tons are also prohibited from operating within 1nmi of any of the Channel Islands unless they are transporting people or supplies to the Island or engaged in fishing or kelp harvesting. As a result of the ATBA and restrictions close to the Islands, ship traffic and, concomitantly, predicted 50 and 100Hz noise received levels in the CINMS primarily occur where the TSS overlaps with the Sanctuary's boundaries (Figure 4-3). This area of overlap contains Biologically Important Areas for blue and humpback whales and sightings of both species. Consequently, acoustic habitat for blue and humpback whales may be compromised within this gap in place-based management.

This risk assessment identifies areas where blue, fin, and humpback whale habitat overlaps with areas of elevated chronic noise. It also shows both the successes of and gaps in place-based management of waters off southern California. This risk assessment framework can be used to evaluate the consequences of potential management actions and further changes in shipping traffic. For example, noise associated with different ship routing options could be modeled and used to quantify the resulting changes in the co-occurrence of whale habitat and noise. Additionally, a time series of annual noise predictions could be developed to understand changes in risk associated with changes in shipping traffic. The next steps for the risk assessment are to incorporate uncertainty and develop metrics to estimate the consequences of the risk. Explicitly identifying uncertainty helps managers understand the degree of confidence they can place in the risk assessment and helps to prioritize future data collection efforts (Hope 2006). There is uncertainty associated with both the predicted species densities and noise received levels used in our risk assessment. The uncertainty in the predicted species densities arises primarily from interannual variability in species distributions (Redfern et al., 2013). This uncertainty can be reduced by extending the data time series, using finer-resolution habitat data, and incorporating prey data. There is also a need to examine the seasonality of the risk estimates because fin whales are present off Southern California all year and some blue and humpback whales may have arrived before or remained after the period in which the data were collected. Finally, the risk assessment could be conducted using the maxima or minima of predicted noise received levels, in addition to time-average predictions.

The current risk assessment identifies areas of co-occurrence between whale habitat and noise from commercial ships. Metrics are needed to estimate the consequences of this co-occurrence. Previous studies have estimated the loss of potential communication opportunities among individuals (e.g., Clark et al., 2009, Hatch et al., 2012) to quantify the influence of chronic noise on large whales. Applying this metric to Southern Californian waters would further highlight frequency-specific implications of noise for transmission of specific call types. The fitness implications of locally degraded acoustic habitat can also be considered within population viability models that include other environmental determinants of foraging and mating success and that account for trends in those variables (e.g., climate change). Finally, stress hormone levels and other health and demographic indicators could be compared among populations, subspecies, or sister species that occur in areas with different long-term noise conditions.

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Case Study 2:
Managing Noise Impacts on Spawning Areas Used by Acoustically Sensitive and Commercially Important Fish and Invertebrate Species

This case study provides a place-based context for examining recommendations from Chapter 1 (expanded focus and attention to NOAA-managed and acoustically sensitive fishes and invertebrate species), Chapter 2 (extended use of existing authorities to address noise impacts to acoustic habitats for sensitive fish and invertebrate species) and Chapter 3 (prioritized development of NOAA-maintained long-term passive acoustic monitoring capacity).

Problem Formulation
Target Species and Habitat:
Many commercially-important fish species that NOAA is charged with managing produce sound or are known to use sound during critical life stages (see Chapter 1 & Appendix A). Along the U.S. Atlantic seaboard, sound production or sensitivity is well documented in the Northeast for Atlantic cod and haddock (Family *Gadidae*) and in South Atlantic Bight for members of the snapper-grouper complex (e.g., Families *Serranidae* and *Lutjanidae*), grunts (Family *Haemulidae*), and croakers and drums (Family *Sciaenidae*), among other species (Normandeau Associates, Inc., 2012; Hawkins et al., 2014). Some of these species are known to make sounds including, though not always exclusively, during spawning (e.g., cod, haddock, red drum, red grouper, black grouper) while others are known to produce sounds, though those sounds have yet to be linked to reproductive activity (e.g., gag grouper, grunts). Hearing sensitivity has not been documented for most of these species, but is predicted to support their detection of low frequency signals, including, but not limited to, the sounds they produce (mostly less than 1000Hz). Hearing has been well studied in Atlantic cod, which are known to very effectively detect as well as avoid low frequency noise sources (Chapman & Hawkins 1973). Some of these species have evolved mechanical connections between the swim bladder (or other gas bubble) and the inner ear (i.e., red drum), or have gas bladders that are close to the ear (i.e., red snapper) (Hawkins & Popper 2014). There is evidence that such connections and proximity can increase hearing sensitivity (ibid). Although best studied as adults, the larvae of some of these species are documented to be sensitive to sound (e.g., cod, red snapper; Simpson et al. 2005) and recently have been found to produce sound as well (e.g., gray snapper; Staaterman et al., 2014). Thus, the acoustic condition of the habitats that support vulnerable early life stages for these acoustically active or sensitive species, such as spawning adults, larvae and juveniles, is relevant to NOAA's fishery science and management actions.

Cod and haddock stocks in New England and snapper and grouper stocks in the South Atlantic are managed by NOAA and regional Fishery Management Councils, with additional inshore management by state fishery agencies. In the Atlantic, red drum is managed exclusively by the Atlantic States Marine Fishery Commission (ASMFC). Most of these Atlantic stocks are considered overfished and/or overfishing is occurring; thus NOAA or state managers (in the case of red drum) are tasked with managing their return to sustainable population levels. The need to protect critical life stages (i.e., spawning adults, pre-settlement and settlement stage larvae and juveniles) is well understood by state and federal fishery managers as playing an important role in stock recovery.

The need to protect spawning and juvenile cod and haddock in the Gulf of Maine beyond current essential fish habitat (EFH) designation is gaining recognition within the Northeast Fisheries Management Council (NEFMC). The NEFSC's Closed Area Technical Team is currently evaluating various options for new or amended spatial and temporal closures to protect spawning or juvenile fishes as part of their revision of current habitat protections in the region (Figure 4-6A; NEFSC CATT 2014). The

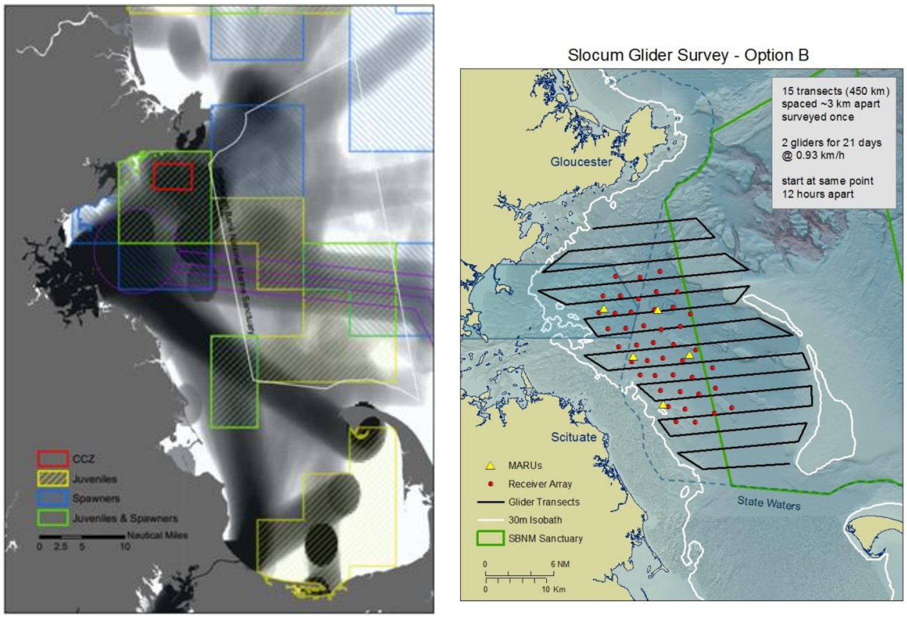

Figure 4-6. Massachusetts Bay off the Northeast Coast of the U.S. (A) Proposed areas associated with spawning Atlantic cod, juvenile Atlantic cod and both (spawning and juvenile) as presented by the Closed Area Technical Team to the Northeast Fisheries Management Council (April 2013); Cod Conservation Zone (CCZ) created by the Commonwealth's Division of Marine Fisheries to protect spring cod spawning activity; large commercial vessel traffic via Traffic Separation Scheme in purple outline and as a density field from Automatic Identification System tracking system in black; boundaries of the Stellwagen Bank National Marine Sanctuary (white).
(B) Instrumentation associated with 2014-2017 collaborative research to further identify spawning cod areas in Massachusetts Bay.
Figures: Michael Thompson, NOAA SBNMS; Micah Dean, Mass DMF

Commonwealth of Massachusetts' Division of Marine Fisheries has identified a predictable inshore area used by spawning cod in the spring, and has established a closure known as the Cod Conservation Zone to protect this site during active spawning. NOAA (Northeast Fisheries Science Center and Stellwagen Bank National Marine Sanctuary) is currently participating in a collaborative effort to identify additional spawning locations used by winter spawning cod, and to identify haddock spawning areas, using both passive (listening) and active (telemetry) acoustic techniques (Figure 4-6B). New spatial protection areas for spawning and juvenile cod could be included in the NEFSC's finalization of Omnibus Habitat Amendment 2.

In the South Atlantic Bight, the South Atlantic Fishery Management Council (SAFMC) has established EFH and habitat areas of particular concern (HAPCs) to increase protections for snapper-grouper complex species both offshore in areas with known spawning aggregations and inshore in areas known to support juveniles (Figure 4-7). Offshore HAPCs include eight marine protected areas (MPAs) established by the SAFMC in 2009 through Amendment 14 to the Snapper Grouper Fishery Management Plan (http://www.safmc.net/managed-areas/marine-protected-areas). Snapper-grouper spawning is known to occur within and around several of these MPAs (SAFMC MPA Expert Workgroup 2013). It is largely unknown whether spawning activity taking place in offshore shelf-break habitats such as these is accompanied by sound production, and if so, by which species. In 2014, researchers from NOAA (Southeast Fisheries Science Center-SEFSC and National Centers for Coastal and Ocean Science-NCCOS), the University of South Florida, Loggerhead Instruments and NC State University deployed an autonomous ocean glider outfitted with hydrophones to survey the continental shelf break off the Carolinas, Georgia and Northern Florida to attempt to document areas used for spawning by acoustically-active fishes on the shelf break, including current MPAs. Sounds produced by red grouper (see Nelson et al., 2011) were recorded in and around the Northern South Carolina and Edisto MPAs off the coast of South Carolina (Figure 4-7A).

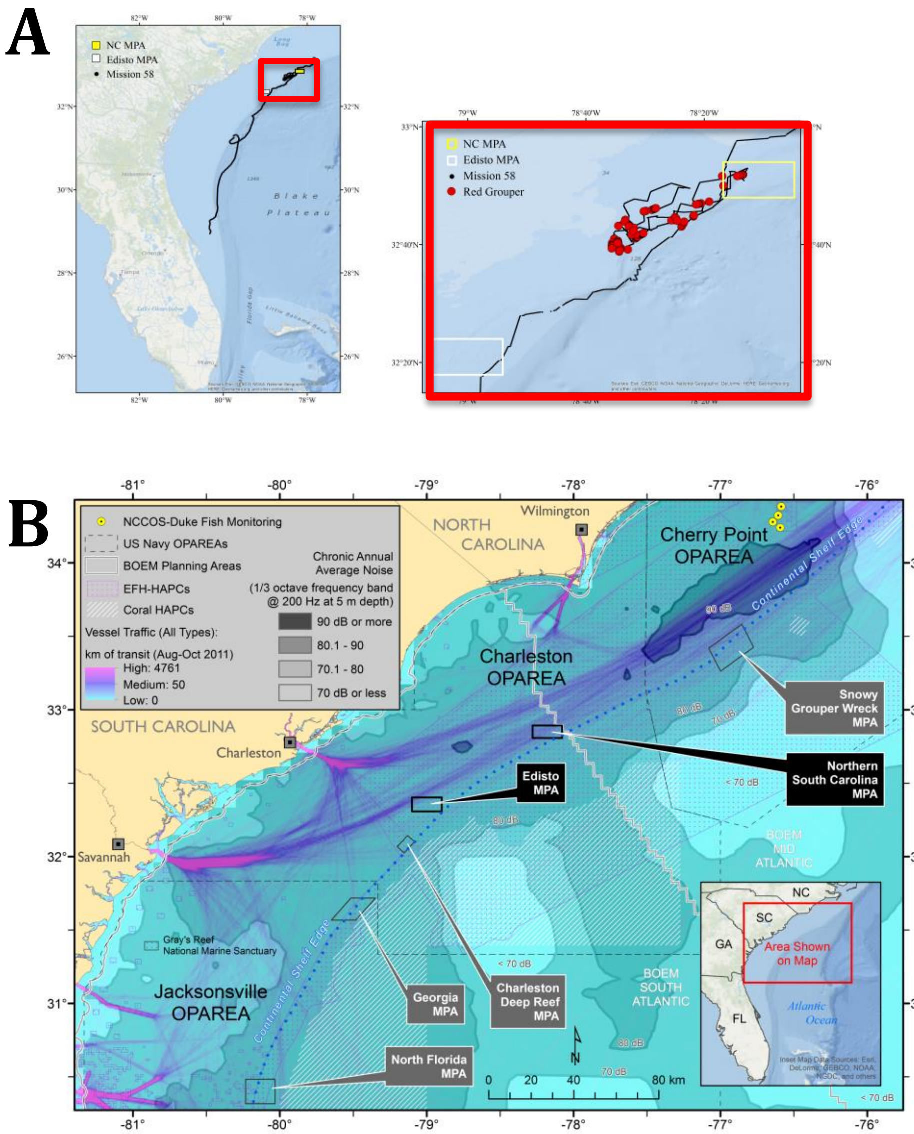

Figure 4-7. Offshore North and South Carolina, South Atlantic Bight, U.S.

(A) Track of passive acoustic glider relative to two SAFMC MPAs; red dots in inset indicate glider locations where red grouper sounds were detected.

(B) Annual average predicted shipping noise (SoundMap) and large commercial vessel density (3 month snapshot) from Automatic Identification System data relative to EFH Habitat Areas of Particular Concern and Marine Protected Areas (MPAs) designated by the South Atlantic Fishery Management Council (SAFMC); BOEM planning areas for offshore energy development (oil and gas, renewable energy, and marine mineral); U.S. Navy operating areas; research stations being used by NOAA NCCOS and Duke University researchers to study impacts to fishes associated with 2014 NSF seismic surveys.

Figures: Carrie Wall and David Mann, Loggerhead Instruments; T.J. Moore, NOAA SWFSC

Juvenile gag grouper, black sea bass and black grouper are known to feed and shelter in estuarine environments, such as the coastal oyster reefs and inlets of Pamlico Sound, North Carolina (Figure 4-8A). These waters have been designated as HAPC for the snapper-grouper complex (inclusive of all Primary and Secondary Nursery Area designated in North Carolina). The acoustic condition of inshore HAPC that supports young and acoustically sensitive (black sea bass) and active (gag and black groupers) snapper-groupers is thus of additional concern for NOAA science and management. Though not managed by NOAA, similar areas are used by state-managed (ASMFC) red drum as spawning and nursery habitats (http://www.asmfc.org/uploads/file/redDrumHabitatFactsheet.pdf). Red drum and other *Sciaenid* spawning habitats have been identified in Pamlico Sound using passive acoustics methods (Luczkovich et al., 2008; Figure 4-8). Proposed studies aim to use passive acoustic gliders to survey large areas of Pamlico Sound that are less well understood (J. Luczkovich, personal communication). Additional proposals are under consideration that would assess impacts of ongoing bridge construction in Beaufort, North Carolina (a main waterway into Pamlico Sound) on resident acoustically active spawning fishes and dolphins (D. Nowachek, personal communication). Estuarine soundscapes within Pamlico Sound have also been the focus of more holistic examination to understand whether reef and non-reef locations supporting different acoustically active species, including snapping shrimps and *Sciaenids*, are producing important acoustic cues for these and additional fish and invertebrate species relying on these habitats (e.g., oysters and juvenile fishes; Lillis et al., 2014).

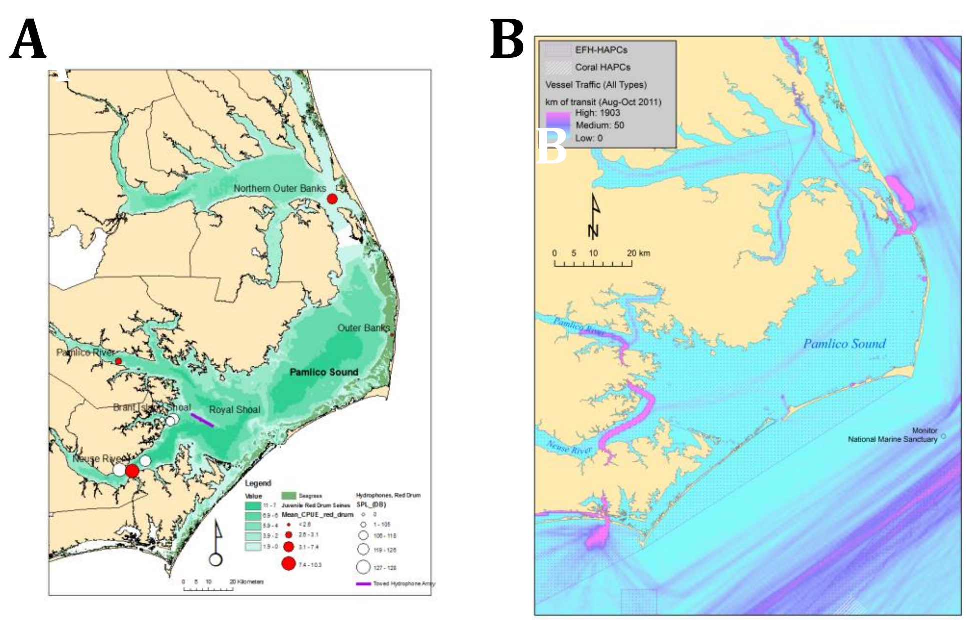

Figure 4-8. Inshore Cape Hatteras to Cape Lookout, Pamlico Sound, North Carolina.
(A) Known red drum spawning areas, based on passive acoustic detections of the advertisement sounds produced by males, larval fish collections and North Carolina DMF seine surveys.
(B) Vessel traffic snapshot (3 months) based on Automatic Identification System data; EFH Habitat Areas of Particular Concern designated by the South Atlantic Fishery Management Council (SAFMC) to support early life stages for snapper-grouper complex.
Figures: Joseph Luczkovich (East Carolina University); T.J. Moore, NOAA SWFSC

Current Status of Ocean Noise Information:
Vessel noise is known to dominate background noise levels within frequency bands used by spawning Atlantic cod and haddock in Massachusetts Bay. Ongoing passive acoustic research conducted by NOAA (Northeast Fisheries Science Center-NEFSC and Stellwagen Bank National Marine Sanctuary-SBNMS) and collaborators (e.g., Cornell University) has documented low-frequency noise contributions from different types of vessels within the SBNMS and Massachusetts Bay. Sound propagation modeling predictions based on Automatic Identification System (AIS) large commercial ship tracking information and empirical measurements (low-frequency sound recordings) are both available in the region at high resolutions (daily for multiple years, ~1 kilometer grid and 10-2000Hz). Fishing vessel and whale watching vessel noise implications have also been estimated in this area. Model predictions for annual average offshore contributions to the region are also available via the SoundMap project (http://cetsound.noaa.gov/sound_data). NEFSC, SBNMS, and Woods Hole Oceanographic Institution, as part of collaborative research with the Commonwealth of Massachusetts' Division of Marine Fisheries, The Nature Conservancy and commercial fishermen, are using passive acoustic gliders and bottom mounted recorders to identify cod spawning areas (Figure 4-6). This effort will provide additional data to support assessments of background noise relative to spawning Atlantic cod sound production.

Chronic low-frequency noise levels within offshore spawning locations in the South Atlantic Bight such as the Northern South Carolina and Edisto MPAs are not well documented. SoundMap predicted annual average influence from large commercial shipping noise at a regional scale (Figure 4-7; http://cetsound.noaa.gov/sound_data). Higher resolution estimates of shipping noise based on AIS data are not currently available, and are necessary for evaluation of impacts within smaller areas such as these MPAs. However, both SoundMap and distribution of AIS-tracked vessels suggests significant low frequency commercial traffic noise along the shelf break, particularly within the Northern South Carolina MPA (Figure 4-7). Influence from other traffic types that may be relevant to offshore vessel noise signatures, including cumulative fishing vessel, research or ecotourism traffic, is unknown. Recent passive acoustic work by NOAA and collaborators could begin to address this uncertainty; in addition to identifying areas of use by acoustically active fishes, glider data could be used to assess anthropogenic contributions to background noise levels.

Two other known sources of noise in the South Carolina MPAs have less overlap with the low frequencies produced by offshore spawning reef fish or are short-term activities that have limited influence on the chronic condition of acoustic habitats. That said, they have the potential to provide NOAA with important data resources for understanding the acoustic status of these areas. First, both the Northern South Carolina and Edisto MPAs are within the U.S. Navy's Charleston operating area (OPAREA). The main active acoustic sources in use in the area are mid-frequency sonars (Atlantic Fleet Training and Testing Environmental Impact Statement-AFTT EIS, http://aftteis.com/). Concentrated military vessel or low-flying air activity or heavy, long-term use of explosions could contribute to more chronically degraded low frequency acoustic habitat conditions in specific offshore areas within the OPAREA, but the coincidence of such patterns over time with EFH HAPC has not been documented. However, as part of AFTT baseline monitoring, the Navy has funded extensive passive acoustic monitoring efforts, including bottom-mounted acoustic recorders off Cape Hatteras, Onslow Bay and Jacksonville, to better understand impacts from sonars and other range activities on whales and dolphins. Although not directly overlapping with currently protected snapper-grouper spawning habitats, some of this effort has recorded low frequencies in addition to higher frequencies of primary focus. These data could potentially be mined to provide information on shelf-break soundscape conditions that are relevant to these stocks. Second, a seismic survey using a 2D air gun array (a low frequency source) was conducted in 2014 by NSF and transited through EFH HAPC off Cape Lookout, North Carolina. To monitor impacts to fishes in this area, including some that are acoustically active, researchers from NCCOS and Duke University deployed time-lapse video and acoustic recorders at stations close to the survey line. Such research will provide regionally-specific information to assist NOAA managers in their evaluations of the impacts of new proposals for more pervasive commercial seismic survey activity on managed fish stocks and habitats, including both physical injury and biologically (or fishery) significant behavioral responses and longer-term impacts to acoustic habitats within EFH HAPCs.

The dominant anthropogenic contributors to low frequency noise within inshore spawning and nursery habitats of Pamlico Sound are not well documented. Soundscape analyses completed thus far have been limited in time and space and have focused on natural contributions, removing anthropogenic signatures (Lillis et al., 2014). Noise from human activities in these shallow water estuarine environments is predicted to be highly variable depending on local source distributions, such as proximity to areas with seasonally high recreational and commercial small vessel use, onshore road and bridge traffic or nearshore construction activities (i.e., pier and harbor work). Physical environmental factors such as sediment types, topography and oceanography will also influence local acoustic signatures, reducing introduction of noise from surrounding areas in some cases, while augmenting noise in other areas. AIS vessel traffic information is known to be a limited representation of smaller and non-oceangoing commercial and recreational vessel types common in inland waterways. However, evaluation of these data does reflect overlap between an area of known importance to spawning red drum and commercial, pleasure and military traffic transiting between Beaufort and New Bern, North Carolina, through the Adams Creek Canal (Figure 4-8). Continuing passive acoustic work by academic scientists from East Carolina, North Carolina State and Duke Universities seeks to further describe priority acoustic habitats for fishes in this region.

Next Steps

Activity-Specific Mitigation and Monitoring:

As discussed above, current or future human activities that are influencing, or are likely to influence, the longer-term conditions of acoustic habitats of spawning sites discussed here could include transiting vessels, offshore energy exploration and development, and some activities associated with military training. Impacts from proposed offshore, non-fishing activities on EFH, including HAPCs, are addressed through EFH consultations between action agencies and NOAA Fisheries. Due to the high ecological importance of these areas, impacts on HAPCs are given heightened scrutiny during EFH consultations. EFH consultations result in conservation recommendations provided to action agencies that would avoid, minimize, or mitigate impacts on the habitats of Federally-managed species of fishes and invertebrates. These recommendations can include spatial and temporal measures (e.g., avoiding specific time periods or areas to reduce impact) and monitoring (e.g., water column sampling). To date, NOAA Fisheries' EFH consultations along the East Coast have primarily addressed acute noise impacts from activities such as pile driving in nearshore habitats, but have yet to address chronic noise impacts that could disrupt sensitive behaviors such as settlement by young fishes, spawning, or foraging. Additionally, NOAA engages in several regional initiatives aimed at promoting marine spatial planning objectives that include dialog and information sharing with other federal, state and tribal governmental interests, as well as additional stakeholders. These venues, both informally and formally, are increasingly providing mechanisms for NOAA to inform early planning stages and siting decisions relative to trust resources and for NOAA to identify partnerships to address key applied research needs.

Vessel Noise

Transiting vessels are conspicuously exempt from current NOAA noise exposure assessment and regulation (Hatch & Fristrup 2009). The general coming and going of international maritime traffic does not require federal action by a U.S. agency that could trigger EFH consultation. That said, periodic large-scale evaluations by the U.S. Coast Guard (USCG) or Maritime Administration (MARAD), such as coast-wide Port Access Route Studies, offer opportunity for interagency dialog regarding potential impacts to NOAA trust resources. To date, Port Access Route Studies have included evaluation of noise impacts to marine mammals, but not to fishes. In addition, NOAA and the USCG have worked together in several regions to shift, extend and narrow shipping lanes. These efforts have focused on reducing vessel-whale collisions, but with additional interest in reducing noise exposure. Such evaluations necessitate comprehensive evaluation of impacts to multiple stakeholders as well as multiple marine taxa to ensure that proposed traffic changes will not create unintended consequences. **NOAA could work with the USCG to evaluate the chronic impacts of commercial vessel traffic on the acoustic conditions of federally designated areas (i.e., EFH) to protect acoustically active or sensitive fishes.** In many cases, current baseline data on noise influence within areas designated or being considered by FMCs to protect fishes that are acoustically active during spawning is insufficient to support route alteration proposals, and thus focus could be engaging the USCG in discussions regarding NOAA's development of targeted noise monitoring programs (see below).

Both the average size and the overall number of ships accessing major East Coast ports is predicted to increase with the completion of an enlarged Panama Canal (MARAD 2013). More and larger ships will increase the levels of low frequency noise on the eastern seaboard, particularly close to major shipping lanes (e.g., traffic separation schemes) and surrounding the East Coast ports that either can already accommodate this new traffic (e.g., Baltimore, MD, Norfolk, VA) or will be able to do so by the time the expanded Panama Canal opens (Miami, FL, and New York/New Jersey). Other East Coast ports are making preparations for dredging to channel depths of 45 feet or more, depths that can accommodate many of the Post-Panamax ships (including Savannah, GA, Charleston, SC, Wilmington, NC, and Boston, MA). Post-Panamax noise levels can thus be expected to increase within spawning locations within Massachusetts Bay and in shipping routes off the Carolinas. It is currently unclear whether, and if so what, federal actions may be necessary to facilitate this growth in East Coast traffic that could be used to evaluate possible route or operational measures to reduce chronic noise exposure in places of importance to NOAA trust resources. **NOAA could work with the USCG and MARAD to evaluate impacts to the acoustic conditions of key fish spawning locations associated with federal actions associated with predicted growth in East Coast traffic.**

Finally, since 2007, NOAA has been working with the USCG to lead a correspondence group at the United Nations' International Maritime Organization (IMO) focused on the development of technical guidelines for quieting commercial vessels. This work progressed significantly in 2014, when the IMO finalized these guidelines, producing a voluntary mechanism by which ship builders and operators could reduce noise emanating from large commercial ships (IMO MEPC 2014). Interests in noise reduction in any local area must include international action to address wide-ranging shipping noise influence. **NOAA could continue work with the USCG at the United Nations' International Maritime Organization to encourage the implementation of new guidelines to quiet commercial vessels.**

Offshore Energy Exploration and Development

The Bureau of Ocean Energy Management (BOEM) produced a Record of Decision on July 11, 2014, following the release of a final programmatic Environmental Impact Statement (BOEM 2014) that renewed geological and geophysical surveying activity in the Atlantic. NOAA acted as a cooperating agency in the EIS analysis. NOAA Fisheries' Habitat Conservation Divisions in the Southeast and Northeast submitted a joint letter to BOEM on the EIS in 2012 which requested that EFH consults be conducted on individual surveys as received by BOEM for permitting. A similar request was made by the Office of National Marine Sanctuaries, and the finalized EIS includes both determinations. Noise generated by Atlantic geological and geophysical surveys has the most potential to influence the shelf break spawning areas discussed here. With potential EFH consultations, probabilities of acute injury to fishes will be evaluated close to survey lines as needed. However, these surveys will increase the level of background noise over a much larger area and could, therefore, disrupt activities that rely on acoustic signals, such as spawning, at far greater distances from the survey lines. Such effects have not yet been addressed. Should these surveys lead to the development of oil and gas resources, other noise sources, associated with the building and operation of platforms, both acute and chronic, will be introduced with the potential for associated acoustic effects on spawning behaviors.

NOAA could work with BOEM to assess potential impacts associated with proposed offshore energy exploration and development activities to the acoustic conditions of key spawning locations for acoustically active and sensitive fishes in the Mid- and South Atlantic. EFH Conservation Recommendations could include spatial (set-back distances, buffer zones and exclusions where necessary) or temporal (avoidance of key spawning time periods) mitigation options. In many cases, current baseline data on noise levels within areas designated or being considered by FMCs to protect fishes that are acoustically active during spawning may be insufficient to support mitigation development. Thus, EFH consultations may focus on presenting monitoring recommendations that can serve to improve NOAA's knowledge base in places of importance and guide adaptive management. The SAFMC is currently focused on expanding spatial protections for offshore spawning activity of key snapper and grouper species. Further passive acoustic work would inform these designs. Understanding of activity-specific impacts requires longer term monitoring investment to understand baseline conditions, a gap that could be addressed by increasing NOAA-maintained PAM capacity (see below).

<u>Military Training Activities</u>
NOAA currently works with the U.S. Navy to reduce noise impacts to marine mammals and endangered species and to resources within National Marine Sanctuaries associated with AFTT activities, including the use of sonars and other sound-producing sources. To date, the impacts of these same activities on acoustically-sensitive fishes have received less attention. As discussed above, concentrated vessel or low-flying helicopter activity, or high rates of explosions within localized OPAREA areas could degrade lower frequency acoustic habitats of known importance to offshore spawning species. **NOAA could work with the U.S. Navy to assess whether such patterns of training activity overlap federally designated areas (i.e., EFH HAPC) that protect acoustically active or sensitive spawning fishes.**

NOAA-Funded or Conducted Research
Documentation of baseline noise conditions as well as improved data on the use of sound by fishes within these sites will be necessary to support management action. As indicated above, NOAA (NEFSC, SEFSC, NCCOS and NOS-SBNMS) is actively engaged in research that responds to rising concern regarding noise impacts to key East Coast fish stocks. Some of these projects have historically been supported by non-NOAA funding but have recently begun to be supported internally (e.g., cod spawning research in Massachusetts Bay) while others are actively seeking funding both inside and outside the agency (e.g., NCCOS-Duke seismic research, Duke bridge-construction/pile driving research). Phase I of the development of a NOAA-maintained Noise Reference Station (NRS) network includes a sensor within the Stellwagen Bank National Marine Sanctuary that will be used to characterize trends in acoustic habitat quality for cod and haddock, and other acoustically active/sensitive species. Such capacity is not

currently available for offshore South Carolina sites (the NRS in South Atlantic region is deployed off the central coast of Florida); however, NEFSC and Duke researchers are currently collaborating to develop PAM capacity in the South Atlantic Bight to establish baseline noise conditions relative to protected resource (e.g., cetacean) management concerns. While non-NOAA researchers are in position to address current gaps in knowledge of noise conditions in Pamlico Sound their research has historically highlighted state rather than federally managed species (e.g., red drum) and thus has targeted state agencies for funding and collaboration**.**

NEFSC, NOS-SBNMS and OAR-PMEL could continue to collaborate with key nongovernmental research partners (e.g., Massachusetts Division of Marine Fisheries, Woods Hole Oceanographic Institution) to identify locations of key long-term PAM interest for spawning cod and haddock in Massachusetts Bay.

NEFSC, SEFSC, NCCOS and Duke University could collaborate to incorporate priority locations for offshore spawning fishes (such as the MPAs discussed here) within protected resource-driven plans to develop PAM capacity on the shelf break in the Mid- and South Atlantic. These parties could also assess whether PAM data associated with the Navy's AFTT monitoring programs could be used to inform baseline characterization of low- frequency noise levels in key offshore Mid- and South Atlantic spawning areas for acoustically active or sensitive reef fishes, and if so, what resources would be necessary to derive metrics of interest.

SEFSC and NCCOS could collaborate with North Carolina DMF and key nongovernmental research experts (e.g., North Carolina State University, East Carolina University, Duke University) to identify locations of common passive acoustic monitoring interest in and around Pamlico Sound.

Support for developing PAM capacity at these prioritized locations could be included in NOAA's plans for phased deployment of Noise Reference Stations (see Chapter 3), within funding by NOAA programs that support fishery science (i.e., Fisheries Collaborative Research, Saltonstall-Kennedy Grants) and acoustic or coastal science (i.e., NOAA Ocean Acoustic Program and Sea Grant) and within dialogs with action agencies via EFH consultation. Data resulting from monitoring conducted by NOAA could be included in PAM archival efforts (see Chapter 3) to ensure that is accessible to inform baseline condition representations in management evaluations.

Fishery Management and Council Education and Engagement

The Ocean Noise Strategy has improved engagement and dialog on this issue within NOAA substantially, but communication remains more extensive among protected resources and protected area colleagues than among fishery habitat and management colleagues. **In parallel with further internal NOAA evaluation of this Strategy Roadmap, opportunities (webinars, briefings, brown bags etc.) could be created within Office of Habitat Conservation and Sustainable Fisheries and regional programs to promote further discussion.** These opportunities would further link NOAA's experts in fish spawning behavior, including acoustic behavior, with experts in the design and deployment of passive acoustic monitoring systems associated with consultations and permitting and experts in fishery management and in fish and invertebrate habitat protection.

Improving communication on acoustic issues within NOAA will allow the agency to engage with the fishing community in a consistent manner. Fishing industries and Fishery Management Councils (FMCs) are becoming more involved in the ocean noise discussion, especially associated with offshore use of seismic air guns in the Atlantic. In 2012, the Mid-Atlantic Fishery Management Council wrote to BOEM to oppose seismic testing on the U.S. East Coast. More recently, NSF-sponsored seismic surveys off the

Mid- to South Atlantic generated significant controversy among fishery interest groups. Engagement to date showcases a need for continuing education through the FMCs. **NOAA could develop outreach materials to educate East Coast fishing communities and other stakeholders on the important role that acoustics play in the life history of many species of fishes and invertebrates, what we know about the impacts of various noise sources on these species and their habitats, where uncertainty exists, and ongoing science that NOAA is conducting or supporting to address that uncertainty.**

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