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 Gisiner (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. The locations of these studies were chosen to showcase the application of methodologies discussed in the Roadmap in differing contexts (e.g., types of information available and relevant NOAA mandates for addressing noise impacts).

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Case Study 1:
Assessing the Risk of Chronic Shipping Noise to Baleen Whales off Southern California[7]

Introduction

Ocean noise produced by human activities has significantly increased since the beginning of the industrial era, although the changes have not been evenly distFributed in space and time. Analyses of data collected between 2004 and 2012 at two locations that are not located near major shipping lanes (one in the equatorial Pacific Ocean and one in the South Atlantic Ocean) showed decreases in the ambient sound floor and other sound level parameters (Miksis-Olds & Nichols 2016). In contrast, low-frequency noise has increased in the Northeast Pacific Ocean since the 1960's (Andrew et al. 2011, Chapman & Price 2011) and in the Indian Ocean over the last decade (Miksis-Olds et al. 2013). The increase in low-frequency noise observed in both locations has been linked to increases in shipping. Frisk (2012) used the Northeast Pacific Ocean data that spans several decades and data from areas in the South Pacific Ocean with extremely low shipping traffic to provide a theoretical explanation for the increases. In particular, they show that the increase can be attributed primarily to commercial shipping and that shipping is linked to the global economy.

The Northeast Pacific Ocean data has also been used to assess spatial and temporal variability in noise. In particular, long-term changes (30-50 years) in low-frequency noise have been observed at several locations off the coast of California (Figure 4-1). At two sites, one off Point Sur and one off San Nicolas Island, that occur in deeper waters beyond the continental margin, noise increased at approximately 3dB re 1µPa per decade in the 30-50 Hertz (Hz) band (Andrew et al. 2002, McDonald et al. 2006). This increase is likely representative of noise increases in the Northeast Pacific Ocean deep sound channel caused by increasing commercial shipping, including both increases in the number of ships and increases in their gross tonnage and horsepower (McDonald et al. 2006). Although the change in noise at these two sites was similar, the 4-8dB higher noise levels at Point Sur than at San Nicolas Island are likely caused by the closer proximity of the Point Sur site to major shipping lanes. In contrast, noise measured during periods with no local ship traffic did not change between the 1960's and the 2000's at a site on the continental shelf (in waters 110m deep) near San Clemente Island, suggesting that noise at this site is influenced more by wind, biological sources, and local shipping than distant shipping noise from the deep sound channel (McDonald et al. 2008). More recent measurements of noise (i.e., 1994-2007) at Point Sur and San Nicolas Island show that low-frequency noise is remaining constant or slightly increasing, with one exception of decreasing 50Hz noise at Point Sur (Andrew et al. 2011).

The noise monitoring locations in the Northeast Pacific Ocean overlap with important habitat for baleen whales. In particular, blue whales feed in southern California waters from June to October (Calambokidis et al. 2015), humpback whales feed in these waters from March to November (Calambokidis et al. 2015), and aggregations of fin whales have been observed in these waters year-round (Forney et al. 1995). A seven year summary of blue and fin whale calls in southern California waters detected blue whale 'B calls' (tonal calls with a downsweep in frequency) between June and January, with a peak in September (Sirović et al. 2015). The 'B calls' are one of three blue whale calls that have been recorded in the southern California Bight (Sirović et al. 2015). Series of 'A calls' (a series of rapid, low-frequency pulses) and 'B calls' (~16Hz) are believed to serve a reproductive function (Oleson et al. 2007). Blue whale 'D calls' are more variable in their characteristics (~25-90Hz) and are

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[7] A version of this work is under review for publication as Redfern, J., Hatch, L.T., Caldow, C., DeAngelis, M.L., Gedamke, J., Hastings, S., Henderson, L., McKenna, M.F., Moore, T.J., and Porter, M.B. *Endangered Species Research.*

believed to serve a social function (Oleson et al. 2007). Fin whale 20Hz calls (these downswept pulses can be produced in regular or irregular sequences, with regular sequences attributed to males) were detected year-round, but occur at the highest levels between September and December, with a peak in November (Sirović et al. 2015). Humpback whale calls (~150-1800Hz) have also been recorded in these waters (Helble et al. 2013).

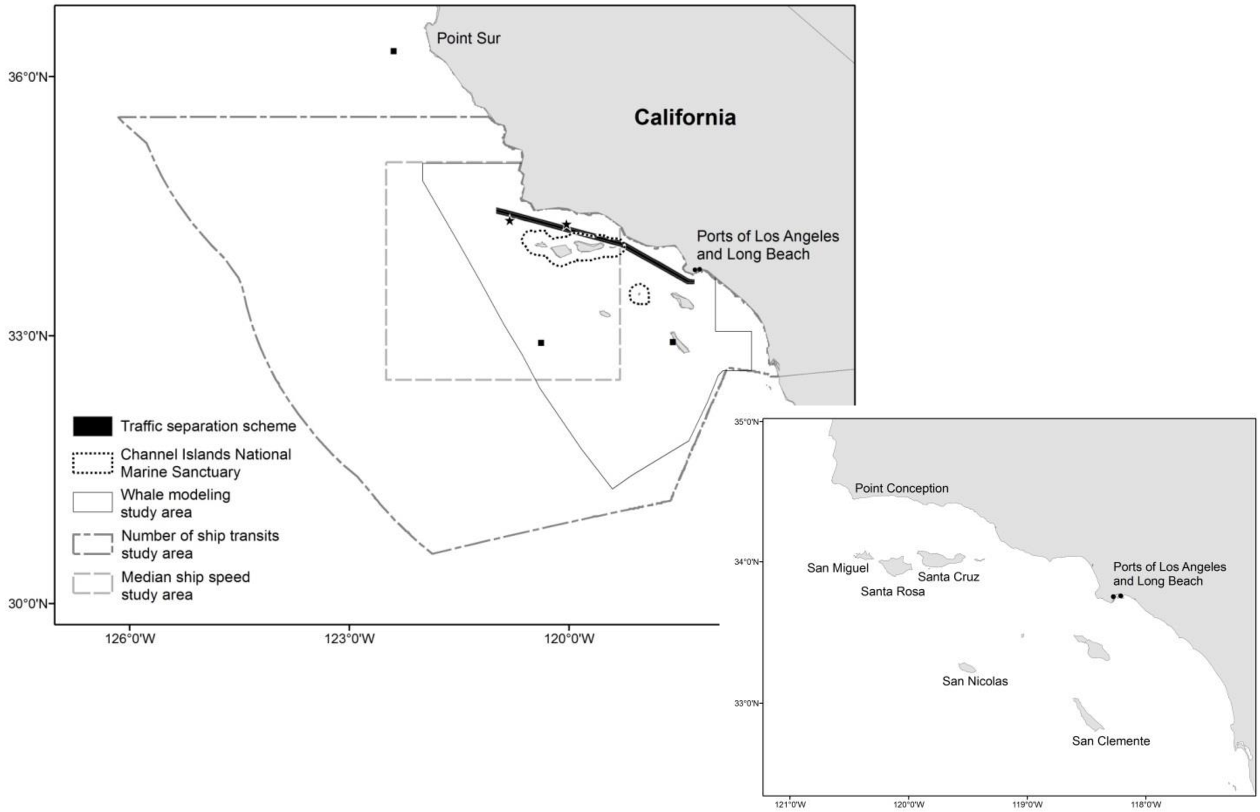

Figure 4-1. Waters off the southwestern United States are shown, including the Channel Islands National Marine Sanctuary, the Traffic Separation Scheme in the Santa Barbara Channel adopted by the International Maritime Organization, and three study areas used in our analyses: the whale modeling, number of ship transits, and median ship speed (see text for details). The two largest ports (Los Angeles and Long Beach) are shown as black circles. The locations of High-frequency Acoustic Recording Packages 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. The inset shows the names of locations mentioned in the text.

All three species are currently listed as Endangered under the Endangered Species Act (ESA 1973) and as Depleted and Strategic under 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, entanglements, and anthropogenic noise. Although poorly understood, use of sound by baleen whales is assumed to include, but not be limited to, hearing conspecific calls. In particular, baleen whales are believed to rely on low-frequency sounds for feeding, breeding, and navigation. The potential effects of noise on baleen whales have been recognized for over 40 years (Payne & Webb 1971) and more recently behavioral responses to shipping noise have been documented for all three species (e.g., Sousa-Lima & Clark 2008, Castellote et al. 2012, Melcón et al. 2012). Low-frequency noise can also result in acoustic masking, which impedes an individual's ability to effectively perceive, recognize, or decode sounds of interest (Clark et al. 2009); consequently, areas with elevated noise may represent degraded acoustic environments. The large noise increases in the Northeast Pacific Ocean have occurred within the lifetime of these baleen whales and at frequencies that form an important part of their acoustic environment.

Southern California waters were 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). The Channel Islands National Marine Sanctuary (CINMS) is located within these waters (Fig. 4-1) and has been a particular focus of these discussions because U.S. National Marine Sanctuaries have unique mandates associated with managing designated areas of the marine environment. For example, CINMS regulations prohibit taking (e.g., harassing, harming, capturing, or killing) any marine mammal within the Sanctuary, except as authorized by the MMPA and the ESA. 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 (2007) concluded that pursuit of sanctuary authority to regulate noise would face obstacles and would not address the influence of shipping noise beyond the boundary of the CINMS. Haren (2007) 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). A PSSA is an area that needs special protection because of its significance and vulnerability to shipping. Management measures associated with the PSSA could require or recommend that ships operate in a manner that reduces noise (e.g., travel at slower speeds or use alternative shipping routes). A better understanding of the risk of noise to marine species in this region is needed to define specific management measures (e.g., seasonal or dynamic slow speed zones and alternative shipping routes).

Estimates of the loss of acoustic communication space can be a valuable tool for assessing risk caused by low-frequency, chronic noise (Clark et al. 2009, Hatch et al. 2012). Spatially explicit risk assessments have also been conducted using spatial representations species of habitats and underwater noise generated by human activity. For example, Erbe et al. (2012) mapped cumulative underwater acoustic energy from shipping using a simple sound transmission model and Automatic Identification System (AIS) data. Erbe et al. (2014) combined these data with species distributions using audiogram weighting across a range of frequencies to identify species-specific hotspots of ship noise. Williams et al. (2015) used the same data and a similar approach to identify important species habitats that occur in areas with little noise.

We conducted a spatially explicit assessment of the risk of noise from commercial shipping to blue, fin, and humpback whale habitats in Southern California waters. We use AIS data to model noise at two frequencies that are part of the acoustic environment for these species and capture the variable contributions from shipping to noise. In particular, we selected 50Hz to represent a peak in the contribution from shipping to noise and 100Hz to represent where contributions from shipping to noise begin to diminish (National Research Council 2003). Predicted noise was compared to noise measurements at two sites within the study area.

Our analyses focus on the contribution of shipping to noise in baleen whale habitats, rather than focusing on masking of specific communication signals (e.g., the techniques that Clark et al. (2009) and Hatch et al. (2012) used). We assume that these species are using low frequencies for a variety of biological functions (feeding, breeding, and navigation) and that they can be broadly impacted by noise occurring at low frequencies. Our analyses identify areas where species habitat (defined using three sources of distribution data that capture different habitat elements) overlaps with low-frequency noise created by commercial shipping. Due to their extreme low-frequency calling activity, we assess risk, or potential for degradation of the acoustic environment, for fin and blue whales using our lower, 50Hz modeled noise. Our slightly higher 100Hz modeled noise is used to assess risk to humpback whales because it better reflects frequencies used in their vocal repertoires. These noise and risk characterizations allow managers and stakeholders to identify areas where chronic noise may impact the acoustic environment of these three species in Southern California waters. Specifically, our assessment identifies hotspots of noise in species habitats, similar to Erbe et al. (2014), and areas within species habitats that are currently quiet, similar to Williams et al. (2015).

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. This approach was used in the NOAA Fisheries CetSound project (http://cetsound.noaa.gov), but our models use higher resolution shipping information obtained from AIS data (see below). 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 models currently only include noise produced by commercial shipping; however, this approach could be used to integrate noise from multiple human activities.

Our models 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 models 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 models 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 that extended farther north and offshore than the whale modeling study area (Fig. 4-1). The whale modeling study area corresponds to the extent of transects covered by NOAA Fisheries’ Southwest Fisheries Science Center on systematic marine mammal and ecosystem assessment surveys. A broader area was used to analyze the shipping data to ensure that the models included noise from as many ships affecting the whale modeling study area as possible. AIS data were downloaded from NOAA Fisheries’ Coastal Services Center’s Marine Cadastre website (www.marinecadastre.gov).

We only used AIS 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 and 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 (2011), 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 for large-scale and long-term noise predictions. However, variability among individual ships within a length 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 length 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 because ships 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), the noise reduction may be offset by the increased time ships spend 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 levels (dB re 1µPa^2 / Hz) 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.

Predictions from the noise models were compared to empirical underwater acoustic data collected at two sites in the region (McKenna 2011), one north of the Santa Barbara Channel Traffic Separation Scheme (TSS) between Santa Rosa and Santa Cruz Islands and one on the southwestern edge of the TSS (Fig. 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 collected in November 2009 were decimated to a sampling frequency of 2kHz and processed to calculate monthly sound spectrum averages. Spectrum measurements (reported as root-mean-square re: 1 μPa^2 /Hz) were produced using 225s samples of continuous data with no overlap between each spectral average using a discrete-time Fast-Fourier Transforms (FFT). All spectra were processed with a Hanning window and 2000 point FFT length, yielding 1Hz frequency bins. We calculated the arithmetic mean of the resulting pressure squared values and converted to dB scale for each frequency bin to be consistent with the modeling methodology. Monthly sound spectrum averages for 49 and 99 Hz (offset by 1Hz to avoid instrument system noise) were reported to represent empirical measurements of background noise that could be directly compared to 50 and 100 Hz noise level predictions. Comparisons were made between the empirical measurements from the HARP and predicted noise in the cell containing the HARP (see Table 1).

Modeled noise was also compared to pre-industrial noise levels, which are considered to represent 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 Island (Fig. 4-1). Wenz (1962) more generally represented “light shipping” conditions to be approximately 65dB at 50Hz. Drawing from this literature, we selected 65dB to approximate an upper bound for both 50 and 100Hz pre-industrial noise conditions in our study area. Modeled noise was summarized using the 10th, 50th (median), and 90th percentiles of predicted values. The estimate of pre-industrial noise conditions and the percentiles were used to define five categories for the predicted noise levels at 50 and 100Hz: <65dB (pre-industrial noise conditions), 65dB to the 10th percentile, 10th to 50th percentiles, 50th to 90th percentiles, and >90th percentile. These five categories were compared to time series of noise measurements off Point Sur (Fig. 4-1) to assess their correspondence to different volumes of shipping traffic.

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 (Fig. 4-2) capture large-scale and long-term 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 (BIAs) in these waters (Fig. 4-2). The BIA boundaries were based on expert judgment and were drawn to encompass concentrations of feeding animals (direct observation of feeding or surfacing patterns suggestive of feeding) that were present in multiple years. Non-systematic, coastal (i.e., within 50nmi) surveys conducted by small boat to maximize encounters with blue and humpback whales for photo-identification and tagging studies were the primary data sources used to delineate the BIA boundaries. The BIAs for both species compare favorably to densities predicted by habitat models developed using data from the entire U.S. West Coast, including the southern California data used by Redfern et al.

(2013). Differences occur because the two data sets provide complementary information: the small boat surveys used to delineate the BIAs were better able to capture nearshore, fine-scale distribution patterns and the habitat models based on the systematic surveys captured broad-scale distribution patterns throughout nearshore and offshore waters (Calambokidis et al. 2015). We compare the BIAs to the densities predicted by Redfern et al. (2013) using whale habitat models developed for just southern California waters. Finally, the CINMS has been collecting opportunistic sightings (primarily from whale watching vessels) in the Santa Barbara Channel since 1999 (Fig. 4-2). These data provide information about where whales were present, but do not provide information about relative densities or absences.

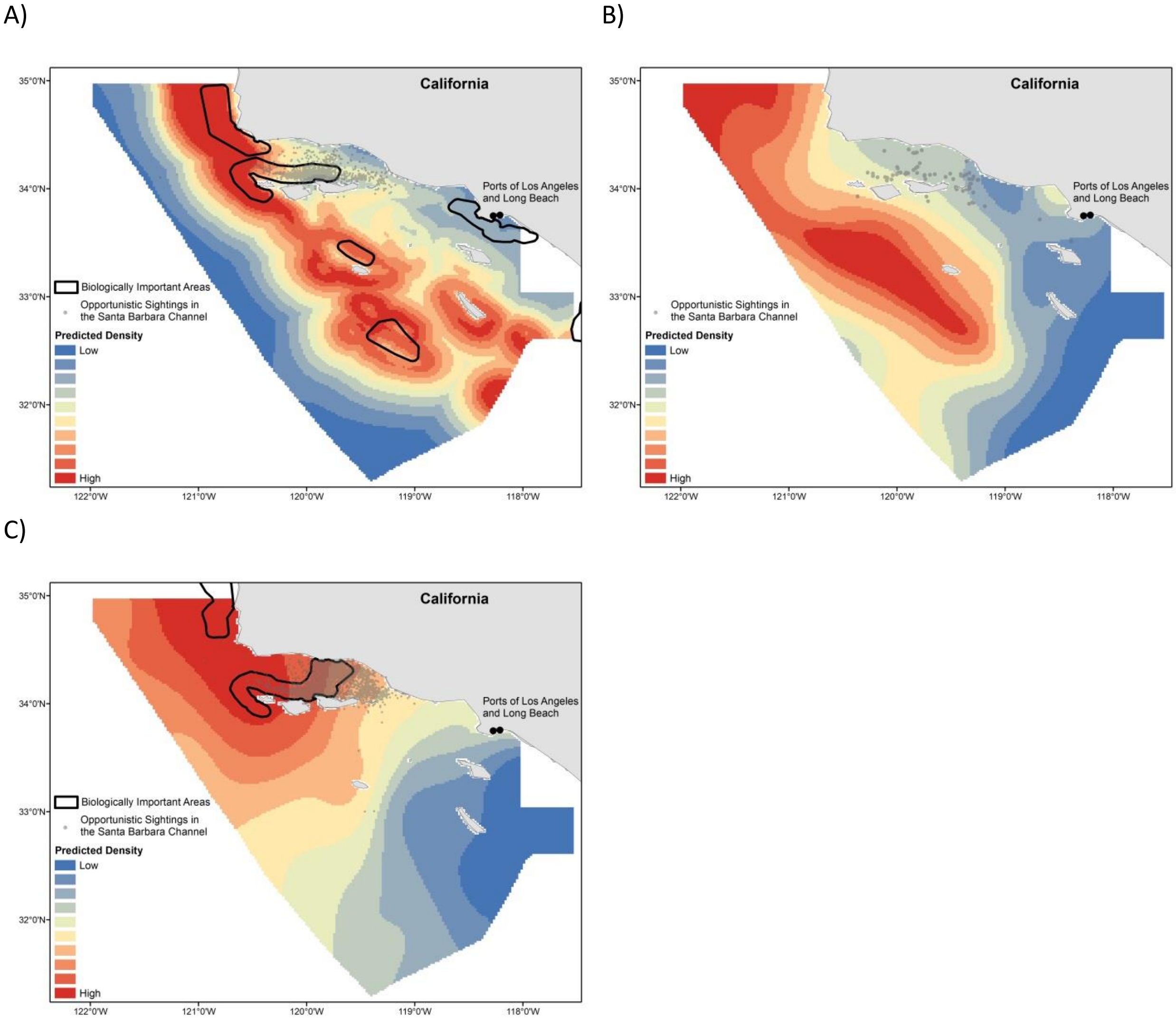

Figure 4-2. Habitat representations for A) blue, B) fin, and C) humpback whales between August and November from three data sources. A habitat model was developed from seven years of line-transect data and used to predict density throughout the whale modeling study area. Predicted densities are shown in 10 approximately equal area categories. Biologically Important Areas (BIAs) represent areas of high concentrations of feeding animals (BIAs have not yet been defined for fin whales). Opportunistic sightings have also been collected in the Santa Barbara Channel (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).

We used all three sources of whale distribution data to estimate the co-occurrence of each species' habitat with noise. We assess risk, or potential for degradation of the acoustic environment, for fin and blue whales using the modeled 50Hz noise. We use the modeled 100Hz noise to assess risk for humpback whales because humpback whale vocalizations occur at higher frequencies than blue and fin whale vocalizations. Predictions from the habitat models were made in a 2km x 2km grid; 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 the five noise categories for the highest 20% of predicted densities, BIAs, and presence cells.

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 (Fig. 4-3A and B). It also shows that smaller ships travel closer to the coast than larger ships. Predicted 50 and 100Hz noise levels at 30m depth reflected these shipping traffic patterns (Fig. 4-3C and D). However, predicted noise also reflects longer-distance, low-frequency propagation from distant shipping traffic in some regions, such as offshore of Point Conception, west of San Miguel Island, and south of the northern Channel Islands. In contrast, the Santa Barbara Channel is not exposed to noise from distant shipping traffic. Median predicted noise levels were 88dB at 50Hz and 77dB at 100Hz (Fig. 4-4). At the HARP north of the Santa Barbara Channel TSS between Santa Rosa and Santa Cruz Islands, predicted 50 and 100Hz noise 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 levels were closer to measured noise (within 3dB) (Table 4-1).

Predicted 50 and 100Hz noise levels at the 10th, 50th (median), and 90th percentiles corresponded to low, moderate, and heavy levels of shipping traffic in a time series of measurements made off Point Sur (Table 4-2). The estimate of pre-industrial noise conditions (65dB at both frequencies) and the percentiles were used to define ranges of predicted noise levels associated with five volumes of shipping traffic: pre-industrial, low, moderate, heavy, and extreme (Table 4-2). Over 99% and 94% of the whale modeling study area contained predicted 50 and 100Hz noise levels, respectively, above pre-industrial noise conditions.

Noise levels predicted in the CINMS spanned the range of noise levels predicted in the whale modeling study area. When considering the entire CINMS and comparing it to predicted noise levels in the whale modeling study area, the CINMS represents a quieter area (Table 4-3). It contained some of the few remaining places within the whale modeling study area that are predicted to have pre-industrial noise conditions. Although the portion of the CINMS with pre-industrial noise levels was small at 50Hz (4%), approximately half of the CINMS was associated with 50 and 100Hz noise levels categorized as either pre-industrial or lower traffic volumes. However, approximately 22-24% of the CINMS also contained predicted noise levels in or above levels associated with heavy volumes of shipping traffic.

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

Location	Sea floor depth	Noise predicted 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

* TSS = the traffic separation scheme adopted by the International Maritime Organization in the Santa Barbara Channel

Table 4-2. Ranges of predicted 50 and 100Hz noise levels (reported in decibels) associated with different volumes of shipping traffic. The upper values in the ranges for low, moderate, and heavy shipping traffic are the 10th, 50th (median), and 90th percentiles of predicted noise levels in the whale modeling study area (rounded to the nearest whole number). The noise levels for each percentile correspond to empirical measurements of different volumes of shipping traffic.

Volume of shipping traffic	50Hz	100Hz	Empirical measurement
Pre-industrial	< 65	< 65	Wenz (1962) “light traffic deep”; McDonald et al. (2008)
Low	65 - 81	65 - 68	Wenz (1962) “usual traffic deep”; Point Sur ~1960
Moderate	81 - 88	68 - 77	Urick (1984) "moderate traffic"; Point Sur ~1980
Heavy	88 - 96	77 - 85	Urick (1984) "heavy traffic”; Point Sur ~1995
Extreme	> 96	> 85	

Table 4-3. The percentage of the Channel Islands National Marine Sanctuary that contained predicted 50Hz and 100Hz noise levels associated with different volumes of shipping traffic (see Table 4-2 for the range of noise levels in each category).

	Channel Islands National Marine Sanctuary	
Volume of shipping traffic	50Hz	100Hz
Pre-industrial	3.9	42.9
Low	49.7	12.8
Moderate	22.3	22.4
Heavy	13.2	14.3
Extreme	10.9	7.6

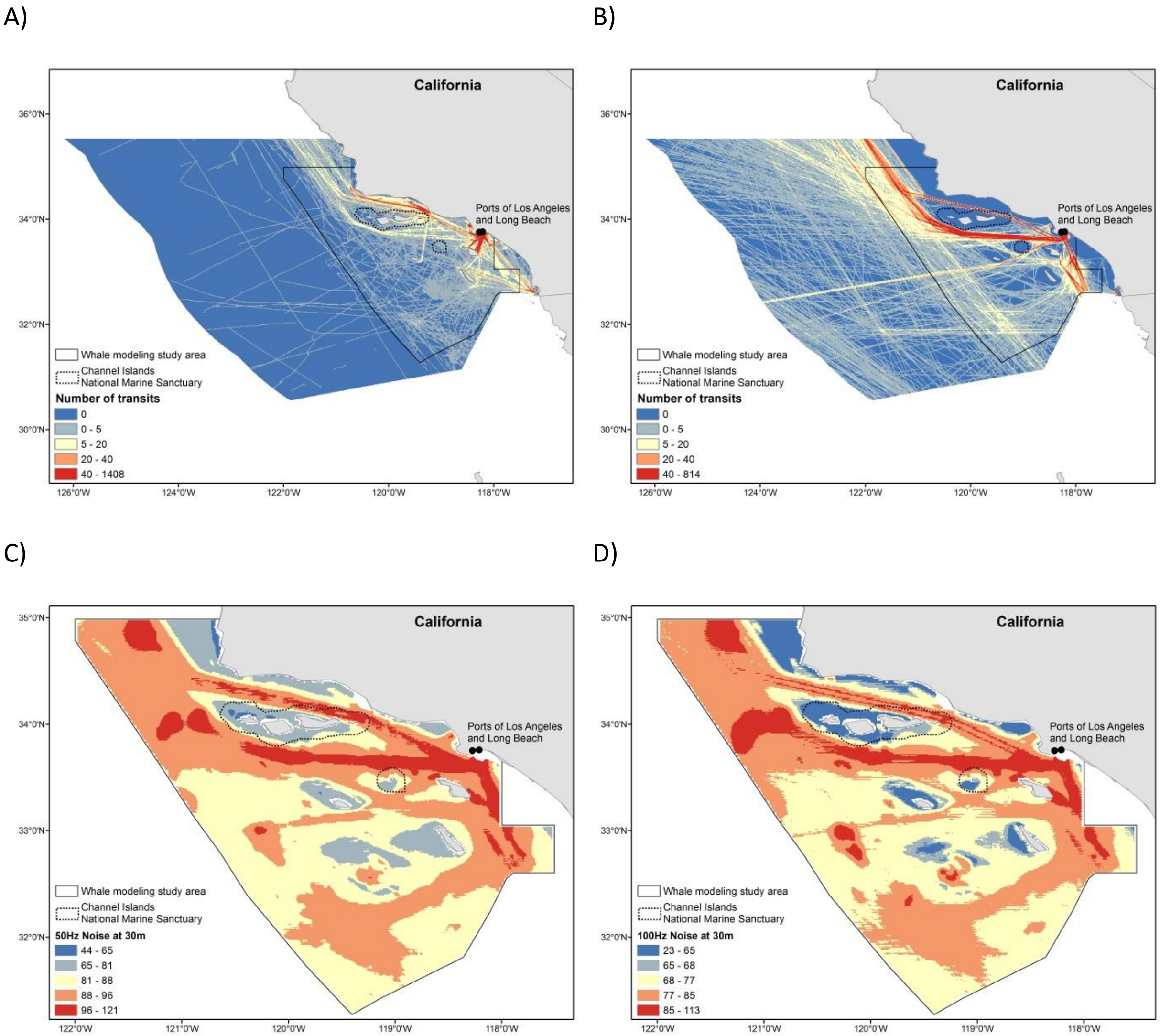

Figure 4-3. The number of transits by ships A) ≥ 18m and ≤ 120m in length and B) >200m and <=320m in length between August and November in 2009 was calculated in an area larger than the whale modeling study area to capture the influence of ships in surrounding waters in the noise predictions. Maps for the two other ship length categories (> 120m and ≤ 200m in length and > 320m in length, see text for details) are not shown because their traffic patterns are similar to the patterns seen for ships >200m and <=320m in length. Predicted C) 50Hz and D) 100Hz noise levels at 30m depth between August and November 2009. Noise predictions at both frequencies are categorized using an estimate of pre-industrial noise conditions (65dB) and the 10th, 50th, and 90th percentiles of the predictions. Noise predictions generally correspond to the traffic patterns for larger ships, although some influence from smaller ships can also be seen.

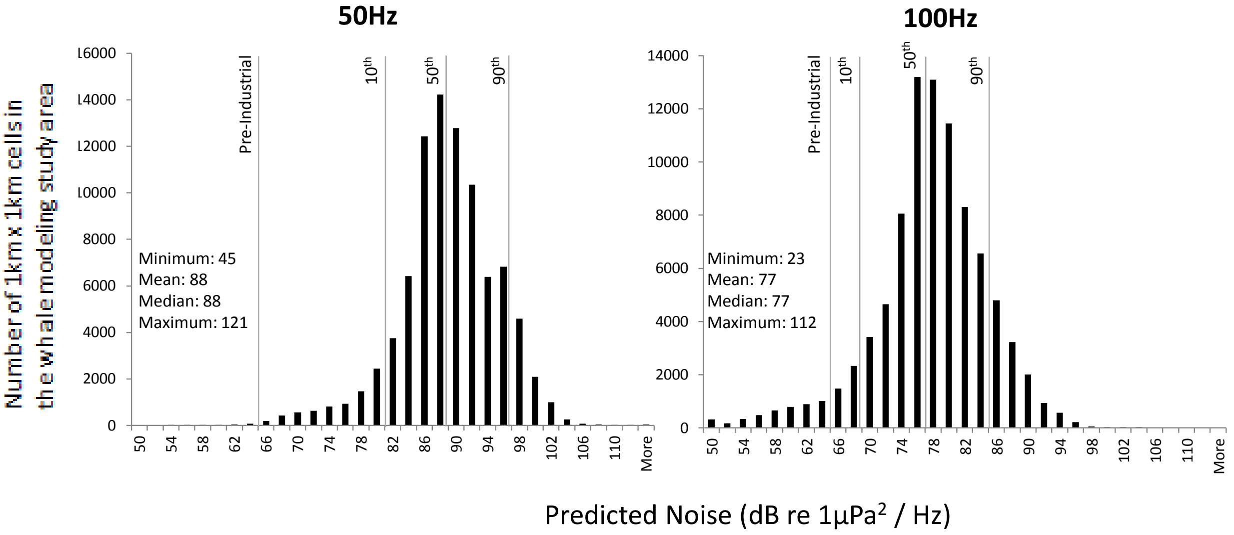

Figure 4-4. Histograms of 50 and 100Hz predicted noise levels within the whale modeling study area. The x-axis and summary statistics are in decibels (dBs). Thin gray lines mark the noise levels used in our analyses: pre-industrial noise below 65dB for both frequencies and the 10th, 50th (median), and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

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 generally overlap with the higher densities predicted by the habitat model; however, the model predicts higher blue whale densities throughout a much broader offshore region (Fig. 4-2A). Almost no blue whale habitat, regardless of the data source used to define habitat, contained pre-industrial noise conditions and the majority of blue whale habitat contained predicted 50Hz noise levels associated with moderate, heavy, and extreme volumes of shipping traffic (Table 4-4). Noise risk hotspots occurred near the ports of Los Angeles and Long Beach, in the Santa Barbara Channel (including areas inside the CINMS), and in discrete offshore locations (Fig. 4-5A). In coastal waters off Point Conception, a blue whale BIA overlaps with a relatively quieter area associated with low volumes of shipping traffic.

Table 4-4. Whale habitat was defined using the highest 20% of densities predicted by a habitat model (Density), biologically important feeding areas (BIA; BIAs have not yet been identified for fin whales), and areas containing opportunistic sightings (Sightings). We estimated the percentage of each habitat type that contained predicted 50Hz (blue and fin whales) and 100Hz (humpback whales) noise levels associated with different volumes of shipping traffic (see Table 2 for the range of noise values in each category).

	Blue Whales			Fin Whales		Humpback Whales		
Volume of shipping traffic	Density	BIA	Sightings	Density	Sightings	Density	BIA	Sightings
Pre-industrial	0.3	1.3	0.1	0.0	0.0	18.9	52.4	25.4
Low	24.7	37.9	29.2	6.8	26.9	4.3	10.1	12.3
Moderate	36.8	26.2	18.3	35.9	16.4	14.2	21.2	29.0
Heavy	32.6	22.8	31.2	50.9	35.8	44.3	13.4	23.8
Extreme	5.6	11.9	21.2	6.4	20.9	18.2	2.9	9.6

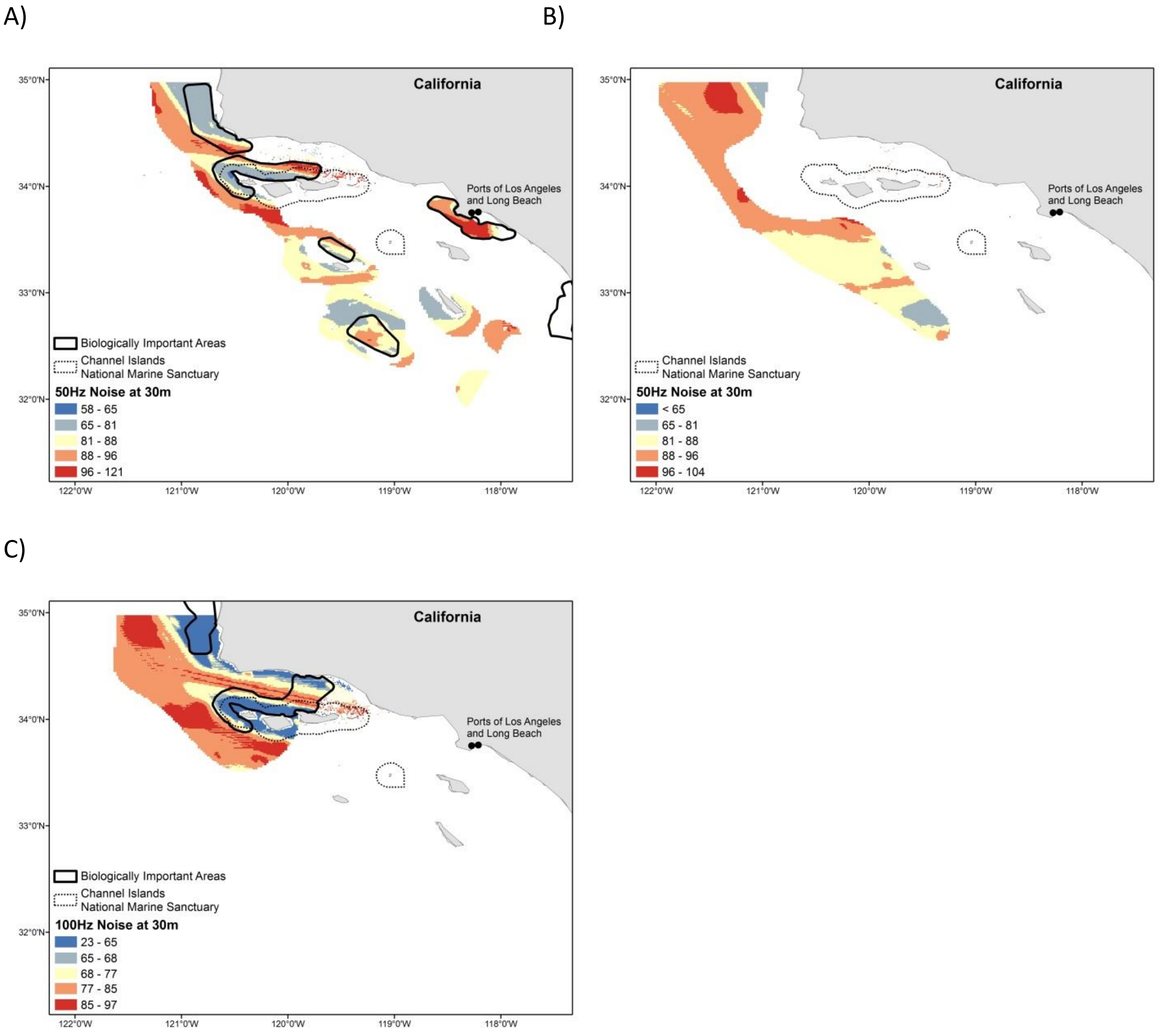

Figure 4-5. Predicted noise levels at 50Hz are shown in categories associated with different volumes of shipping traffic (< 65dB = pre-industrial; 65-81 = low; 81-88 = moderate; 88-96 = heavy; >96 extreme) for A) blue and B) fin whale habitat (i.e., the highest 20% of predicted densities, within BIAs, and in cells with opportunistic sightings). Fin whale BIAs have not yet been defined. No fin wale habitat contained predicted noise levels below 65dB. Noise at 100Hz is also shown in categories associated with different volumes of shipping traffic (< 65dB = pre-industrial; 65-68 = low; 68-77 = moderate; 77-85 = heavy; >85 extreme) for C) humpback whale habitat. Noise risk hotspots, areas where species habitat contained elevated noise, can be identified and represent areas where the acoustic environment for the species may be degraded by shipping noise. Quieter areas within species habitat can also be identified.

Fin whale habitat (Fig. 4-2B) occurred in offshore waters and generally had the least overlap with predicted 50Hz noise levels associated with pre-industrial and low volumes of shipping traffic (Table 4). In particular, no fin whale habitat contained pre-industrial noise conditions. Additionally, over 50% of fin whale habitat contained predicted 50Hz noise levels associated with heavy and extreme volumes of shipping traffic (Table 4-4). Noise risk hotspots occurred offshore of Point Conception and to the west and south of the northern Channel Islands (Fig. 4-5B).

Humpback whale habitat occurred in the northernmost portion of the whale modeling study area (Fig. 4-2C). The humpback whale BIAs overlap with the higher densities predicted by the habitat model; however, the model predicts higher humpback whale densities farther offshore than the BIAs (Fig. 4-2C). Humpback whale habitat contained a larger percentage of area associated with pre-industrial noise conditions, compared to blue and fin whales (Table 4-4). These quiet areas occurred in the CINMS and in coastal waters off Point Conception (Fig. 4-5C). Noise risk hotspots occurred primarily in offshore habitat, but also occurred in the Santa Barbara Channel and the CINMS (Fig. 4-5C).

Discussion

Predicted noise levels in southern California waters suggest high, region-wide exposure to shipping noise. For example, over 99% and 94% of the whale modeling study area contained predicted 50 and 100Hz noise levels, respectively, above our approximation of pre-industrial conditions. The predicted noise levels were broadly comparable to time series of ocean noise measurements made in central and southern California (Urick 1984, McDonald et al. 2008). The agreements and differences between predicted noise levels and the HARP measurements highlight the many sources of variability that influence predicted noise 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. 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 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).

Our noise models were developed using the number of ship transits between August and November 2009. In contrast, the HARP measurements were made in November 2009. The much higher (5-12dB) differences between predicted and measured noise at the northern HARP likely occurred because the HARP measured reduced traffic in the Santa Barbara Channel during November, compared to the higher traffic within the Santa Barbara Channel during the earlier part of time period used in the noise models (August through November). The smaller differences (less than 3dB) between predicted and measured noise at the southwestern HARP likely occurred because the increased traffic traveling south of the northern Channel Islands was measured by the HARP during November and incorporated in the later part of time period used for the noise models (August through November).

The differences in predicted versus measured noise may also be the result of ship source levels. The noise models 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 1Hz-band ship source levels used in the noise models 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 models 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 models could be improved by increasing the resolution of bottom-type data for waters off Southern California because sound propagation is influenced by bottom type. As more measurements of ocean noise become available in southern California waters, the comparison between predicted and measured noise should be expanded spatially and temporally.

Our risk assessment identified several areas in southern California waters where the acoustic environment may be degraded for blue, fin, and humpback whales because their habitat overlaps with predicted areas of elevated noise from shipping traffic. In particular, the Santa Barbara Channel contained higher predicted densities and biologically important feeding areas for blue and humpback whales that overlap with elevated noise from the TSS. The TSS was changed in 2013 to reduce the risk of ships striking whales. To understand how this change affects the overlap between whale habitat and noise, risk assessments must be conducted using traffic data collected after this change. Areas offshore of Point Conception, west of San Miguel Island, and south of San Miguel Island and Santa Rosa Island contained higher predicted densities of all three species and elevated noise from commercial shipping.

In general, fin whale habitat was predicted to occur in noisier waters than blue and humpback whale habitat. The habitat models developed by Redfern et al. (2013) predict higher fin whale densities farther offshore than higher blue whale densities, resulting in a higher overlap between fin whale habitat and predicted 50Hz noise levels. 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 levels were lower. In general, predicted 100Hz noise levels were lower 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 noise risk to humpback whales because their conspecific vocalizations span a broad range of low frequencies. The co-occurrence of blue and fin whale habitat and predicted 50Hz noise levels raises concerns about the quality of their acoustic environment and how it supports their communication at extreme 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.

Our risk assessment also identifies two places where biologically important blue and humpback whale feeding areas overlap with lower predicted noise levels: in coastal waters off Point Conception and in the CINMS. When considering the entire CINMS, it represents a relatively quieter area within the generally noisy southern California waters. In particular, approximately half of the CINMS contained predicted noise levels associated with pre-industrial and low volumes of shipping traffic. Noise has not been directly managed in the CINMS; instead, areas containing reduced noise levels in the CINMS are likely an ancillary benefit of the Area to be Avoided (ATBA) that was created around most of 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 an island or engaged in fishing or kelp harvesting. As a result of the ATBA and restrictions close to the islands, ship traffic and, concomitantly, elevated noise in the CINMS has been primarily restricted to where the TSS overlaps with the Sanctuary's boundaries (Fig. 4-3). This overlap results in approximately 22-24% of the CINMS containing predicted 50 and 100Hz noise levels in or above levels associated with heavy volumes of shipping traffic.

Our 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 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 interannual variability is caused by changes in oceanographic conditions on annual (e.g., the El Niño Southern Oscillation), decadal (e.g., the Pacific Decadal Oscillation), and longer time scales (e.g., climate change). 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 levels during the August to November time period, in addition to predicted values averaged over this time period. It could also be expanded beyond the single frequencies we selected to capture the variable contributions from shipping to noise using one-third octave bands or audiogram weighting (e.g., the approach developed by Erbe et al. 2014).

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 environments 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.

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, new and different types of management may be needed to address low-frequency ocean noise. Place-based management focuses on a specific ecosystem and the range of activities that impact it (Hatch & Fristrup 2009). Our risk assessment highlights how noise is affected by several place-based management techniques: a National Marine Sanctuary, an IMO Area to be Avoided, and an IMO traffic separation scheme. Previous evaluations concluded that pursuit of sanctuary authority to directly manage low-frequency noise would face obstacles and would not address the influence of shipping noise beyond sanctuary boundaries (Haren 2007). However, our risk assessment suggests that the IMO's designation of most of the CINMS as an ATBA has resulted in lower noise in many areas of the sanctuary, compared to southern California waters in general. Consequently, a variety of international management tools focused more broadly on reducing spatial overlap between human activities and vulnerable marine areas may provide opportunities for successful noise management.

Traffic Separation Schemes concentrate shipping traffic and noise. Where the TSS occurs in the CINMS, resources are exposed to high levels of low-frequency noise creating a gap in the sanctuary's placed-based protection. This gap is of particular concern due to the biologically important blue and humpback whale feeding areas that occur in this region. Offshore areas containing the highest predicted densities of fin whales were also heavily impacted by noise. Noise in heavily impacted biologically important areas could be reduced by designating these areas as Particularly Sensitive Sea Areas (highlighting their need for special protection) and implementing management measures that require or recommend that ships operate in a manner that reduces noise.

Biologically important areas for humpback and blue whales in coastal waters off Point Conception contained some of the remaining quiet areas in southern California waters. Areas that support feeding and breeding for these populations and that are currently quieter, relative to regional levels, could be designated as Areas to be Avoided to ensure they remain free of high levels of shipping traffic. Studies of ship-strike risk have also been conducted in southern California waters (Redfern et al. 2013). Strategies for reducing ship-strike risk have been implemented in many parts of the world and include moving or creating a TSS, moving or creating voluntary shipping routes, and reducing ship speed. These strategies may also reduce noise. Hence, the consequences of low-frequency noise should be considered with ship strikes in cumulative risk assessments and marine spatial planning. Most placed-based management strategies are static in space and time. There is also a need to consider dynamic management strategies to respond to the spatial and temporal variability inherent in marine mammal distributions and human use patterns.

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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

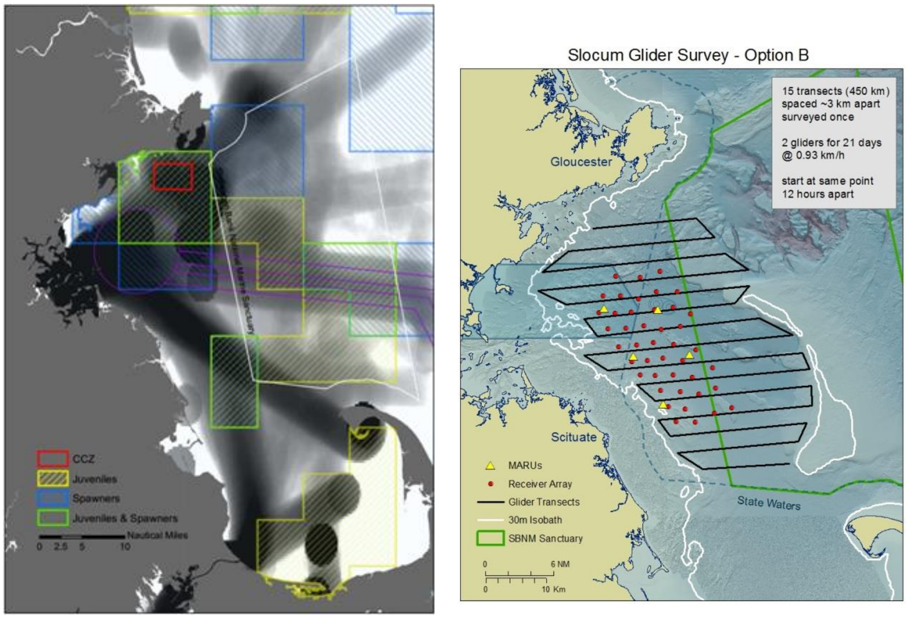

Figure 4-6. Massachusetts Bay off the Northeast Coast of the U.S. (A) Proposed areas associated with spawning Atlantic cod, juvenile Atlantic cod and both (spawning and juvenile) as presented by the Closed Area Technical Team to the Northeast Fisheries Management Council (April 2013); Cod Conservation 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).

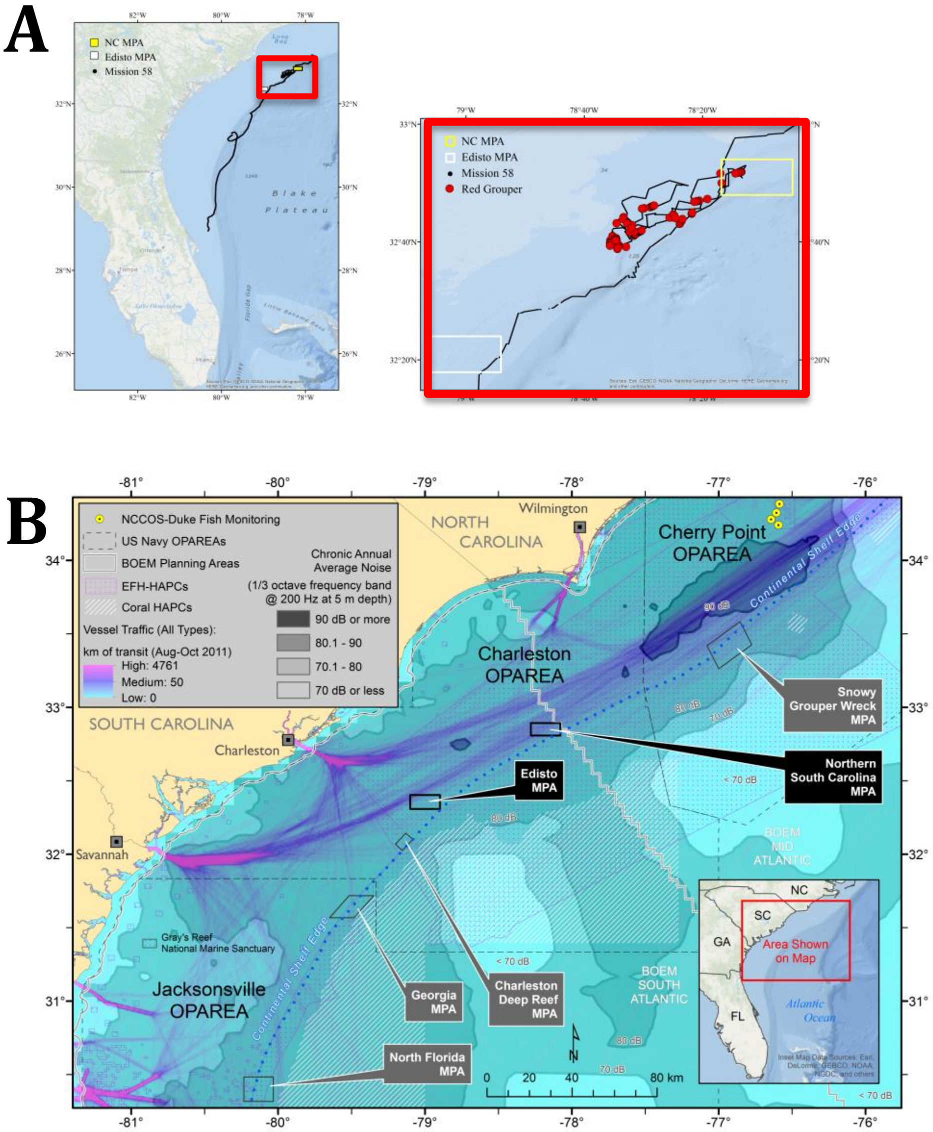

Figure 4-7. Offshore North and South Carolina, South Atlantic Bight, U.S.

(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).

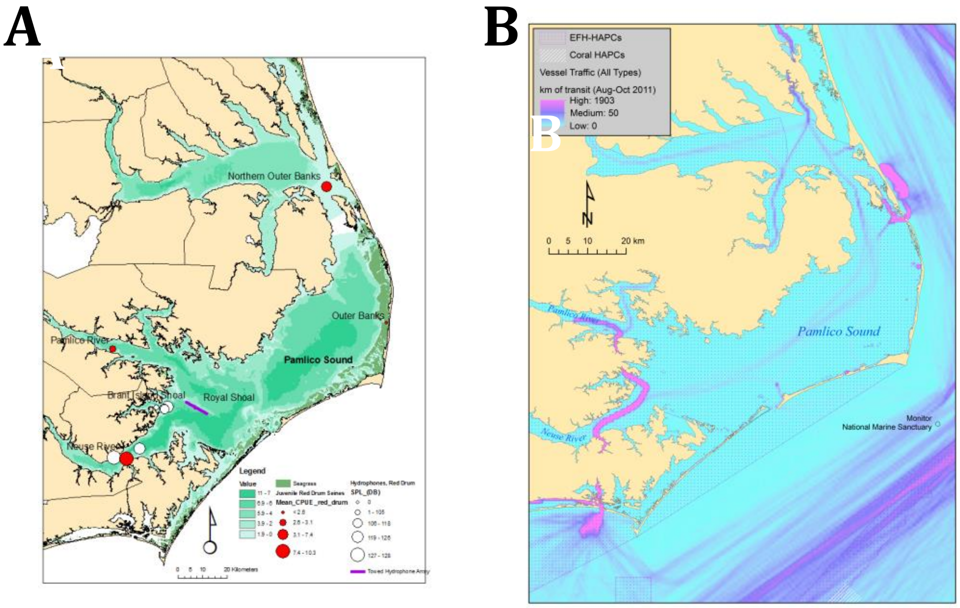

Figure 4-8. Inshore Cape Hatteras to Cape Lookout, Pamlico Sound, North Carolina.
(A) Known red drum spawning areas, based on passive acoustic detections of the advertisement sounds produced by males, larval fish collections and North Carolina DMF seine surveys.
(B) Vessel traffic snapshot (3 months) 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/). 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).

Military Training Activities

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. **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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