OCS Study
BOEM 2021-022

Marine Mammal Risk Assessment for Gulf of Mexico G&G Activities

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

BOEM
Bureau of Ocean Energy Management

OCS Study
BOEM 2021-022

Marine Mammal Risk Assessment for Gulf of Mexico G&G Activities

March 2021

Authors:

Brandon Southall (Contractor, Technical POC)
William Ellison
Christopher Clark
Dominic Tollit
Jennifer Amaral

Prepared under Contract: 140M0120C0007

By:
Southall Environmental Associates, Inc.
9099 Soquel Dr, suite 8
Aptos, CA 95003

and

Marine Acoustics, Inc.
SMRU Canada, Consulting

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Contract Number 140M0120C0007. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

To download a PDF file of this report, go to the US Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2020-xxx. The report is also available at the National Technical Reports Library at https://ntrl.ntis.gov/NTRL/.

CITATION

Southall B, Ellison W, Clark C, Tollit D, Amaral J. 2021. Marine mammal risk assessment for Gulf of Mexico G&G activities. Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2020-xxx. xx p.

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

ANNR	Ambient noise-noise ratio
BOEM	Bureau of Ocean Energy Management
dB re 1 μPa	decibels relative to 1 micropascal
DEIS	Draft Environmental Impact Statement
G&G	geological and geophysical
GoMex	Gulf of Mexico
HF	high-frequency
IUCN	International Union for the Conservation of Nature
LF	low-frequency
MF	mid-frequency
rms	root-mean-square
SAR	stock assessment report
TL	transmission loss

1 Overview

An expert working group of acousticians and biologists with extensive backgrounds in research, engineering, interpretation, and policy applications of science initially began developing risk assessment methods for evaluating the effects of noise on marine mammals in 2012. The initial approach was to derive methods for evaluating discrete (“acute”) noise exposure events (e.g., a defined period of time and area for a single seismic survey operation) that applied elements of the common U.S. regulatory evaluations at that time within a common sense and biologically based risk assessment framework. The first analytical framework resulted from a project jointly supported by several petrochemical companies (BP and Shell) that were interested in seeing earlier risk assessment concepts developed further. Aspects of the acute noise risk assessment methodology were presented in open scientific meetings by Ellison et al. (2015) and Southall et al. (2018). The acute noise risk assessment framework was the basis for further development and improvements within the context of an earlier project jointly supported by the Bureau of Ocean Energy Management (BOEM) and National Oceanic and Atmospheric Administration that preceded the current project (Southall et al., 2019). This effort developed both the existing acute framework (for single, defined events) and, notably, a novel parallel approach to assess the potential effects of human disturbance from aggregate human activities (multiple, potentially overlapping sources) on broader time and space scales.

The evaluation of noise impacts within the acute risk assessment framework explicitly considered the potential for physical injury (hearing loss) and behavioral responses. This was done deliberately in order to provide some continuity and to provide conclusions that could be evaluated with regard to current U.S. regulatory evaluation methods of considering Level A and B harassment under the U.S. Marine Mammal Protection Act. Modifications made to the initial Ellison et al. (2015) methods for improving the acute framework included relatively minor changes to approaches for evaluating potential hearing loss and more substantive changes to the behavioral response analyses and evaluation of potential vulnerability in terms of a species’ life history, population status, and other known stressors in the area.

In order to evaluate the potential effects of multiple (aggregate) activities using a risk assessment approach, Ellison et al. (2015) built upon some of the general principles and aspects of the acute exposure framework, but developed new approaches for application to broader scales (larger than any single activity) and multiple overlapping sources (Southall et al., 2019). Both approaches have, as their core, risk assessment methods using a combination of qualitative and structured expert-assessment analytical approaches framed within a population level and biologically based perspective. Importantly, both are also inherently dependent on the spatial, temporal, and spectral dynamics of noise-generating activities as they relate to population and biological characteristics of exposed animals. The intent was to provide systematic and increasingly quantitative methods that enable the evaluation of potential aggregate effects over variable spatial and temporal scales (i.e., be inherently scalable). This scalability was intended to provide means of evaluating relative risk over defined periods and ultimately provide a means of evaluating chronic impacts. Given this objective and the fundamental recognition that essentially all potential effects of noise depend critically on the temporal, spatial, and spectral interactions of noise-generating activities and the species in question, the authors here developed several objective means by which to consider these key factors using novel risk assessment metrics.

The overall approach for evaluating a range of potential effects (hearing loss, disturbance, auditory masking) of aggregate anthropogenic activity within longer time and larger areas scales is similar in some regards to the acute risk assessment method for evaluating behavioral responses. The approach for behavioral impact analysis for a discrete exposure is given briefly below, as it is derived and applied as the basis of the overall risk assessment framework for aggregate noise assessments (see Southall et al., 2019). It provides a structured analytical basis for the overall risk assessment that is based on a systematic evaluation of species-typical life history, population, and other stressors as the basis for rating the species-specific "vulnerability" and a magnitude-duration algorithm based on population-based evaluation of disturbance magnitude as the basis for rating the overall magnitude of exposure. For the acute risk assessment, this magnitude is referred to as the exposure "severity," while for the aggregate assessment described in this report, this is quantified as an relative spatial-temporal-spectral "exposure index" value (described more below). These integrated risk ratings (from very low [blue] to very high [red]) are integrated within the matrix given below (Fig. 1) to provide a species-specific assessment of potential disturbance risk.

Exposure Index						
	5	M	H	H	VH	VH
	4	M	M	H	H	VH
	3	L	M	M	H	H
	2	VL	L	L	M	M
	1	VL	VL	L	L	M
	Rating	1	2	3	4	5
	Vulnerability					

Key	Color	Risk Assessment Rating
	Red	Very High
	Orange	High
	Yellow	Moderate
	Green	Low
	Blue	Very Low

Figure 1. Integrated risk assessment matrix for behavioral response analysis (derived from Ellison et al., 2015; Southall et al., 2019) based on calculated exposure index and species-specific vulnerability rating scores

Within the current project, we reassessed the matrix presented in Southall et al. (2019) and made some slight changes based on the intended approach, taking a somewhat more consistent and simplified approach. The resulting integrated assessments remains roughly symmetrical yet slightly skewed toward weighting the exposure index more heavily, but rendering the most extreme very low and very high ratings, the rarest outcomes. For each cell where the mean value of the exposure index and severity score is a round number, the integrated rating is equivalent to that number. For example, a low exposure index score (2) and a high vulnerability score (4) yields a mean of 3 and a resulting moderate assessed integrated risk score. Where the mean score is a fraction (0.5), the final rating is rounded to the next score up for exposure index values of 3–5 or rounded down for exposure index scores of 1–2. For example, a moderate exposure index score (3) and a low exposure index score (2) yield 2.5, which is rounded up to 3 (moderate final risk score), whereas and a low exposure index score (2) and a moderate vulnerability score (3) also yields 2.5 but is rounded down to 2 (low final risk score). This slight skew weights the overall magnitude of the relative exposure based on the spatial-temporal-spectral intersection of potential disturbance and animal density slightly more than the factors contributing to species vulnerability. Again, this method is conceptually similar to the integrated final matrix presented in Southall et al. (2019) but is somewhat more consistent and also reduces the likelihood of the most severely low or high ratings.

In adapting the analytical concepts for the aggregate noise risk assessment process, we considered aspects of the overall exposure “magnitude” with the context-dependent aspect of exposure in light of species-typical biological, behavioral, and population level factors (Southall et al., 2019). However, substantial modifications on both dimensions of this matrix were required in order to assess potential effects from multiple, co-occurring activities over longer time periods (e.g., months to years) and larger areas (e.g., 100s to 10,000s of square km) than generally occurring for single activities.

First, an objective, relativistic “exposure index” was developed to quantify overall exposure magnitude given the temporal, spatial, and spectral information about defined categories of human activities in aggregate relative to species-specific biological factors (e.g., seasonal distribution patterns, hearing filter types). The analogous metric for acute exposure to this index was the disturbance severity metric described above. Notably, the exposure index provides a consistent, objective means of evaluating the relative magnitude of predicted exposure from many exposure events. Unlike the acute risk assessment where specific “takes” are estimated for injury and behavioral disturbance and then put into an analytical framework, in this aggregate risk assessment framework, no effort is made to explicitly distinguish among potential auditory injury (hearing loss) or behavioral effects in terms of exposure magnitude. Rather, **this species-specific, relativistic exposure index serves as a proxy for identifying aggregate temporal and spatial conditions under which a range of potential effects (auditory injury, masking, behavioral effects) are deemed more or less likely based on the relative overlap between the temporal, spatial, and spectral features of the noise fields generated by the aggregate activities and the species-specific attributes of exposed animals**. The exposure index is also inherently scalable and is quantified independently for each species for a defined time period (e.g., one month, one year, five years) for defined geographical areas based on the temporal, spatial, and spectral interaction of aggregate, noise-generating activities and predicted species distribution patterns. This approach is described and derived in greater detail below (Section 2).

For the acute exposure framework, the “disturbance severity” and for the aggregate noise risk assessment the exposure index are subsequently evaluated relative to the context-dependent, species-specific “vulnerability” in order to provide an integrated risk assessment of the exposure scenario. This evaluation therefore takes a population-based perspective in considering the overall magnitude of relative exposure as well as the evaluated vulnerability of the species within the ocean region (“zone”) being considered. Each of these assessments is based on earlier approaches for evaluating exposure (Ellison et al., 2015), but with important modification and adaptation. These adaptations (Southall et al., 2018; 2019) included a novel quantitative method for evaluating auditory masking, increasing the weighting masking is given within the vulnerability assessment, and moving beyond the conventional Level A and B threshold paradigm to a broader spatial-temporal-spectral perspective of overall potential disturbance. The species- and location-specific vulnerability is then determined using a structured process in which categories of life history, distribution, population demographics, and contextual variables of exposure (e.g., general human activity within the area) are evaluated. These are based on the same high-level categories (population factors; habitat use and compensatory abilities; masking factors; and other environmental risk factors) that were defined and applied within the acute risk assessment framework (Ellison et al., 2015). However, here the potential aggregate effects of multiple exposures that may be occurring concurrently are considered and evaluated with increasingly quantitative methods. This additional quantitative basis is particularly true with regards to auditory masking, where a more objective means of evaluating the masking potential of aggregate activities is incorporated into the assessment and slightly more heavily weighted relative to other aspects of the species-specific vulnerability assessment of the overall risk assessment.

Based on representative data on spatial and temporal distribution of geological and geophysical (G&G) activities provided by BOEM, Southall et al. (2019) applied these methods to a realistic scenario for a one-year (2014) period in the Gulf of Mexico (GoMex) and assessed the potential risk for a subset of marine mammal species present. This study was conducted for a defined time resolution (monthly) and spatial zone resolution (seven GoMex planning zones defined by BOEM [Fig. 2]).

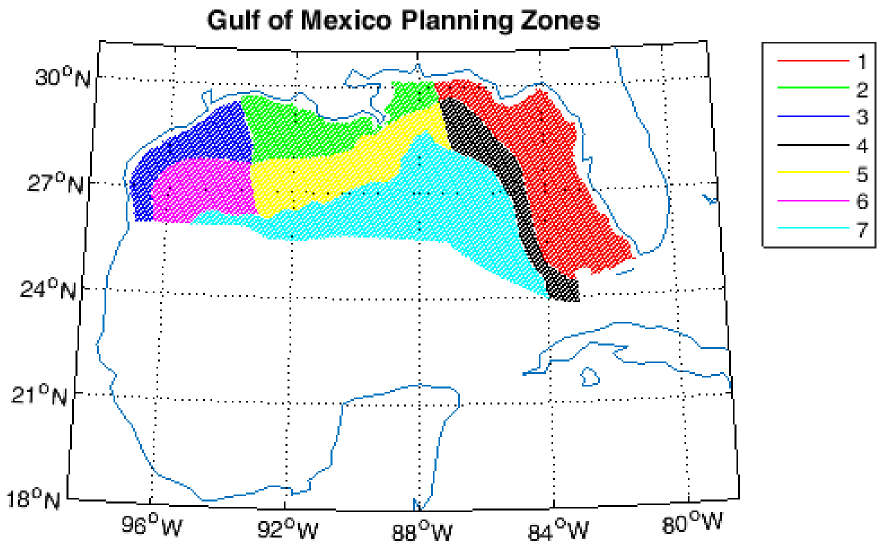

Figure 2. BOEM Gulf of Mexico planning zones

Within each zone, finer-scale analyses (based on 10 km x 10 km grid resolution for marine mammal density values) were used to quantify the zone-specific exposure index and masking factor scores. Median values from these finer-scale grids were then used to provide a representative value for both the exposure index and masking calculations for the entire zone. The use of median values was an acknowledged compromise between what would be a desired finer-scale resolution and what may be realistic in terms of available information on the spatial and temporal distributions of human activities and animals (Roberts et al., 2016). Evaluations of both the species-specific vulnerability and the exposure index were conducted at effective 10 km x 10 km resolutions in order to derive an average "adverse effect rating" for each species for each geographical zone (using the matrix above). These adverse effect ratings were derived on monthly scales (see Appendix A) but are inherently scalable and can be integrated over seasonal, annual, or multi-annual temporal scales using simply the median values of monthly (or finer scale) adverse effect rating scores across the full temporal period. The temporal scale used for the example analyses in Appendix A was at a one-month resolution, and the spatial scale was at a 10 km x 10 km grid resolution.

Each of the dimensions/axes of this aggregate risk assessment evaluation matrix (including the EI [y-axis] and species-specific "vulnerability" [x-axis]) are defined and derived separately below. Further, a specific example of the application of these evaluative methods for a defined year-long period (2014), with known source types and areas of operation for a defined geographical zone (Zone 5) in the GoMex (provided to the authors by BOEM), is given (Appendix A) to illustrate the approach. The review process of Southall et al. (2019) with BOEM provided several means for improving and expanding the aggregate risk assessment both methodologically and in this example scenario. These improvements included adding temporal resolution to the spatial term for the exposure index in terms of methodology and enhancing the exposure scenario by considering all GoMex marine mammals. These expansions of the original effort were specified as elements of Task 3 for the current BOEM-funded contract. In this report, we provide a complete derivation of the aggregate risk assessment methods that include this enhanced approach (Section 2) as well as a substantially expanded application of it for Zone 5 for all marine mammal species using the enhanced exposure index calculations (Appendix A).

2 Aggregate Risk Assessment Methods: Evaluating Species-Specific Exposure Magnitude ("Exposure Index")

We developed a robust and modular method that calculates an activity and exposure index (resulting from the execution of seismic surveys) in each of the BOEM planning zones in the GoMex. An "activity index" quantifies the seismic survey activity in each zone and is based on the location, date, and duration of the surveys along with the area that each survey covers. The exposure index relates the presence and duration of seismic activity in each zone to the abundance and distribution of specific marine mammal species in the GoMex. The exposure index is an arbitrary metric that aims to quantify potential acoustic exposure and risk to the species based on their distribution throughout the GoMex by combining the activity index, abundance distribution of the animals, and spectral content of the acoustics (airguns). The activity index is a function of the spatial and temporal parameters of the surveys and is independent of marine mammals. The exposure index relates the activity index to the acoustic abilities of marine mammals and their distribution by including spatial, temporal, and spectral components.

The design of the method requires the user to obtain specific information about each survey that will be conducted. The activity and exposure indices can then be calculated based on the spatial and temporal parameters of the survey. These indices can be used as a metric to compare the survey activity between specified periods in specified areas.

The exposure index is a combination of an activity index and a spectral index. The exposure index calculated in this method is meant to give the user a metric to use to assess the potential impact on marine mammals in the GoMex due to seismic activity. The metric combines the spatial extent, temporal duration, and spectral content of the surveys, as well as the distribution of the animals within the GoMex. The activity index is determined on a zone-by-zone basis and then incorporated with the animal abundance layers (based on Roberts et al., 2016) to yield exposure index values on a 10 km x10 km grid for each zone (see Fig. 2).

2.1 Activity Index Calculation

The activity index quantifies the seismic survey activity and is essentially the percentage of time and space occupied by seismic activity in each GoMex zone on a monthly or annual basis. This index is independent of the marine mammals and is only a function of where in the GoMex the seismic activity takes place, when it happens, and how long it lasts. It is calculated separately for each of the seven GoMex zones according to Equation 1 and contains a spatial and temporal component that describes the amount of time and area that will be occupied by surveys in each month or year.

$$A_{overall} = A_{spatial} + A_{temporal} \ (1)$$

The spatial and temporal terms, which are defined below, are calculated using the surveys that occur during a specific month or year of interest to yield an activity index for each month and for the entire year. Each term will be calculated using the same surveys.

The activity index is a summation of two percentages (percent of space and time occupied by surveys) and is unbounded. Therefore, the activity index could be greater than 1 if more than 100% of the time and space in a zone are occupied by survey activity. Because an activity index is calculated for each month or for each year, it can be used as a metric to compare across months and years, as it is a function of the time and space that surveys will occupy during that time period.

The surveys used in this method are real-world examples and do not necessarily follow the arbitrary boundaries defined by this method for space, such as the zones in Fig. 2, and time, such as monthly or annually. The survey itself might span multiple zones and occur over the course of multiple months or years. This transcending of boundaries is accounted for by scaling the survey area and duration in order to determine how much of the survey occurs in and how long it operates in each month or year within each zone.

Note: Because the activity index will be used to generate an acoustic exposure risk for marine mammals from the survey activity, it is necessary to define the acoustic exposure area of each survey. This “acoustic footprint” is defined by expanding the area of each survey by a uniform margin of 10 km along each side. This additional area will represent the “acoustic footprint” of each survey out to a received level of 160 decibels relative to 1 micropascal root-mean-square (dB re 1 μPa rms). This expanded area is used in the calculation of the spatial and temporal terms described below. For example, a 10 km x 10 km survey has a survey area of 100 km^2. Adding a 10-km acoustic buffer length to each side of the survey box yields an acoustic footprint that is 30 km x 30 km or 900 km^2.

2.1.1 Spatial Activity Index

The spatial activity index was updated here from Southall et al. (2019) based on comments received by BOEM. The revised index incorporates a temporal aspect so that only the surveys that occur during the specific month or year are used instead of all the surveys. Also, the overlapped area term was removed. The overlapping area is accounted for in the revised calculation and is no longer an additional term. The original index calculation is copied below for reference.

Spatial Activity Index (from Southall et al., 2019)

The spatial activity index was initially calculated accordingly, where *n* is the number of surveys present in each zone, and was calculated on a zonal basis.

$$A_{spatial} = \frac{\sum_1^n Survey\ Area + \sum Overlapped\ Area}{Total\ Zone\ Area}$$

After a survey was defined in the tool, the region encompassing the survey tracks was expanded by a uniform margin of 10 km along each side to represent the “acoustic footprint” of each survey out to a received level of 160 dB re 1uPa rms. This expanded area was used in the calculation for the spatial activity index. For the example considered above, the earlier calculation of spatial activity index was a two-part calculation. The first part determined the area of each survey that occurred in each zone and then summed the area of all the surveys in each zone to determine the “Survey Area” parameter. The second part compared each survey to the others and determined if there was any spatial overlap between them within a zone. The overlapping area between each survey pair was summed for the “Overlapped Area” parameter. The summation of the survey area and the overlapped area was divided by the total area of the zone. This resulted in the spatial activity index term, which could be greater than 1 if the sum of the survey area and overlapped area was greater than the total area in the zone.

Spatial Activity Index (Modified Approach)

In this study, we adapt and increase the temporal resolution for the spatial term. The spatial activity index answers this question: what percentage of area in each zone is surveyed during a specific time period? It is calculated according to Equation 2, where *n* is the number of surveys. A separate spatial index is calculated for each of the seven GoMex zones and for each month or year. If calculating for a certain month, then only surveys that occur in that month are used in the analysis. The same applies for the annual index, only the surveys that occur in that year are used.

$$A_{spatial} = \frac{\sum_{1}^{n} Spatial\ Slice_{Month\ or\ Year}}{Area\ of\ the\ Zone} \quad (2)$$

The numerator in Equation 2 is the total amount of area that is surveyed in a zone due to all the surveys that take place during a specific month or year. To find the total surveyed area, the *Spatial Slice* of each survey is found according to Equation 3. This is the area that a survey covers (in square kilometers) in each zone within each month or year.

$$Spatial\ Slice_{Month\ or\ Year} = Survey\ Area\ in\ Zone * \frac{Survey\ Days_{Month\ or\ Year}}{Survey\ Days_{Total}} \quad (3)$$

As an example, say we are calculating the spatial activity index for Zone 5 for the month of April. In this case, we only want to use surveys that occur in April, and there is one survey during this month. This survey has a total area of 100 km^2; 50 km^2 of it takes places in Zone 5, and 50 km^2 takes place in Zone 6. The survey starts on March 1 and ends on June 28, so it lasts a total of 120 days. The *Spatial Slice* in this example is the amount of area that will be surveyed during April in Zone 5. In this case, the amount of survey area in Zone 5 is 50 km^2, but it spans multiple months. So how much area could be covered during only April? As the survey will be operating for all 30 days in April and there are 120 total days in the survey, during April, one-fourth of the total survey will be completed. This ratio is multiplied by 50 km^2 to yield a *Spatial Slice* value of 12.5 km^2. This is the total area that could be surveyed in Zone 5 during April. When calculating the annual *Spatial Slice* for Zone 5, the entire survey is used, because the survey takes place within one year. So, the *Spatial Slice* of the survey would be 50 km^2 because the scaling factor of survey days to total survey days becomes 1. Because the survey starts and finishes in that year, the entire area in Zone 5 must be surveyed.

The *Spatial Slice* is calculated for each survey individually and then summed to yield the total area in each zone that could be surveyed during each month and year. This total surveyed area is then divided by the area of the zone to yield the percentage of the zone that is surveyed during each month and year (Equation 2). This percentage is the spatial activity index and is calculated for each zone individually. The spatial activity index term can be greater than 1 if the sum of the surveyed area is greater than the area of the zone.

2.1.2 Temporal Activity Index

The temporal activity index answers this question: what percentage of time within a specific month or year are surveys occurring in each zone? It is calculated according to Equation 4, where *n* is the number of surveys. A separate temporal index is calculated for each of the seven GoMex zones and for each month or year. If calculating for a certain month, then only surveys that occur in that month are used in the analysis and the *Season Days* term would be the number of days within that month. The same applies for the annual index—only the surveys that occur in that year are used and the *Season Days* term is the number of days in that year.

$$A_{temporal} = \frac{\sum_{1}^{n} Temporal\ Slice_{Month\ or\ Year}}{Season\ Days_{Month\ or\ Year}} \quad (4)$$

The numerator in Equation 4 is the total number of survey days in each month or year. A survey day is defined as a day when a survey is taking place. If there are two surveys that both take place for the entire month of April, then this equates to 60 total survey days in April. The *Temporal Slice* of each survey—found according to Equation 5—is the number of survey days that occur in each zone.

$$Temporal\ Slice_{Month\ or\ Year} = Survey\ Days_{Month\ or\ Year} * \frac{Survey\ Area\ in\ Zone}{Area\ of\ Survey} \quad (5)$$

As in the previous example, let's calculate the temporal activity index for Zone 5 for April. The example survey operates for 30 days in April, but how many of these days take place within Zone 5? If 50 km^2 of the survey occurs in Zone 5, and the total area of the survey is 100 km^2, then one-half of the survey area is in Zone 5. Thus, of these 30 survey days during April, 15 days will be spent surveying Zone 5. An assumption is made that the survey days will be split between zones because more resolution on the exact location of the survey at certain times is not known. When calculating the annual *Temporal Slice* for Zone 5, the scaling factor of the survey area in the zone to the total survey area does not change, but the *Survey Days* term does. The *Survey Days* is 120 because that is the length of the survey in that year. Because the survey area spans Zones 5 and 6 equally, the number of days spent in each zone is 60.

The *Temporal Slice* is calculated for each survey individually and then summed to yield the total number of survey days in each zone during each month and year. This total number of survey days is then divided by the total number of *Season Days* to yield the percentage of time within a month or year when surveys are occurring (Equation 4). This percentage is the temporal activity index and is calculated for each zone individually. The temporal activity index term can be greater than 1 if there are more survey days than days in the month or year (i.e., if there are 60 survey days in April, then the temporal activity index for April will be 2, meaning that surveys will be operating for 200% of the time in April).

2.2 Exposure Index Calculation

The exposure index is a function of either the monthly or annual activity index and a spectral index term. The first step in this calculation is the spectral index.

2.2.1 Spectral Index

The spectral term takes into consideration the species distribution within the GoMex and the functional hearing range of different species groups. This step quantifies the spectral difference between the low-frequency (LF), mid-frequency (MF), and high-frequency (HF) functional hearing groups and combines this with the abundance distribution to yield the spectral index, which is calculated according to Equation 6.

$$Spectral\ Index = \frac{Energy\ in\ weighted\ spectrum}{Energy\ in\ unweighted\ spectrum} * \ Abundance \ (6)$$

The spectral index compares the hearing abilities of a species and the frequency content of the airgun array. A nominal airgun source spectrum is used to represent all surveys (Fig. 3). The spectrum is integrated between 0 and 100 kHz to calculate the total energy in the spectrum. Then, the spectrum is weighted according to hearing class (LF, MF, and HF) using M-weighting (Southall et al., 2007). These weighted spectrums are integrated, and the total energy in the weighted spectrum is normalized by the total energy in the unweighted spectrum (Fig. 3). This calculation provides a ratio of total energy in the spectrum that is within the species functional hearing range and aims to represent how much spectral energy is available for the animals to hear and potentially react to.

The spectral ratio for each functional hearing group are provided in Table 1. For an airgun array, much of the energy is in the lower frequencies, which falls within the best range of hearing for LF animals. Therefore, for this example, the spectral ratio for the LF hearing group is much larger than that of the MF and HF hearing groups. If the source contained more energy at higher frequencies, then the MF and HF ratios would increase.

This spectral ratio is multiplied by the abundance of the species in the 10 km x10 km grid to produce a spectral distribution grid. This term aims to highlight both the spectral overlap of the species with the airgun array and the distribution of the animals within the GoMex. It is worth noting as well that the percentage of the total population present within the zone is later used in normalizing the raw exposure index scores (below).

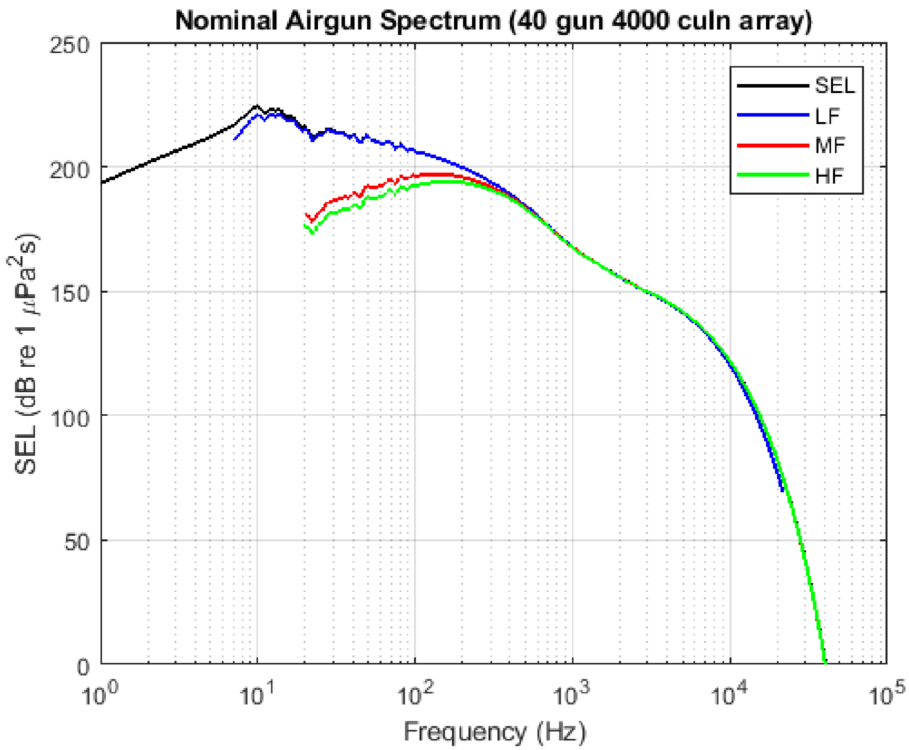

Figure 3. Unweighted airgun spectrum (black line) compared to the spectrum weighted for LF, MF, and HF species using M-weighting

Source: Southall et al., 2007

This representation of spectral exposure excludes the propagation and thus the range and depth dependence of the airgun signal. It aims simply to look at the difference in amplitude of the signal from the airgun versus the signal that an LF, MF, or HF animal would receive at the source based on their frequency range of hearing. The spectral ratios for each function hearing group are given below (Table 1).

Table 1. Spectral ratios for each functional hearing group used in Equation 6

Hearing Group	Spectral Ratio
LF	0.7063
MF	0.0334
HF	0.0196

2.2.2 Exposure Index

The total exposure index by planning zone is a combination of each of the activity index components for each zone (Equation 1) and the spectral index term (Equation 6). These terms are multiplied together to yield the exposure index for a specific species on a 10 km x 10 km grid according to Equation 7. The overall activity index term can be either on an annual or monthly basis. Although the activity index is a non-dimensional term, the exposure index will have units of spatial density (# of animals/100km^2).

$$Exposure\ Index = A_{overall} * Spectral\ Index\ (7)$$

2.2.3 Exposure Index Risk Assessment Rating

Following calculation of exposure index values for each grid for the defined time period within each zone, several processes are required in order to determine a zone-specific and species-specific severity rating by which (in combination with the vulnerability rating) to provide an overall risk assessment.

First, a zone-wide representation of the exposure index results must be determined. A mean value of all grid cells was selected as the most appropriate summary statistic. However, in order to avoid skewing results (through zero-inflation) for areas in which species were not present within zones, grid cells where predicted species density was < 0.5 animals (based on Roberts et al., 2016) were excluded prior to the calculation of mean exposure index values. This threshold of 0.5 animals per 100 km^2 was selected based on an initial sensitivity analysis of the population density of the species of interest and the observation that the inclusion of cells with very low densities for species with non-uniform distributions would result in potentially large underestimates of resulting zone-wide index scores. Ultimately, the species-specific mean value of all non- and near-zero density grids (specifically all 10 km x 10 km grid cells with < 0.5 individuals) was used as a representative exposure index value for the entire zone.

Second, zone-specific index values were normalized in terms of the relative magnitude of the species population that occurs within the zone relative to the entire population. Specifically, for all the species, the calculated monthly mean raw exposure index is multiplied by the percentage of the total GoMex population present within the zone (these percentages are identical to those used within the species vulnerability habitat rating). Values for all species are then multiplied by a scaling factor (100) to generate the final, normalized exposure index value. This process is intended to provide a relative means of normalizing the exposure index within the zone relative to the whole area population.

Finally, normalized, species-specific, overall zone exposure index scores for a specified time period are evaluated using the below scale (Table 2) to determine an exposure index risk rating for use in the overall risk assessment (along with the vulnerability score discussed below). It is clearly acknowledged that this process and scaling approach is based upon an initial, limited application of this approach (Southall et al., 2019) using four selected species from three different cetacean hearing groups (Bryde's whale, sperm whale, spotted dolphin, pygmy sperm whale). These severity ratings are applied here for all species (Appendix A), but it is noted that further analyses and sensitivity testing for more areas, species, and exposure scenarios are required to evaluate the broader applicability of these exposure index risk rating decisions to other contexts.

Table 2. Normalized zone- and species-specific exposure index values and corresponding severity ratings

Exposure Index	Exposure Index Risk Rating
> 5	Very high (5)
> 3–5	High (4)
> 1–3	Moderate (3)
> 0.5–1	Low (2)
0–0.5	Very low (1)

2.2.4 Exposure Index Discussion

This method was developed as an attempt to quantitatively describe the exposure of specific species due to the presence and duration of seismic surveys in the GoMex. The metrics developed are referred to as the activity index and the exposure index. The exposure index is a combination of a spectral, spatial, and temporal component, along with the species distribution, whereas the activity index is function of only the spatial and temporal components. Because the exposure index is a function of the species distribution, there can be large differences between species of the same functional hearing group due to their distribution within the GoMex. The metric is most focused on understanding how seismic activity in a particular zone is affecting the proportion of that species in that zone. It is important to note that the resulting relative index is zone specific and that, for broader assessments, more or all zones should be viewed together.

The exposure index is a species dependent term that is proportional to the number of animals/100km^2, i.e., the number of animals in any given 10 km x 10 km grid cell. This final exposure index is amplified by both spectral matching to the source and the level of spatial and temporal exposure. The spectral index used to calculate the exposure index is largely dependent on the accuracy of the species distribution and abundance data sets, while the source spectrum and M-weighting are straightforward calculations.

The spatial and temporal indexes that make up the activity index term are both non-dimensional terms and therefore serve as a multiplier to the spectral index. The activity index can be tracked from year to year to see how the spatial and temporal relationship of the survey activities change. Comparing the annual with the monthly activity index yields information on how the survey presence changes by month. The annual activity index could also be combined with the requested annual track length in each zone to become a measure of regional survey activity per track line. With the continued presence of surveys in the GoMex, this tool will provide a visual representation of the combined effect of these surveys on certain species.

In future versions of this method, the utility of the activity, irrespective of sound exposure, could be developed into a new index. This new index would be calculated the same as the exposure index but would leave out the spectral shading ratio. This index could be termed the Activity-Only Exposure Index and would fall in line with the methods and conclusions in Ellison, et al. (2012, 2018).

3 Aggregate Risk Assessment Methods: Determining Species-Specific "Vulnerability"

For the aggregate noise exposure risk assessment method, the species-specific vulnerability rating (x-axis on the overall risk assessment matrix, Fig. 1) is determined using a structured evaluation of key species and context-specific factors. These vulnerability ratings are based directly upon and are largely similar to the vulnerability ratings derived for discrete exposures (see Southall et al., 2019). They include the following factors, each of which is used to determine an overall potential vulnerability rating and is described below:

- Species population factor
- Species habitat use and compensatory abilities
- Potential masking factor
- Other environmental stressors

3.1 Species Population Factor

Population parameters are a critical consideration in evaluating the potential vulnerability of a species to disturbance from aggregate noise exposure. Although the exposure index relates the population distribution relative to noise sources as the inherent basis for evaluating exposure magnitude, other parameters that are not explicitly considered include the conservation status, population trend, and overall population size. Higher relative vulnerability is assigned for species that are endangered or depleted, have a clearly negative population trajectory, or have a low overall population size. Though this factor has the benefit of relatively well-defined quantitative criteria, it should be noted that a limitation in this component of assessment can be the lack of current or sufficiently precise stock assessment reports. This factor includes a maximum possible score of 7 out of a total possible score of 30 for the overall vulnerability rating.

Table 3. Species population factor (defined for area-specific stock)

Population Factor Elements	Score (max 7)
Population status: • Endangered (ESA) or depleted (MMPA) = 3 • Threatened = 1	**max = 3**
Population trend: • Decreasing (last three stock assessment reports [SARs] for which new population estimates were updated) = 2 • Unknown (last three SARs) or data deficient = 1	**max = 2**

• Stable (last three SARs) for which new population estimates were updated within 5%) = 0 • Increasing (last three SARs) = -1	
Population size: • Small (n < 2,500, as specified by International Union for the Conservation of Nature [IUCN] designation) = 2	**max = 2**

3.2 Species Habitat Use and Compensatory Abilities

In this study, the relative biological importance of a specified area[1] where a noise-generating activity will occur is evaluated as an element of potential species-specific vulnerability. Ideally, relatively fine-scale spatial (km to tens of km) and temporal (days) overlap between activities and species-typical habitat usage would be evaluated, given the importance of this overlap in determining exposure and the likely magnitude of potential response. Given that information at such fine-scale resolution is typically limited or not available because of data limitations, particularly in terms of species-typical habitat usage, a relatively coarse and subjective assessment of vulnerability is applied here. Relatively higher potential vulnerability is assessed for areas where a species is known to occur in relatively higher concentrations, or where there is a relatively higher degree of spatial overlap between a noise-generating activity and a biologically important activity, including mating, rearing of offspring, foraging in a concentrated area, and/or migrating. This factor includes a maximum possible score of 7 out of a total possible score of 30 for the overall vulnerability rating.

Table 4. Species habitat and temporal factors

Species habitat and temporal factor elements	Score (max 7)
Habitat use: • Specified area contains ≥ 30% of total regionwide or estimated population (during defined survey period) = 4 • < 30% and ≥ 15% = 2 • < 15% and ≥ 5% = 1 • < 5% = 0	**max = 4**
Temporal overlap: • High probability that activity will overlap with concentrated breeding/maternal care periods and/or key feeding or migration periods within specified area = 3 • Moderate probability = 2 • Some (low) probability = 1 (also assigned when insufficient data on species biology exists by which to assess potential overlap)	**max = 3**

[1] This area is the area over which a specified activity is evaluated and a local population is determined; herein, this was defined as each of the seven BOEM zones.

3.3 Potential Masking Factor

An important characteristic of low-frequency masking situations, especially when considered from an aggregate noise perspective that persists over large areas for long periods of time (months to years), is that the actual aggregate noise field (whether in the spectrum [re 1 $\mu Pa^2/Hz$] or level [re 1 μPa] form) is mostly below threshold levels used for estimating potential behavioral and/or injurious impacts

The potential masking factor addresses this issue in that it considers the potential for disturbance and disruption of bioacoustically mediated behaviors within the domain of behavioral vulnerability. Masking potential depends critically on the location and nature of each anthropogenic noise source; the noise field generated by each source; the aggregate noise field generated by multiple sources; and the degree of spectral overlap between the aggregate noise field and the hearing, signal functions, ongoing activity, and acoustic ecology of the species of interest. A rating of masking potential is assessed relative to a baseline ambient noise condition, which is assumed to represent a natural noise condition devoid of anthropogenic sources.

For the acute risk assessment, the potential masking factor was evaluated using largely subjective considerations of relative spectral overlap between the predominant energy from a single noise source and species-typical sounds of interest. Here, for the aggregate noise risk assessment, a more quantitative and objective approach for deriving the potential masking factor is used. This method is described in further detail below and demonstrated explicitly in Appendix A. Additionally, given the broader temporal and spatial scales considered within the aggregate risk assessment process, the weight of this factor is increased slightly relative to the three other factors evaluated, such that the potential masking factor includes a maximum possible score of 9 out of a total possible score of 30 for the overall vulnerability rating.

This process has a series of iterative, quantitative steps to characterize noise sources and associated aggregate sound fields and relate them to marine mammals within large spatial areas (e.g., GoMex zones) during long periods of time (months to years) for biologically appropriate frequency bands. We define three biological, contextual frequency bands as those in which basic bioacoustic functions that are potentially liable to masking occur, where the three masking contexts considered susceptible to disturbance and disruption are communication, foraging, and navigation/orientation. The ranges include an LF band (10–1000 Hz), in which many baleen whale communication signals occur, and potential navigational cues are available via passive listening to a variety of species; an MF band (1–10 kHz), in which odontocete communication signals occur; and an HF band (> 10 kHz), in which odontocete echolocation signals occur.

The four basic steps in the process for deriving a species-specific, potential masking factor score are as follows:

1. Generate an M-weighted, aggregate noise spectrum (levels in dB re 1 $\mu Pa^2/Hz$) throughout a region at 10 km x 10 km spatial resolution and one-month time resolution for each of the three M-weighted conditions (M_{lf}, M_{mf}, and M_{hf}).

2. Estimate relative spectrum level differences between the M-weighted, aggregate noise spectrum levels (using the typical seismic airgun spectrum portrayed in Fig. 3) and a spectrum level representing a baseline wind speed ambient noise condition that is assumed to be uniformly distributed throughout the region.

3. Convert these ambient noise-to-noise spectrum differences into ambient noise-noise ratio (ANNR) for each of three context-specific frequency bands representing masking under the LF, MF, and HF biological contexts.

4. For each species of interest, determine the masking factor score for each of the M-weighted, activity-specific contexts.

As in the acute noise risk assessment, we aim to differentiate among sounds that may be primarily utilized for communication (conspecific or auto-communication, i.e., echolocation) and those used in passive listening for spatial orientation, foraging, or other contexts. We assign greater weight in the potential masking factor score to signals most likely associated with communication, defined as signals within the primary species-specific communication band (e.g., LF for LF cetaceans; HF for HF cetaceans). However, for all species a consideration of potential masking within the LF band, which is most likely to convey information relevant to navigation and spatial orientation, is made based on the M-weighted ANNR values.

Further details for each of the steps in the potential masking factor process are provided in Appendix A, where we apply a simplified analytical approach to evaluate aggregate exposures (Ellison et al., 2016) and use data given to the authors by BOEM. Those data cover a defined period (calendar year 2014), with known source types and areas of operation within Zone 5 in the GoMex. Given that the known highest density of occurrence for the only LF mysticete, Bryde's whale (*Balaenoptera edeni*), in the GoMex is in Zone 1, for comparative purposes, the potential masking factor assessment for this LF species includes both Zone 5 and Zone 1[2]. The assessment for MF and HF species only includes Zone 5.

Table 5. Potential masking factor

Masking Factor Elements	Score (max 9)
Communication masking factor: • Median ANNR (for all cells within zone in which species is predicted to occur) within primary species-specific communication (conspecific and auto-communication) band > 30 dB = 6 • 10–30 dB = 3 • 1–10 dB = 1 • < 1 dB = 0	**max = 6**

[2] Scientific evidence for the Bryde's whale in the GoMex indicates that this stock is distinct from stocks in other parts of the world and has a very low level of genetic diversity. This has led the National Marine Fisheries Service to list the stock as endangered.

Spatial orientation and navigation masking factor: • Median ANNR within LF band > 30 dB = 2 • 10–30 dB = 1 • < 10 dB = 0	**max = 2**
Spatial orientation and navigation masking factor: • Median ANNR within MF band is > 30 dB = 1 • < 30 dB = 0	**max = 1**

3.4 Environmental Risk Factors

Other (chronic) noise and non-noise stressors: An important aspect of the revised vulnerability assessment considers other environmental factors beyond those associated with a discrete noise-generating activity (e.g., seismic survey, sonar operation) that may increase species-specific vulnerability to disturbance. Although this was considered to some extent within the Ellison et al. (2016) framework, there has been substantial revision and further distinctions to criteria for assessing the magnitude of other potential sources of disturbance or other stressors that may influence a species response to noise from a defined/proposed activity. Specific factors consider both the relative levels of ongoing human activity in an area, as well as the existence and severity of other biological risk factors such as disease or nutritional stress. Conditions under which chronic anthropogenic disturbance from other activities or biological stressors are relatively higher are evaluated as having a higher potential impact compared to identical noise-generating activities. This risk factor includes a maximum possible score of 7 out of a total possible score of 30 for the vulnerability rating.

Table 6. Other stressors

Other Stressors Factor Elements	Score (max 7)
Chronic anthropogenic noise: Species subject to variable levels of current or known future chronic anthropogenic noise (i.e., dense or overlapping concentrations of industrial activity such as shipping lanes, sonar testing ranges, areas of regular seismic surveys)	**Up to 2**
Chronic anthropogenic risk factors (non-noise): Species subject to variable degrees of current or known future risk from other chronic, non-noise anthropogenic activities (e.g., regular documented cases of fisheries interactions, ship-strike; last SARs to serve as reference)	**Up to 3**
Chronic biological risk factors (non-noise): Variable presence of disease, parasites, prey limitation, or high predation pressure (last SARs as reference)	**Up to 2**

3.5 Total Vulnerability Score

The total vulnerability score is then based on the total (aggregate) score from factors 1-4. Based on the total risk probability (as a percentage of the possible total score), an associated vulnerability rating is then assigned, as identified within Table 7 below. As with the final exposure index scores, we emphasize that for more generalizable applications, subsequent testing sensitivity assessments would be important to further evaluate the break points identified.

Table 7. Normalized zone- and species-specific exposure index values and corresponding severity ratings

Total Vulnerability Score (from factors 1-4)	Total Risk Probability (% of total possible)	Vulnerability Rating
24–30	80–100%	Very high
18–23	60–79%	High
12–17	40–59%	Moderate
6–11	20–39%	Low
0–5	0–19%	Very low

4 Integrating Species-Specific Exposure Index and Vulnerability

Following the parallel determination of zone- and species-specific exposure index and vulnerability ratings for a defined category of activities (e.g., seismic surveys), period (e.g., month, year), and area (e.g., zone), an integrated risk assessment is made. As described above, the overall aggregate risk assessment rating is based on an integrated assessment of the resulting exposure index and vulnerability ratings, as described above (Fig 1.).

Appendix A presents the resulting overall risk assessment scores and an assessment of results based on the integration of exposure index and vulnerability scores for all GoMex marine mammal species in one GoMex zone (Zone 5). Appendix B lists the references for both this report and Appendix A.

5 Synthesis Conclusions: Modified Risk Assessment Framework

- The overall design of the risk assessment approach is based on a similar overall approach to the acute noise behavioral disturbance assessment in that the intersection of species-specific vulnerability, and a relative overall exposure “magnitude” is used to evaluate risk. There are fundamental differences, however, in that an overall evaluation of potential disturbance (rather than injury or behavioral response) is used, and a more quantitative basis for aspects of vulnerability are derived.

- The fundamental basis for the evaluation of exposure “magnitude” is a relative exposure “index” that is based on the extent of spatial, temporal, and spectral overlap of human activity and marine mammal distribution. This approach is inherently and deliberately scalable in space and time such that it can be applied on finer or broader scales of each. However, it is inherently dependent upon the resolution and reliability of available data on the spatial and temporal distribution of human activities and marine mammals.
- Many aspects of the species-specific vulnerability ratings are common to the approach derived for acute noise risk assessments regarding and related to population trends, compensatory abilities, and environmental factors. The key difference and one of the main accomplishments represented here is a quantitative approach to evaluating risk of auditory masking. Methods are developed to account for the spatial and temporal distribution of activities, apply conventional noise propagation, and account for differences in spectral sensitivity in evaluating masking potential as it relates to both communication and spatial orientation/navigation. This approach is also inherently scalable in space and time—and also depends critically on the resolution of information regarding activities and animals.
- For the current project, we have followed the BOEM recommendations on the Southall et al. (2019) report in providing (1) additional temporal resolution to the spatial term of the activity index used in calculating the exposure index; and (2) analysis of all GoMex marine mammal species and discussion of results for the example scenario application of the aggregate risk assessment (see Appendix A).

Appendix A: Example Scenario for Applying Aggregate Noise Exposure Risk Assessment

The primary effort for Southall et al. (2019) was to develop novel methods to evaluate risk from many overlapping activities on broader temporal and spatial scales than are conventionally considered within the evaluation of a discrete activity. The goal was to adapt and apply some aspects of the acute exposure risk assessment approach for aggregate anthropogenic activity scenarios, particularly some aspects of the species-specific vulnerability to human disturbance although with some important improvements. Southall et al. (2019) applied this approach for a selected number of species (with at least one species representing each cetacean hearing group) within a single zone using a realistic scenario example with multiple seismic surveys of known duration and locations. The purpose of this appendix is to both demonstrate the stepwise methodology applied to determine an exposure index, vulnerability rating, and ultimate risk assessment, as well as to inform subsequent improvements and evolutions of this process.

As described, for the current project, this report consisted of a methodological enhancement of the spatial term of the activity index (increasing temporal resolution; see Section 2.1.1) and a full exposure index calculation (using this adapted methodology) for all GoMex species (including the original four evaluated by Southall et al. (2019). For this example scenario, the exposure index ratings will be shown first for all species (given alphabetically), followed by their vulnerability ratings. Finally, these ratings are cross-evaluated using the overall rating assessment to provide an assessed risk for each species

In order to apply the aggregate risk assessment process in an example scenario, specific information regarding the spatial, temporal, and spectral features of activities was required. The authors coordinated with BOEM, which provided the authors a detailed post hoc description of the seismic survey activities that took place over one calendar year (2014; see Table A-1) within one defined area of the GoMex (Zone 5; see Fig. A-1).

Table A-1. Seismic survey operations (12) that occurred in 2014 as simplified from information provided by BOEM (see Figure A-1)[3]

Permit	Survey Type	Center Lat	Center Lon	Horizontal Extent (+/-km)	Vertical Extent (+/-km)	Acquisition Started	Acquisition Completed
L14-042	4D	27.25	-89.93	15	15	1-Dec-14	3-May-15
L13-015	3D	26.70	-92.35	90	45	2-Jun-13	28-Feb-14
T13-006	3D	26.93	-93.20	45	45	1-Mar-14	10-Oct-14
L14-008	3D	27.80	-89.68	35	15	8-Jun-14	29-Aug-14
T13-004	3D	26.93	-93.00	50	40	28-Nov-13	5-Aug-14
L13-041	3D	27.00	-89.10	75	35	4-Mar-14	22-Jun-14
L14-012	3D	28.47	-88.29	55	60	20-Oct-14	14-Apr-15
L13-032	3D	26.75	-92.35	25	25	25-Jan-14	2-May-14
L13-038	3D	28.00	-88.29	40	60	1-Jan-14	22-Feb-14
L14-018	3D	28.50	-88.29	45	35	25-Sep-14	8-Jan-15
L14-021	3D	28.22	-90.42	40	15	2-Oct-14	2-Dec-14
L14-033	3D	27.00	-92.10	75	30	12-Dec-14	8-Jul-15

[3] The center latitude (Center Lat) and center longitude (Center Lon) represent the geometric center of each survey block as shown in Figure A-1.

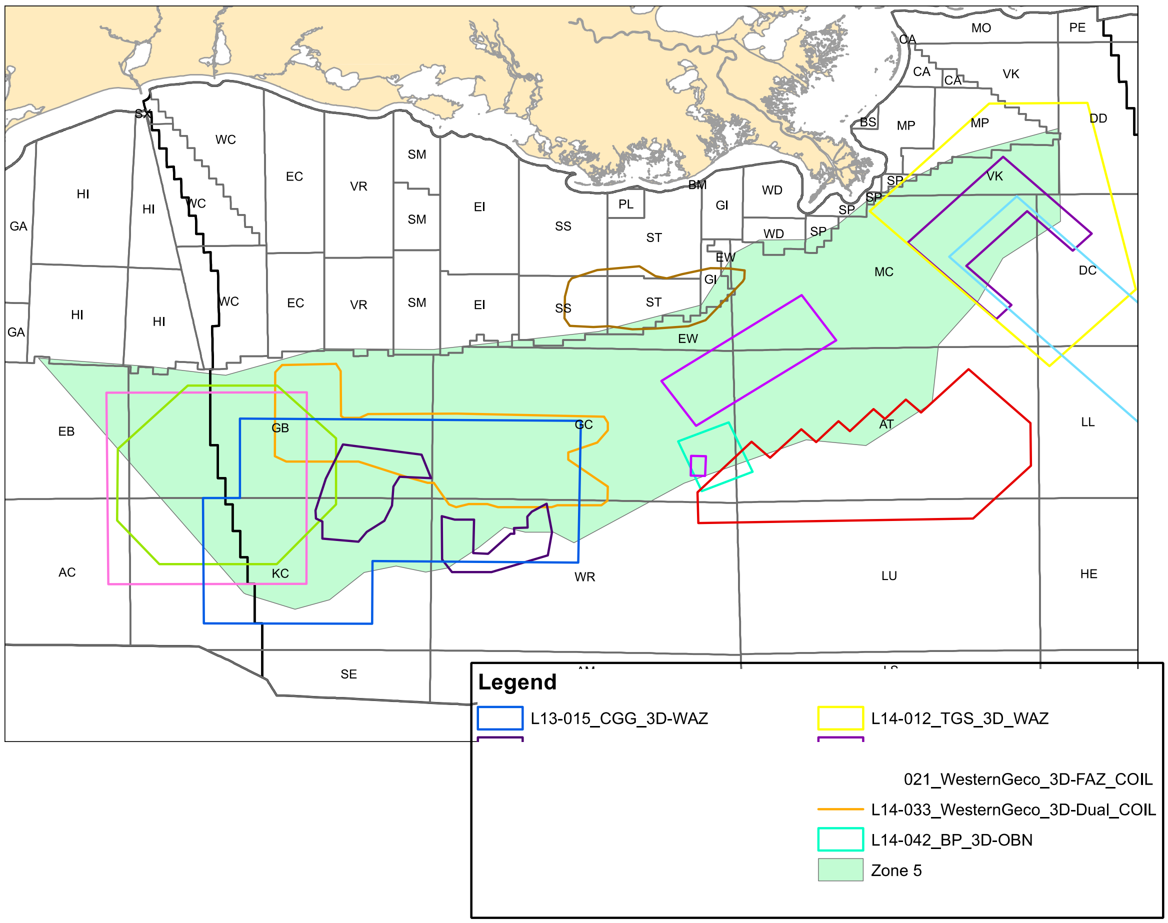

Figure A-1. Geometries for each of the 12 seismic survey areas that occurred in whole or in part within Zone 5 during 2014 in the Gulf of Mexico (Map courtesy of BOEM)

The analytical tool used in calculating exposure indices cannot support arbitrary shaped surveys, and they must be added as squares or rectangles. The surveys added into the tool are shown below (Fig. A-2).

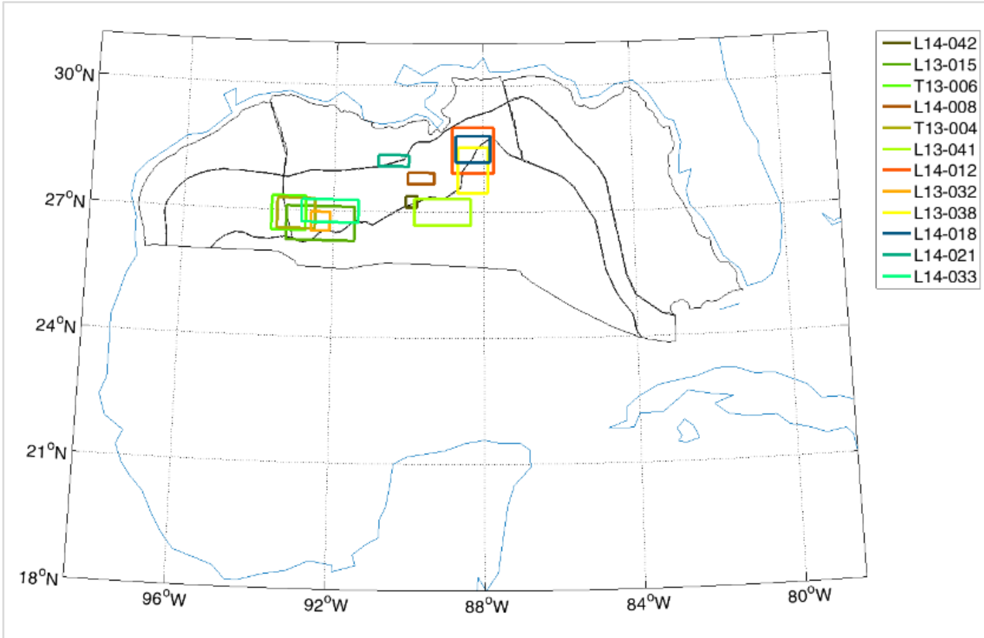

Figure A-2. Rectangular representation of example surveys for 2014 used in exposure index calculations.

The spatial extent of the surveys shown above (Fig. A-2) indicates that the majority of these surveys occur in Zone 5. The temporal extent of the surveys is shown below (Fig. A-3), indicating that they range from 2013 through 2015, and there is a differential degree of temporal overlap throughout the year.

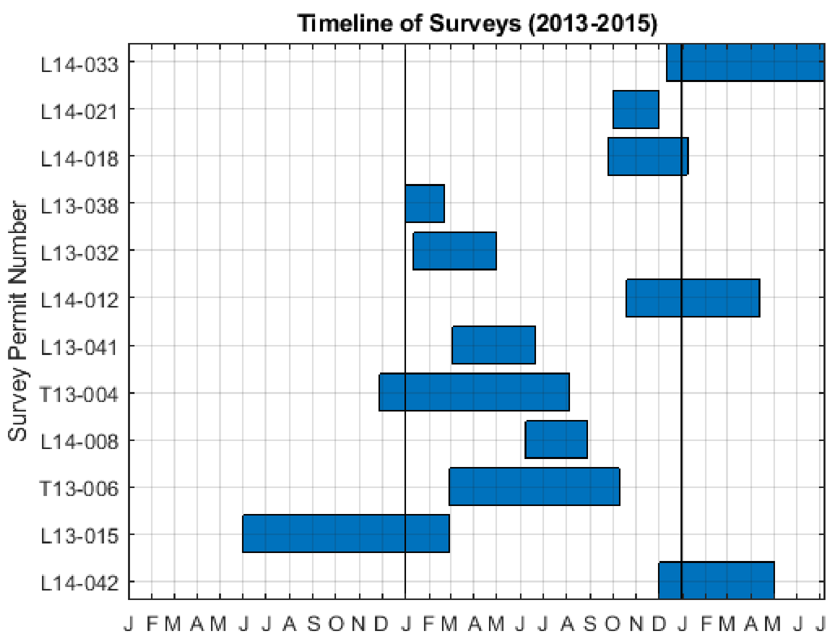

Figure A-3. Diagram showing the start and end dates for each of the 12 seismic airgun surveys used in this example scenario.

Annual and Monthly Examples

An example of the exposure index for 18 species are given on an annual and monthly scale to demonstrate how the exposure index varies based on the hearing abilities of the LF, MF, and HF groups and the species distribution. The abundance distribution is presented for each species to visualize the spatial distribution of the species in relation to the survey locations.

Because the activity index is independent of species, it will be constant for all the species examples, but it will vary on a monthly and annual basis. For the annual example, most of the surveys occur in 2014, and therefore this will be the year used for these examples. March and December were chosen as the representative months for the monthly example.

The two terms that define the activity index are the spatial and temporal indexes. In the following examples, the surveys used are those defined in Table A-1 and shown in Fig. A-2. The surveys that occur in each month are used to calculate the respective monthly indices. The spatial and temporal indices calculated on an annual and monthly basis are shown in the following tables (Tables A-2 and A-3, respectively).

Table A-2. Annual activity index for Zone 5 for 2014

Zone	Zonal Annual Activity Index (2014)	Annual Spatial Index (2014)	Annual Temporal Index (2014)
5	2.483	0.547	1.936

Table A-3. Monthly activity index for Zone 5 for 2014

Month	Monthly Activity Index	Monthly Spatial Index	Monthly Temporal Index
Jan	1.932	0.060	1.872
Feb	2.122	0.053	2.069
Mar	2.324	0.042	2.282
Apr	2.331	0.041	2.290
May	1.413	0.028	1.385
June	2.107	0.039	2.067
July	2.282	0.042	2.239
Aug	1.617	0.031	1.586
Sep	0.699	0.015	0.684
Oct	1.850	0.056	1.794
Nov	2.170	0.068	2.102
Dec	2.856	0.072	2.783

December had the highest activity index because it contained the most amount of survey days (86 days) and had the largest combined survey area as compared to any other month. September had the fewest number of survey days (21 days) and the smallest amount of survey area in Zone 5. The amount of survey area that can be covered is dependent on the amount of survey days available, but the area covered will also depend on the overall size of the survey. Months with lower activity indexes had fewer number of survey days than months with higher index values. The variation of the monthly activity indexes in comparison to the annual index is shown below (Fig. A-4). Variation of the number of survey days and area for each month are also shown (Fig. A-5).

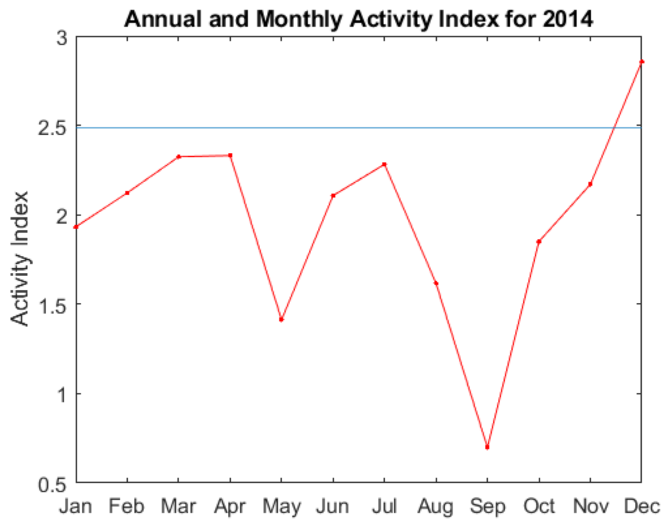

Figure A-4. Comparison between the annual (blue line) and monthly (red line) activity index for 2014 for Zone 5

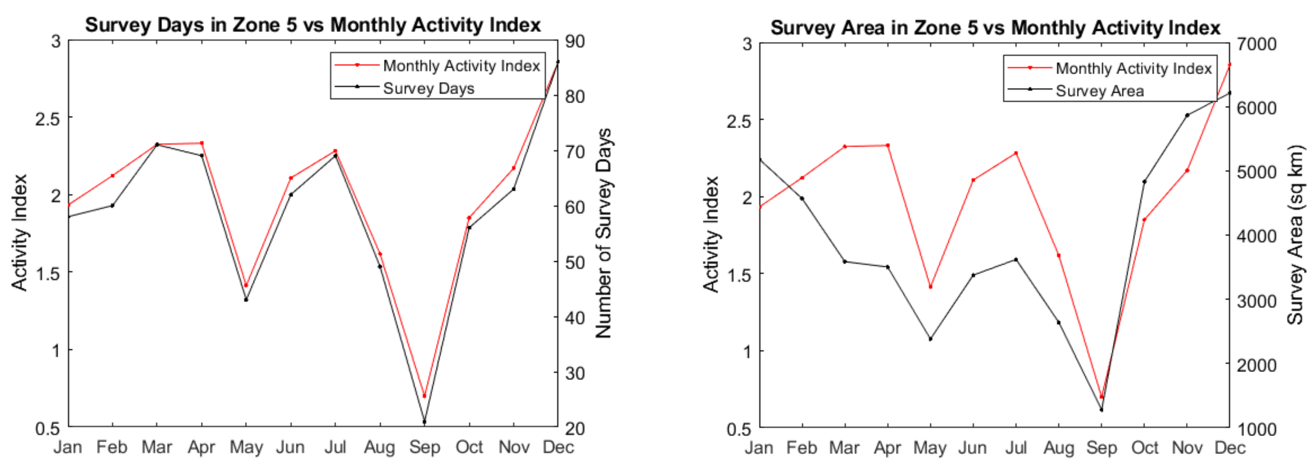

Figure A-5. Comparison of the survey days (left) and survey area (right) in Zone 5 during each month compared to the monthly activity index

Species of Interest

The monthly and annual exposure index was calculated for 18 different species in Zone 5 for 2014. The species and their hearing group designation are provided in Table A-4.

Table A-4. GoMex marine mammal species evaluated and their associated hearing group designations

Species	Hearing Group Designation
Atlantic spotted dolphin	MF
Beaked whales (Cuvier/Blainville/Gervais)	MF
Bottlenose dolphin	MF
Bryde's whale	LF
Clymene dolphin	MF
False killer whale	MF
Fraser’s dolphin	MF
Killer whale	MF
Kogia (dwarf, pygmy sperm whale)	HF
Melon-headed whale	MF
Pantropical spotted dolphin	MF
Pygmy killer whale	MF
Risso’s dolphin	MF
Rough-toothed dolphin	MF
Short-finned pilot whale	MF
Sperm Whale	MF
Spinner dolphin	MF
Striped dolphin	MF

Notes: LF = low-frequency, MF = mid-frequency, HF = high-frequency

Zone 5 Example Scenario: Exposure Index Calculations

Atlantic Spotted Dolphin

Relative distribution of Atlantic spotted dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-6).

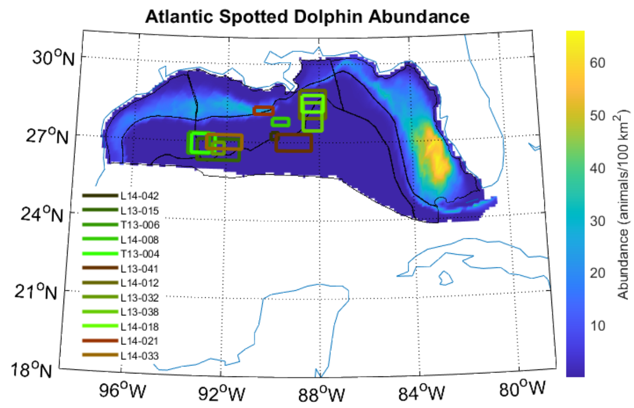

Figure A-6. Atlantic spotted dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-7) on an annual basis (2014).

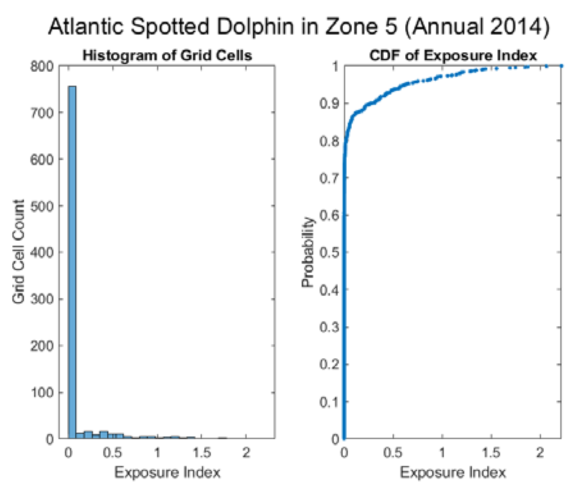

Figure A-7. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Atlantic spotted dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-8) for two selected 2014 months (March and December).

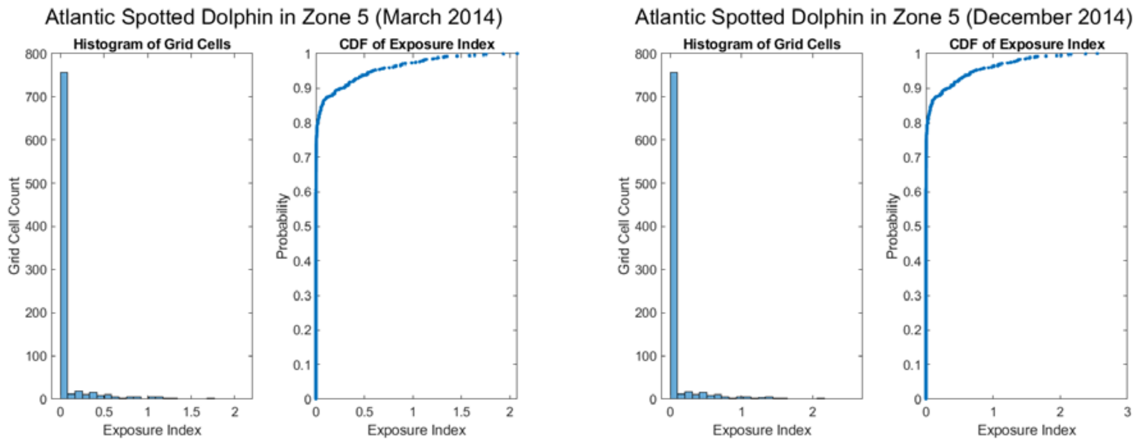

Figure A-8. Exposure index histograms and cumulative distribution functions for Atlantic spotted dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Atlantic spotted dolphin in Zone 5 were 0.0848 (March) and 0.1044 (December). Using these values, the zone-specific population (0.037) of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.3145 (March) and 0.3863 (December). Consequently, the exposure index risk assessment ratings for Atlantic spotted dolphin (using the preliminary rating conversions described in Table 2) for March and December 2014 in Zone 5 were VERY LOW for both months.

Beaked Whales (Cuvier/Blainville/Gervais)

Relative distribution of beaked whales (Cuvier/Blainville/Gervais) in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-9).

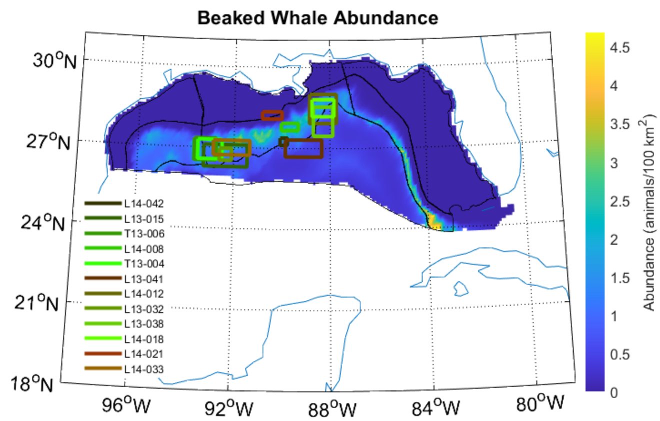

Figure A-9. Beaked whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-10) on an annual basis (2014).

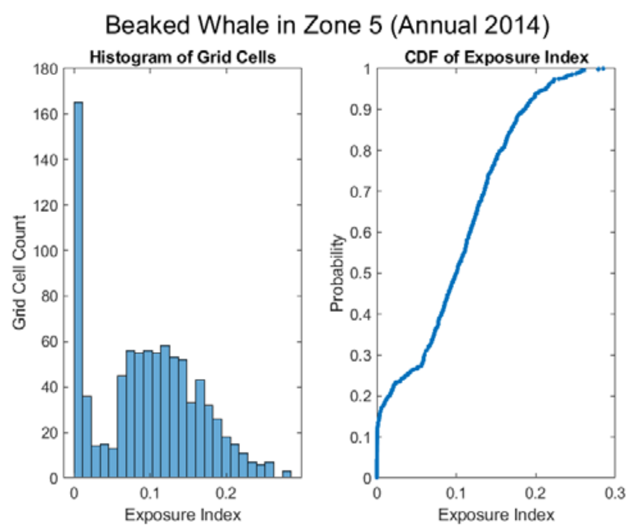

Figure A-10. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for beaked whales in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-11) for two selected 2014 months (March and December).

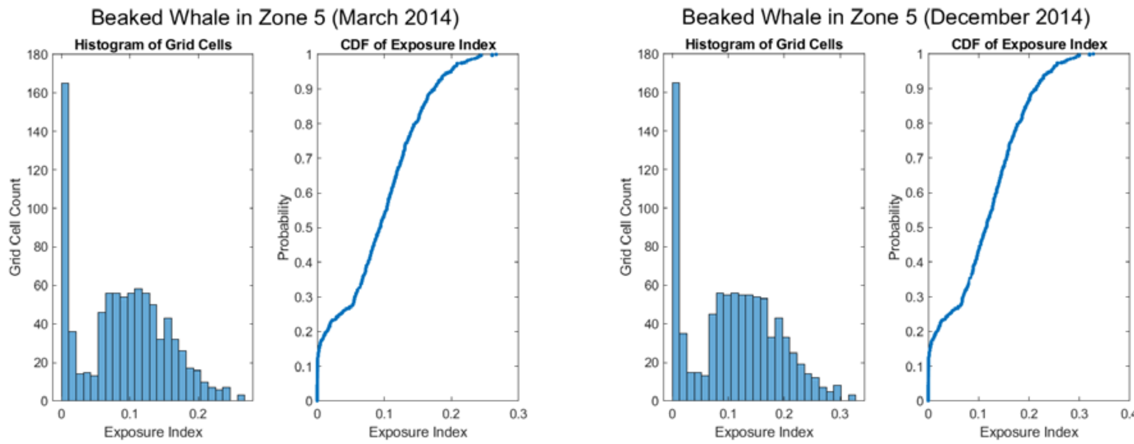

Figure A-11. Exposure index histograms and cumulative distribution functions for beaked whales in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for beaked whales in Zone 5 were 0.0906 (March) and 0.1114 (December). Using these values, the zone-specific population (0.326 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 2.9536 (March) and 3.6316 (December). Consequently, the exposure index risk assessment ratings for beaked whales (using the preliminary rating conversions described in Table 2) for March and December 2014 in Zone 5 were MODERATE and HIGH, respectively.

Bottlenose Dolphin

Relative distribution of bottlenose dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-12).

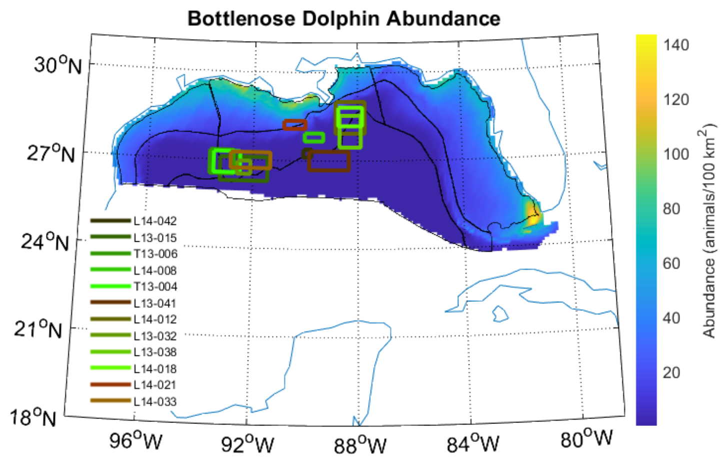

Figure A-12. Bottlenose dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-13) on an annual basis (2014).

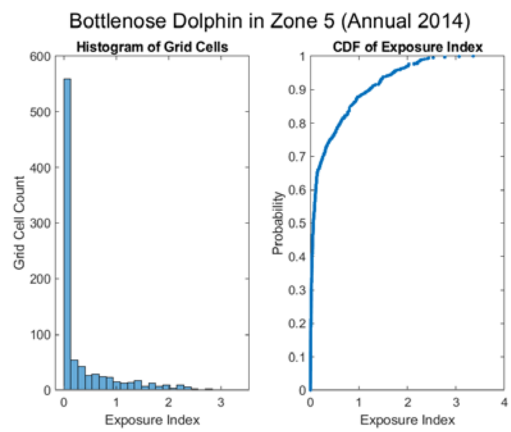

Figure A-13. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for bottlenose dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-14) for two selected 2014 months (March and December).

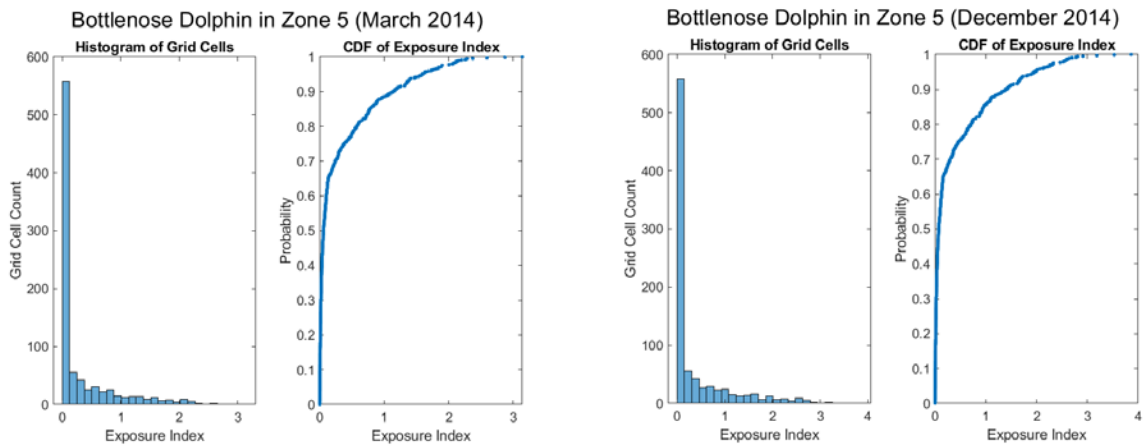

Figure A-14. Exposure index histograms and cumulative distribution functions for bottlenose dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for bottlenose dolphin in Zone 5 were 0.3239 (March) and 0.398 (December). Using these values, the zone-specific population (0.036 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 1.166 (March) and 1.4328 (December). Consequently, the exposure index risk assessment ratings for bottlenose dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Bryde's Whale

Relative distribution of Bryde's whale (see also Roberts et al., 2015) in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-15).

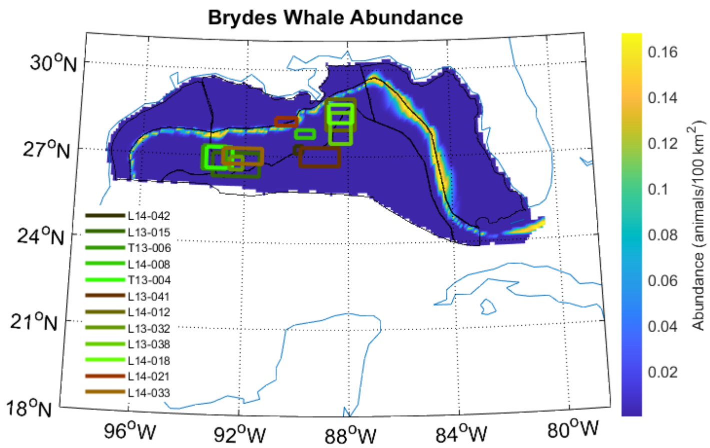

Figure A-15. Bryde's whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-16) on an annual basis (2014).

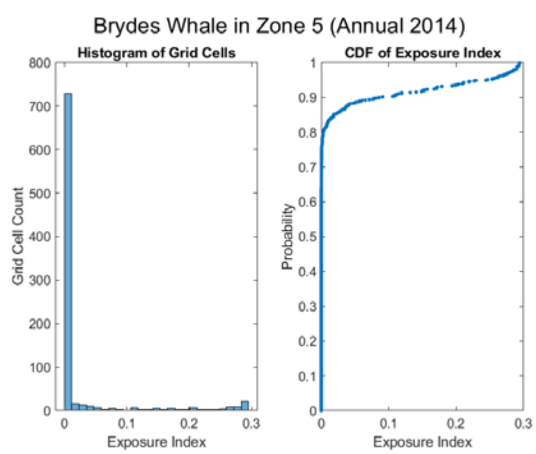

Figure A-16. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Bryde's whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-17) for two selected 2014 months (March and December).

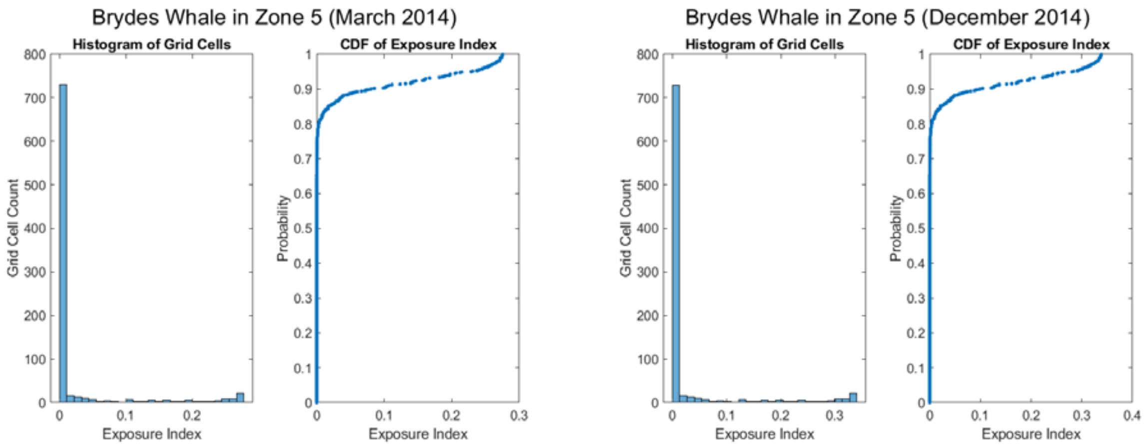

Figure A-17. Exposure index histograms and cumulative distribution functions for Bryde's whale in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Bryde's whale in Zone 5 were 0.0235 (March) and 0.0289 (December). Using these values, the zone-specific population (0.19 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.4465 (March) and 0.5491 (December). Consequently, the exposure index risk assessment ratings for Bryde's whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY LOW and LOW, respectively.

Clymene Dolphin

Relative distribution of Clymene dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-18).

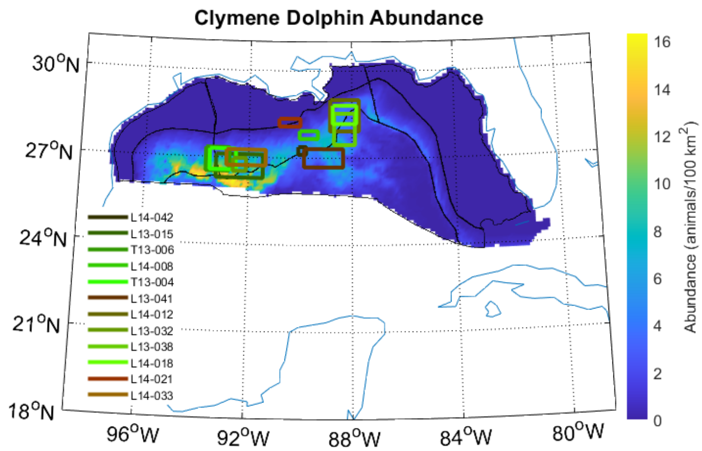

Figure A-18. Clymene dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-19) on an annual basis (2014).

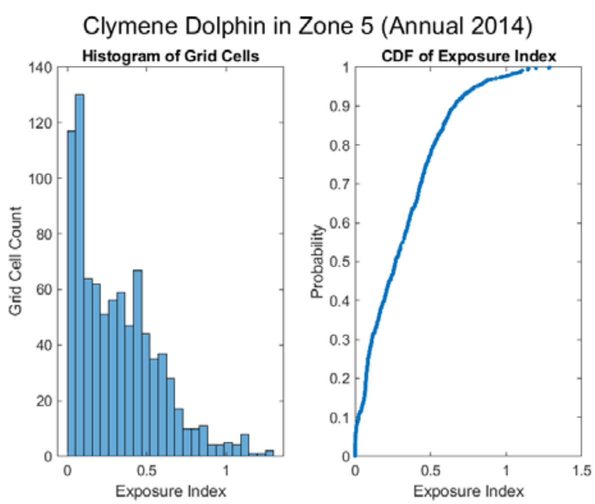

Figure A-19. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Clymene dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-20) for two selected 2014 months (March and December).

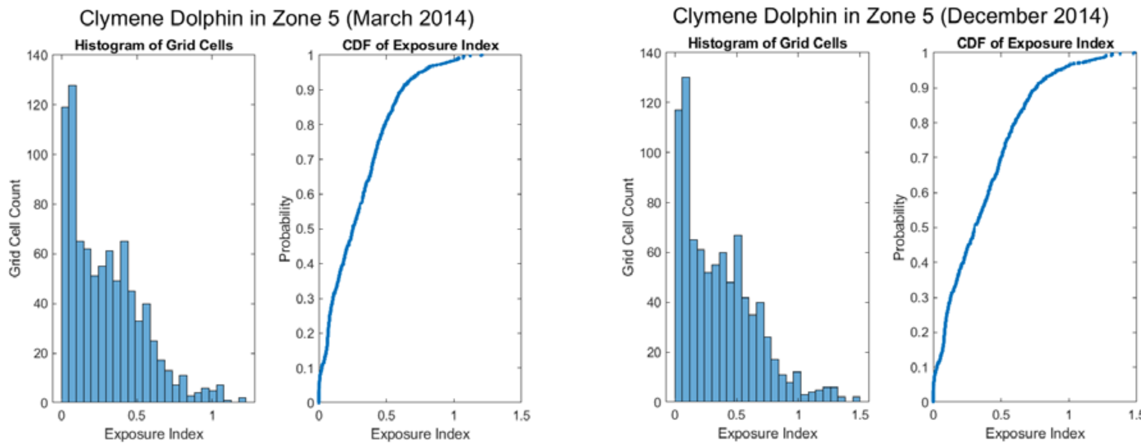

Figure A-20. Exposure index histograms and cumulative distribution functions for Clymene dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Clymene dolphin in Zone 5 were 0.2955 (March) and 0.3631 (December). Using these values, the zone-specific population (0.274 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 8.0967 (March) and 9.9489 (December). Consequently, the exposure index risk assessment ratings for Clymene dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY HIGH for both months.

False Killer Whale

Relative distribution of false killer whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-21).

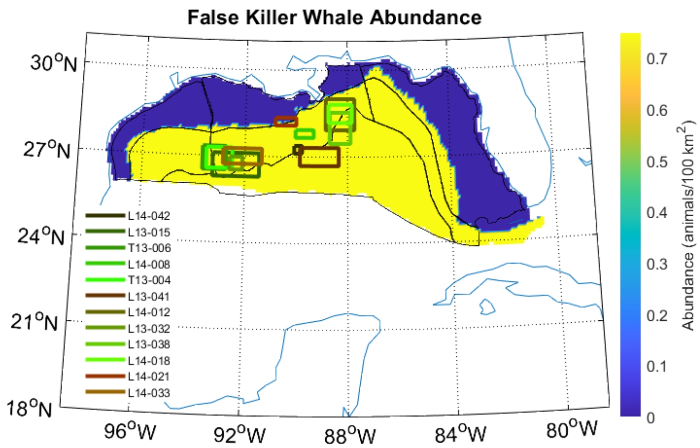

Figure A-21. False killer whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-22) on an annual basis (2014).

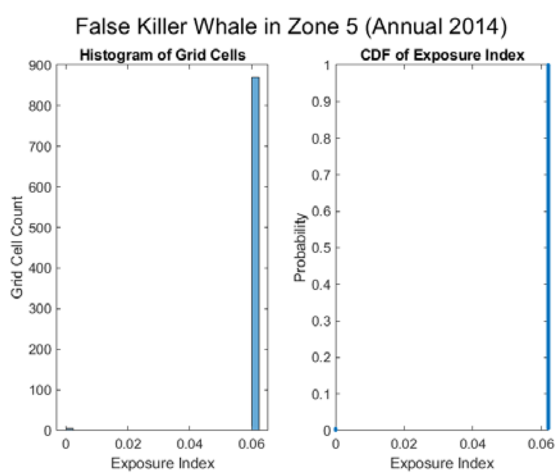

Figure A-22. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for false killer whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-23) for two selected 2014 months (March and December).

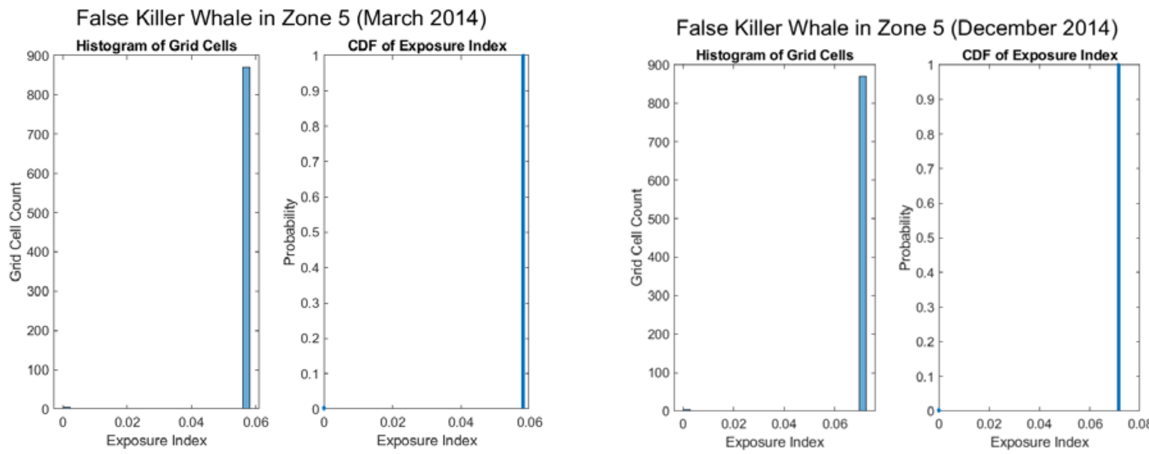

Figure A-23. Exposure index histograms and cumulative distribution functions for false killer whale in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for false killer whale in Zone 5 were 0.0578 (March) and 0.071 (December). Using these values, the zone-specific population (0.198 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.5940 (March) and 1.4058 (December). Consequently, the exposure index risk assessment ratings for false killer whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were LOW and MODERATE, respectively.

Fraser's Dolphin

Relative distribution of Fraser's dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-24).

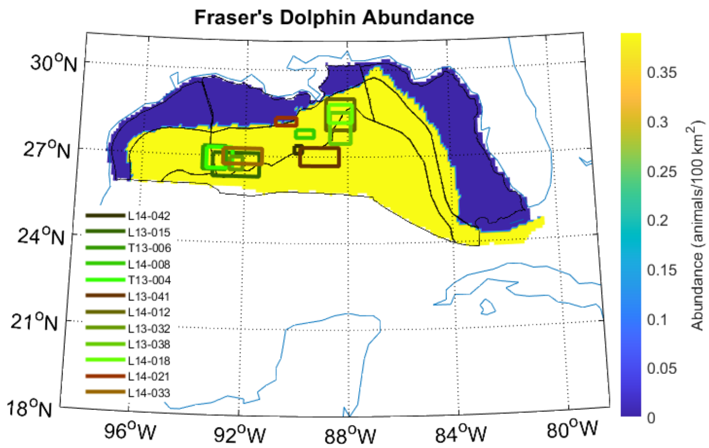

Figure A-24. Fraser's dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-25) on an annual basis (2014).

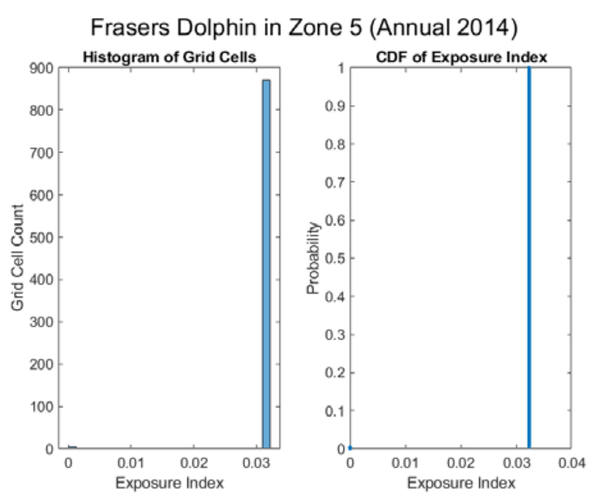

Figure A-25. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Fraser's dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-26) for two selected 2014 months (March and December).

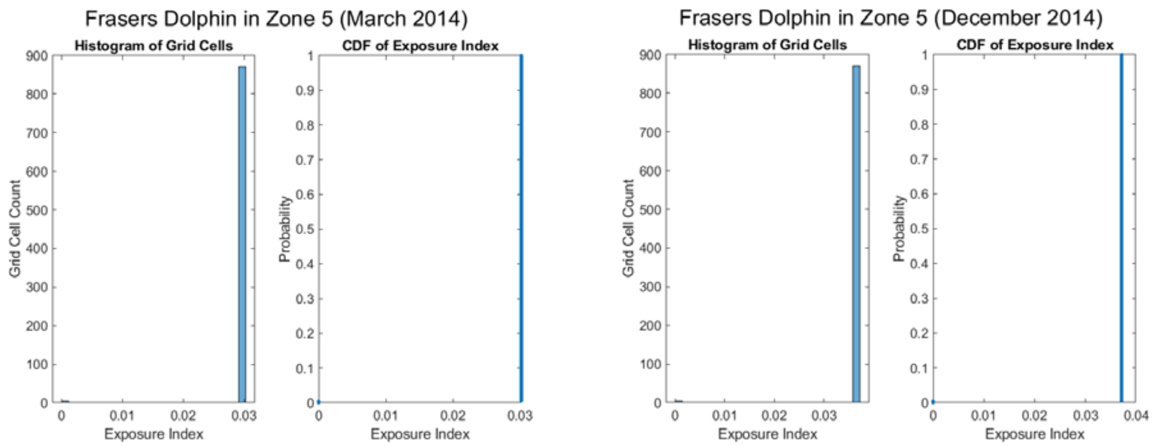

Figure A-26. Exposure index histograms and cumulative distribution functions for Fraser's dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Fraser's dolphin in Zone 5 were 0.03 (March) and 0.0369 (December). Using these values, the zone-specific population (0.198 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.5940 (March) and 0.7306 (December). Consequently, the exposure index risk assessment ratings for Fraser's dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were LOW for both months.

Killer Whale

Relative distribution of killer whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-27).

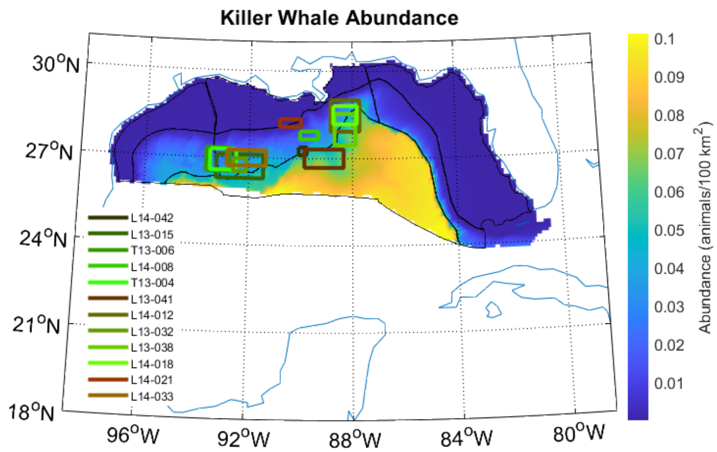

Figure A-27. Killer whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-28) on an annual basis (2014).

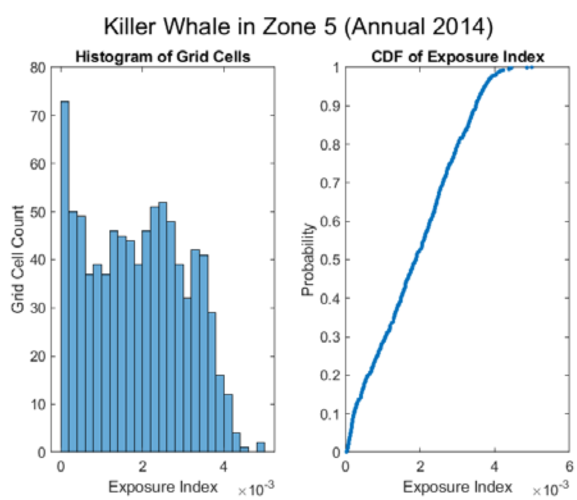

Figure A-28. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for killer whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-29) for two selected 2014 months (March and December).

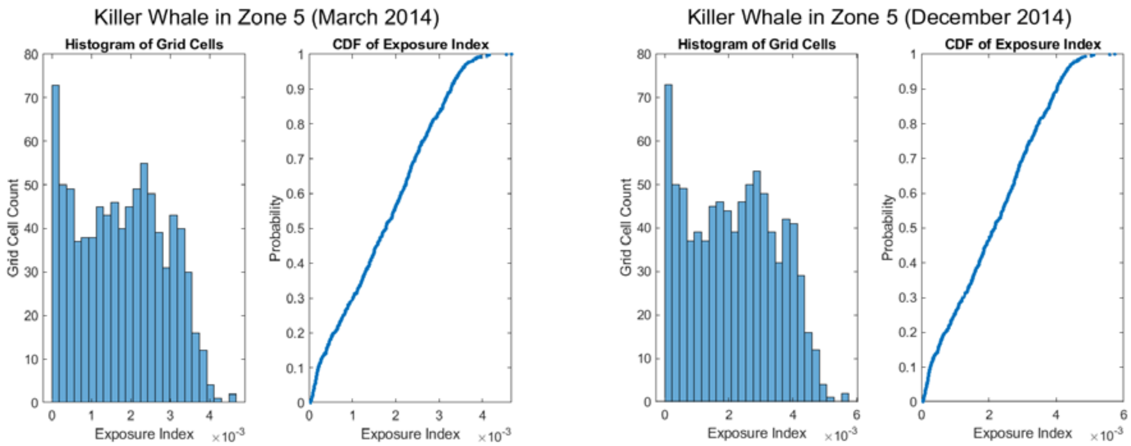

Figure A-29. Exposure index histograms and cumulative distribution functions for killer whale in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for killer whale in Zone 5 were 0.0018 (March) and 0.0022 (December). Using these values, the zone-specific population (0.095 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.0171 (March) and 0.0209 (December). Consequently, the exposure index risk assessment ratings for killer whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY LOW for both months.

Kogia (Dwarf, Pygmy Sperm Whale)

Relative distribution of Kogia in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-30).

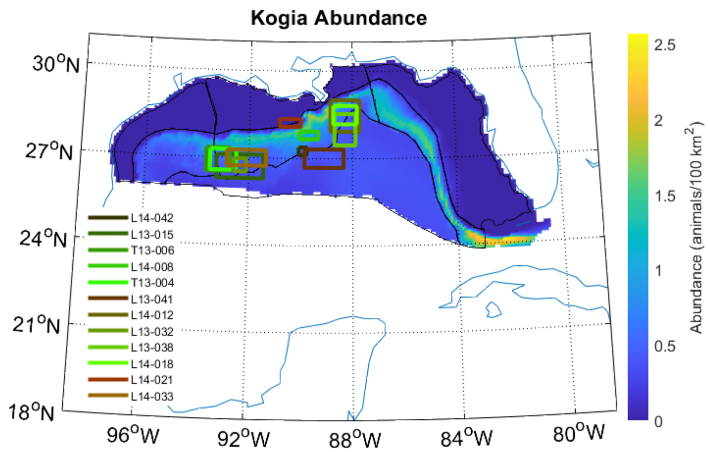

Figure A-30. Kogia abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-31) on an annual basis (2014).

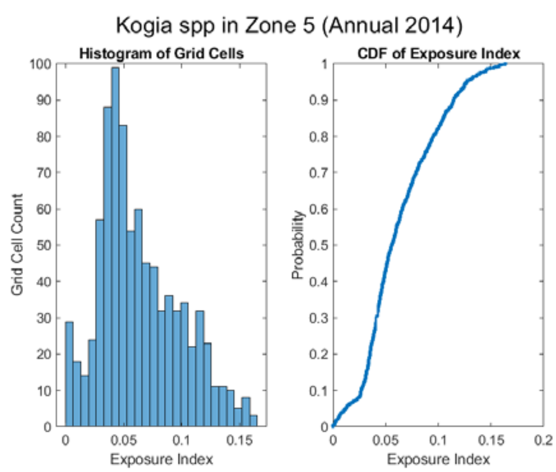

Figure A-31. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Kogia in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-32) for two selected 2014 months (March and December).

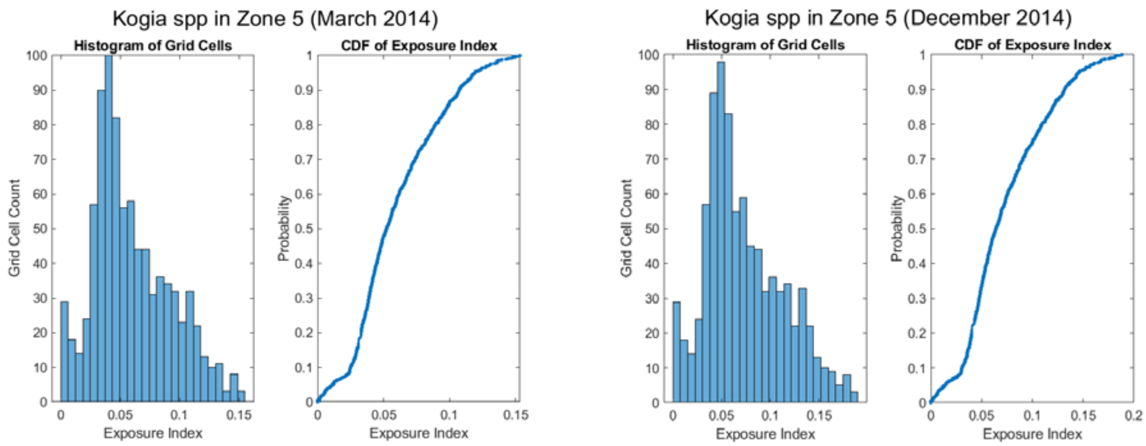

Figure A-32. Exposure index histograms and cumulative distribution functions for Kogia in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Kogia in Zone 5 were 0.0596 (March) and 0.0732 (December). Using these values, the zone-specific population (0.285 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 1.6986 (March) and 2.0862 (December). Consequently, the exposure index risk assessment ratings for Kogia (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Melon-headed Whale

Relative distribution of melon-headed whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-33).

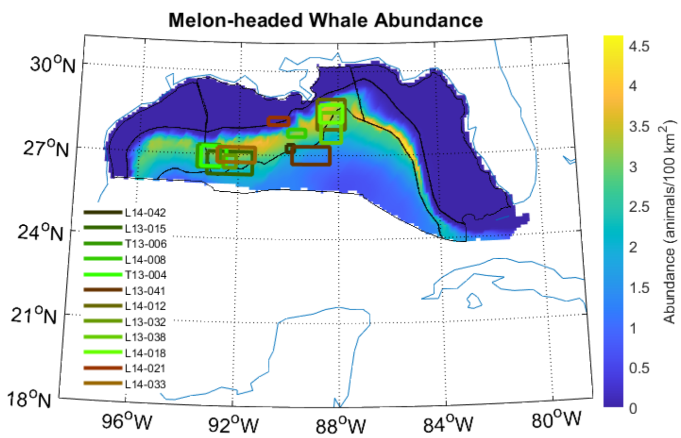

Figure A-33. Melon-headed whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-34) on an annual basis (2014).

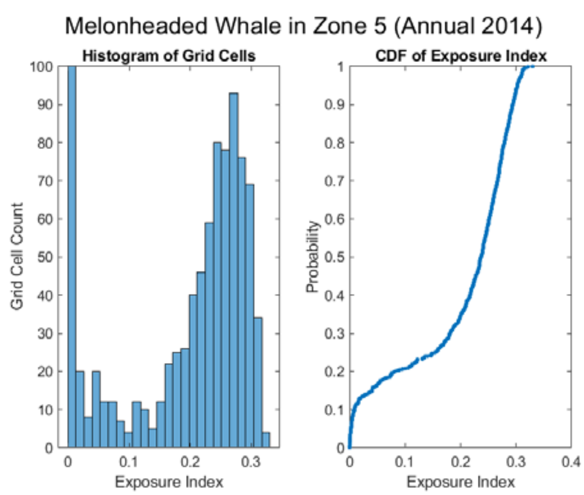

Figure A-34. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for melon-headed whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-35) for two selected 2014 months (March and December).

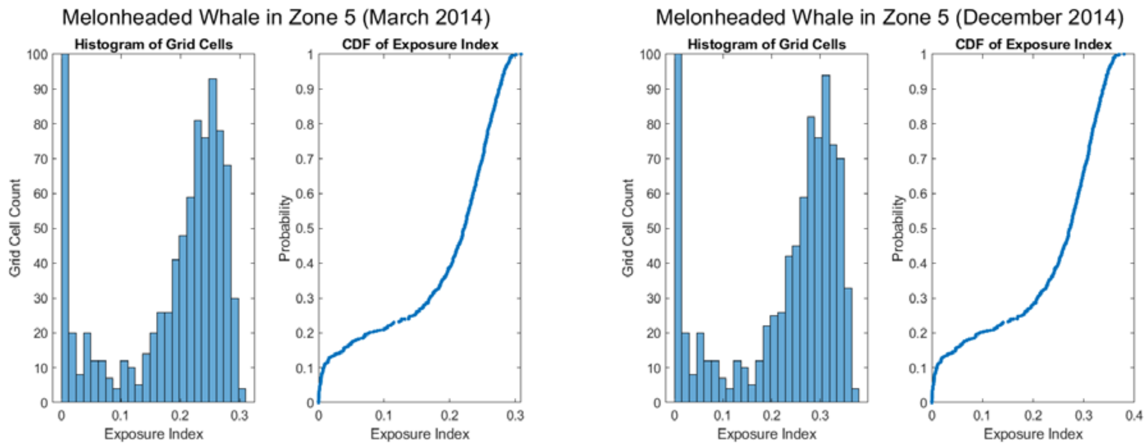

Figure A-35. Exposure index histograms and cumulative distribution functions for melon-headed whale in Zone 5 for March (left), and December (right) 2014.

Corresponding raw mean index scores for melon-headed whale in Zone 5 were 0.1856 (March) and 0.2281 (December). Using these values, the zone-specific population (0.288 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 5.3453 (March) and 6.5693 (December). Consequently, the exposure index risk assessment ratings for melon-headed whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY HIGH for both months.

Pantropical Spotted Dolphin

Relative distribution of pantropical spotted dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-36).

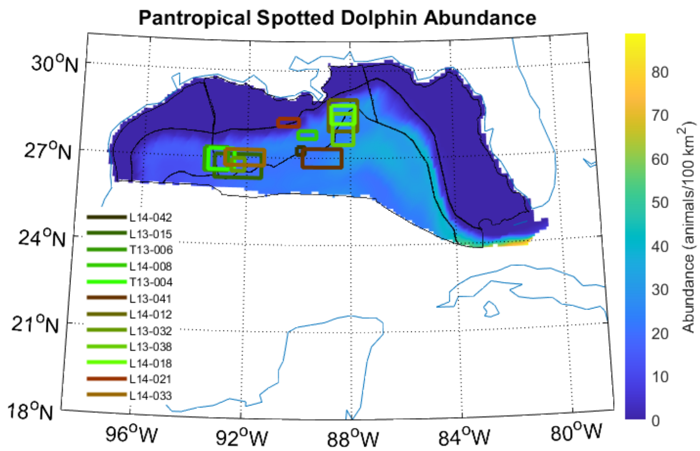

Figure A-36. Pantropical spotted dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-37) on an annual basis (2014).

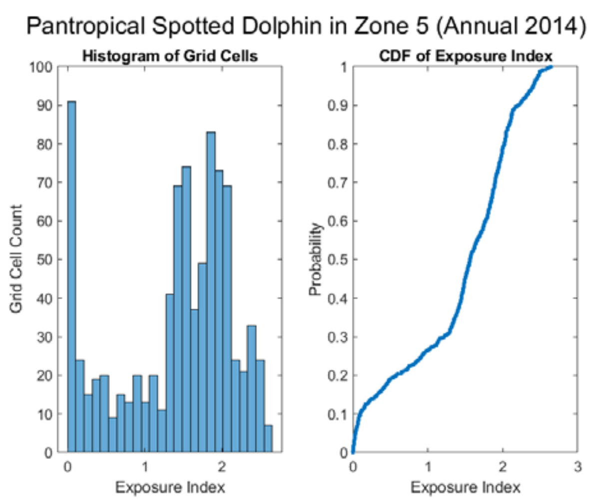

Figure A-37. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Pantropical spotted dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-38) for two selected 2014 months (March and December).

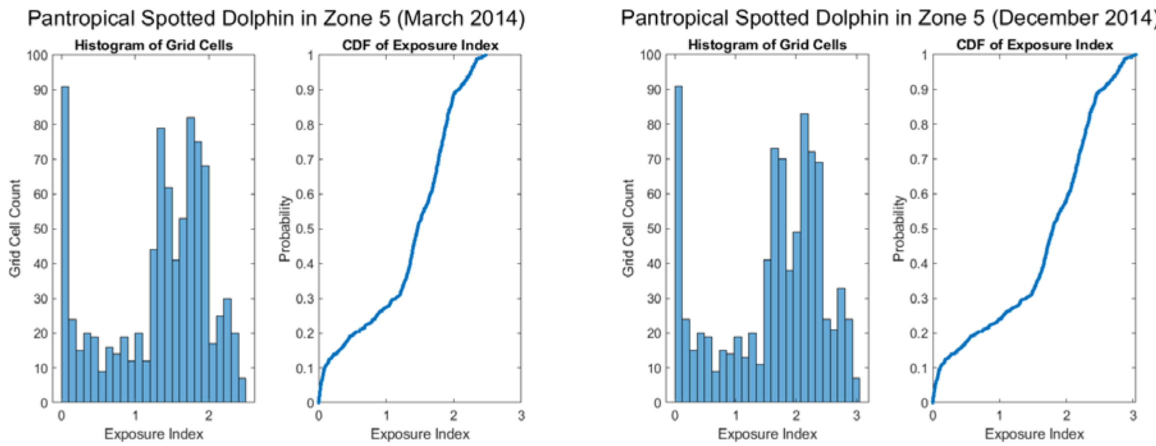

Figure A-38. Exposure index histograms and cumulative distribution functions for Pantropical spotted dolphin in Zone 5 for March (left), and December (right) 2014.

Corresponding raw mean index scores for pantropical spotted dolphin in Zone 5 were 1.3185 (March) and 1.6203 (December). Using these values, the zone-specific population (0.161 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 21.2279 (March) and 26.0868 (December). Consequently, the exposure index risk assessment ratings for pantropical spotted dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY HIGH for both months.

Pygmy Killer Whale

Relative distribution of pygmy killer whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-39).

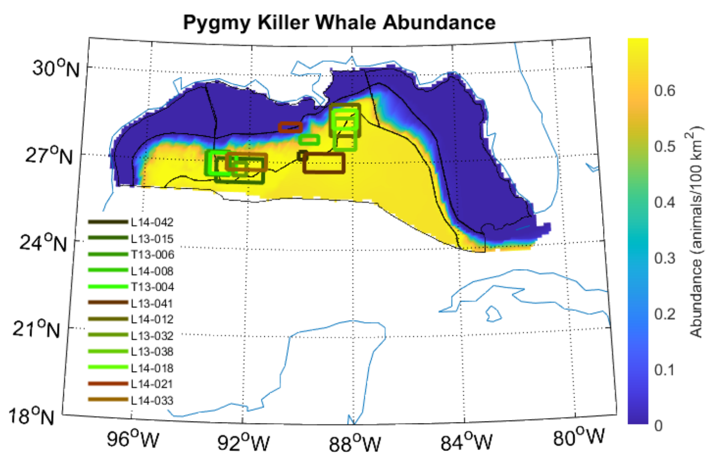

Figure A-39. Pygmy killer whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-40) on an annual basis (2014).

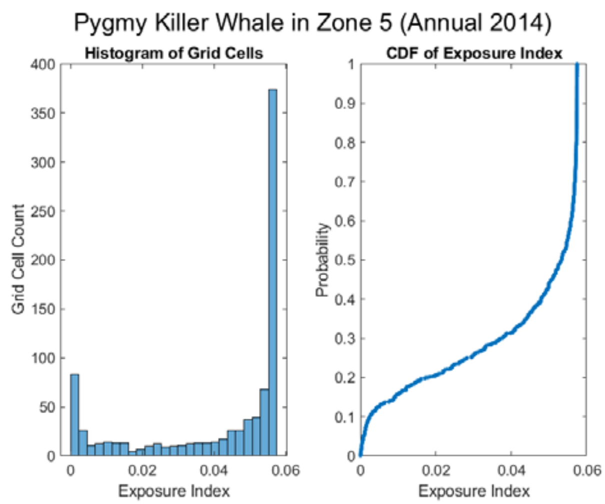

Figure A-40. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for pygmy killer whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-41) for two selected 2014 months (March and December).

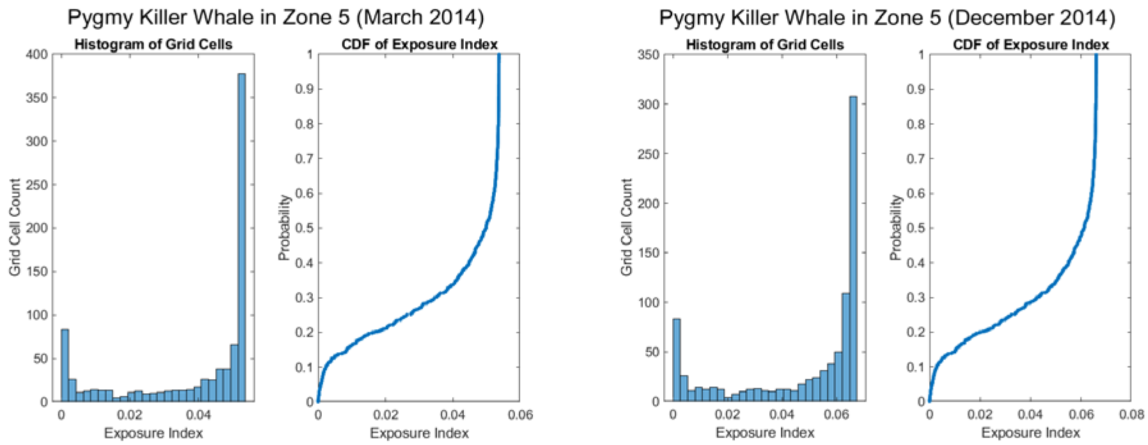

Figure A-41. Exposure index histograms and cumulative distribution functions for pygmy killer whale in Zone 5 for March (left), and December (right) 2014.

Corresponding raw mean index scores for pygmy killer whale in Zone 5 were 0.0388 (March) and 0.0477 (December). Using these values, the zone-specific population (0.189 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 0.7333 (March) and 0.9015 (December). Consequently, the exposure index risk assessment ratings for pygmy killer whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were LOW for both months.

Risso's Dolphin

Relative distribution of Risso's dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-42).

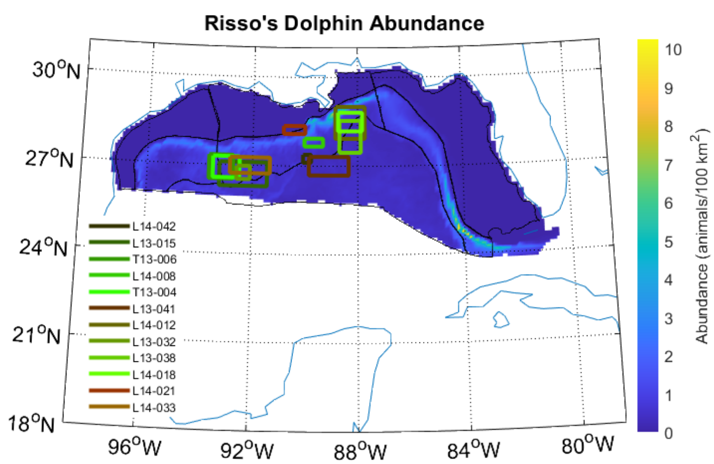

Figure A-42. Risso's dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-43) on an annual basis (2014).

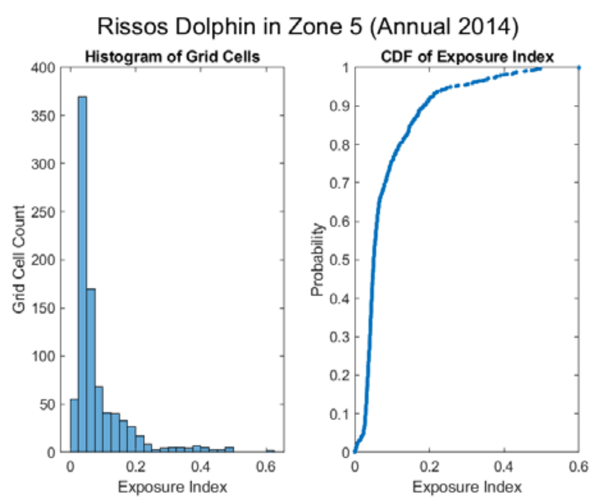

Figure A-43. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for Risso's dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-44) for two selected 2014 months (March and December).

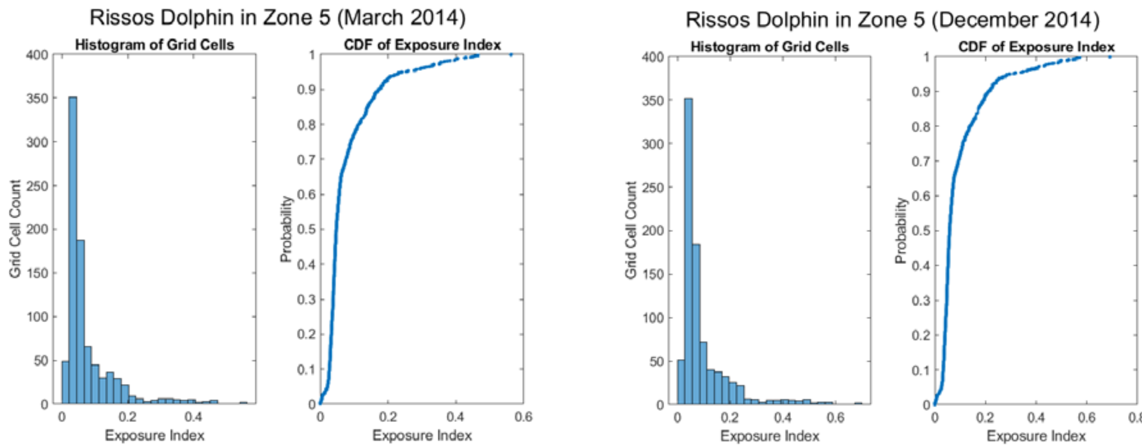

Figure A-44. Exposure index histograms and cumulative distribution functions for Risso's dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for Risso's dolphin in Zone 5 were 0.08 (March) and 0.0984 (December). Using these values, the zone-specific population (0.271 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 2.168 (March) and 2.6666 (December). Consequently, the exposure index risk assessment ratings for Risso's dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Rough-toothed Dolphin

Relative distribution of rough-toothed dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-45).

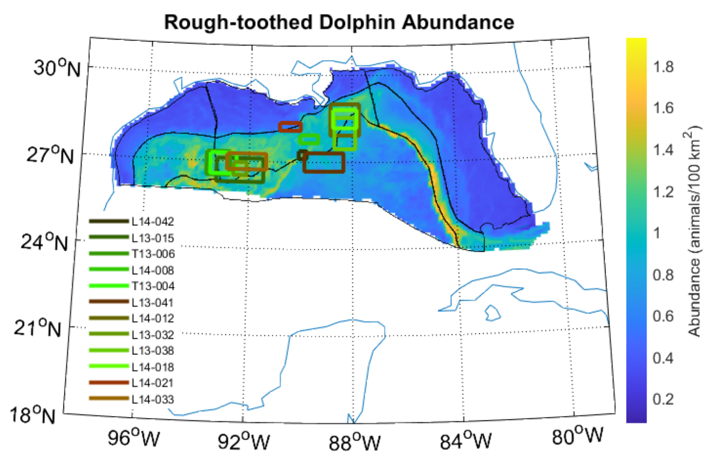

Figure A-45. Rough-toothed dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-46) on an annual basis (2014).

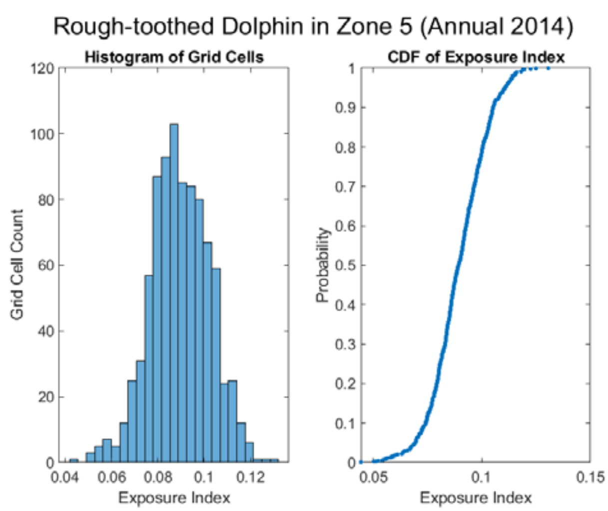

Figure A-46. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for rough-toothed dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-47) for two selected 2014 months (March and December).

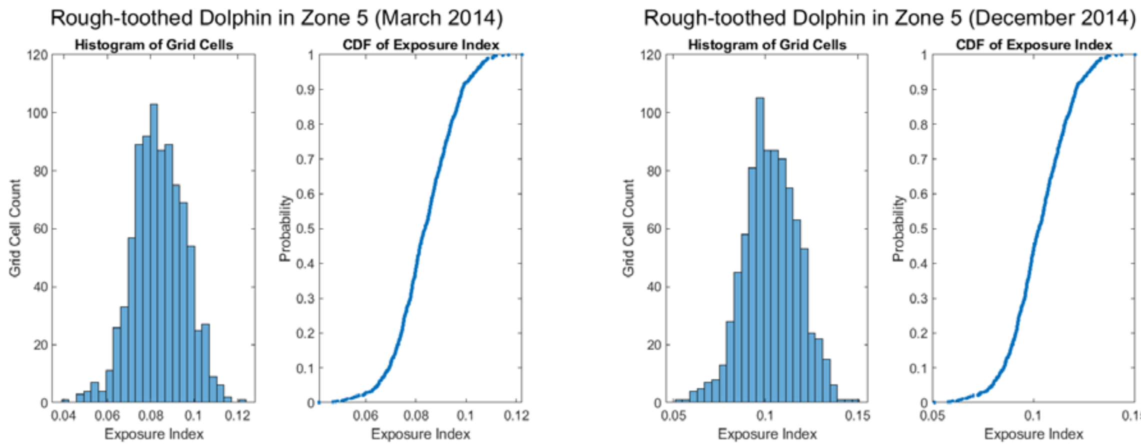

Figure A-47. Exposure index histograms and cumulative distribution functions for rough-toothed dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for rough-toothed dolphin in Zone 5 were 0.0838 (March) and 0.103 (December). Using these values, the zone-specific population (0.189 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 1.5838 (March) and 1.9467 (December). Consequently, the exposure index risk assessment ratings for rough-toothed dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Short-finned Pilot Whale

Relative distribution of short-finned pilot whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-48).

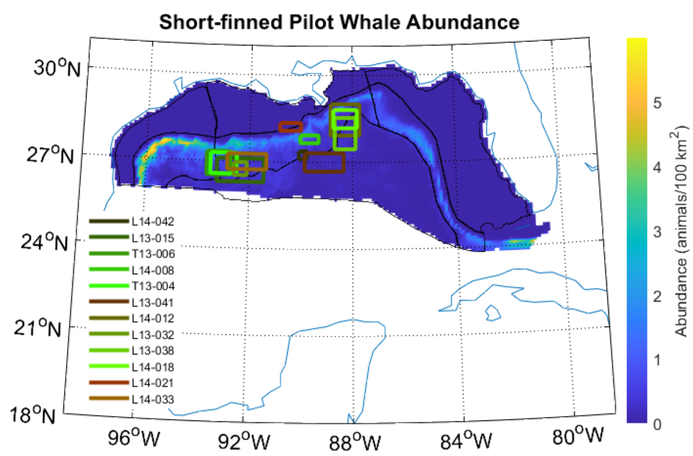

Figure A-48. Short-finned pilot whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-49) on an annual basis (2014).

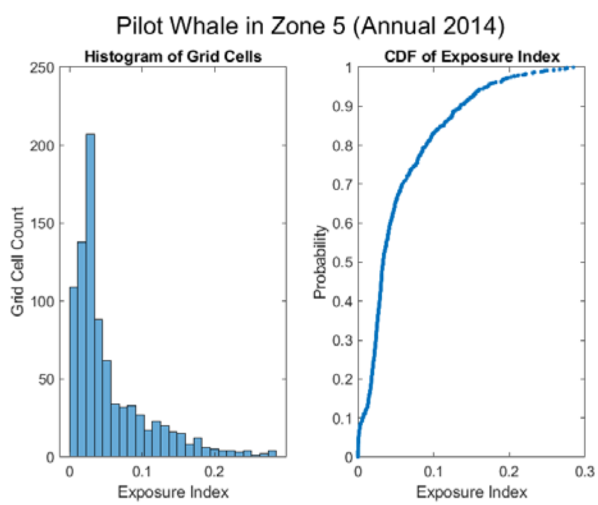

Figure A-49. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for short-finned pilot whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-50) for two selected 2014 months (March and December).

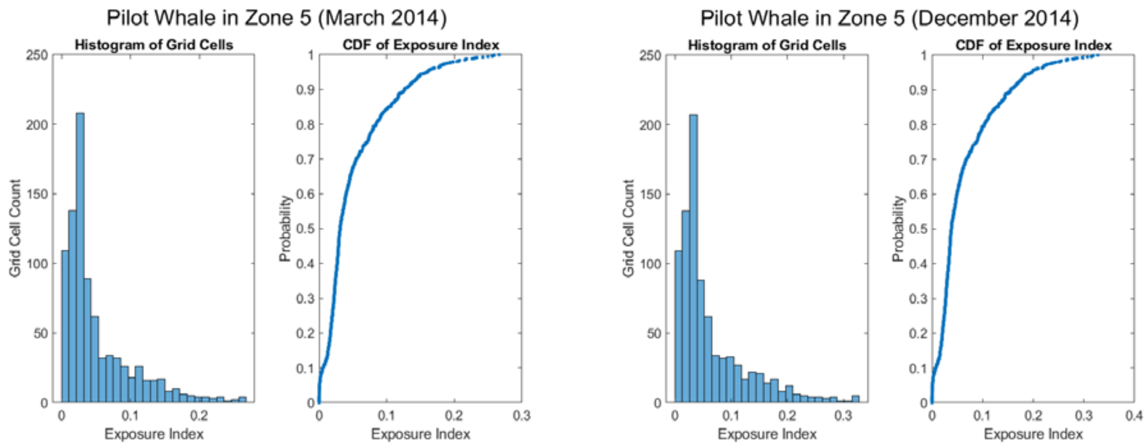

Figure A-50. Exposure index histograms and cumulative distribution functions for short-finned pilot whale in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for short-finned pilot whale in Zone 5 were 0.0514 (March) and 0.0631 (December). Using these values, the zone-specific population (0.284 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 1.4598 (March) and 1.792 (December). Consequently, the exposure index risk assessment ratings for short-finned pilot whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Sperm Whale

Relative distribution of sperm whale in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-51).

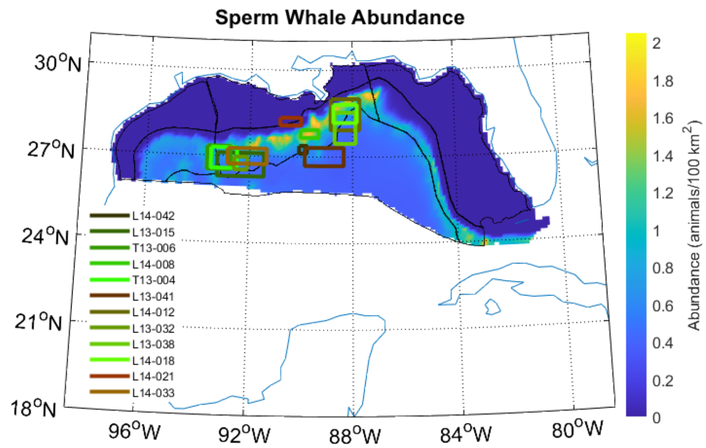

Figure A-51. Sperm whale abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-52) on an annual basis (2014).

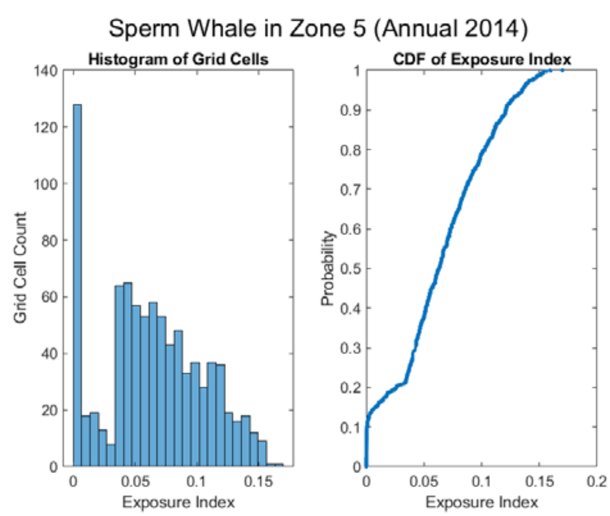

Figure A-52. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for sperm whale in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-53) for two selected 2014 months (March and December).

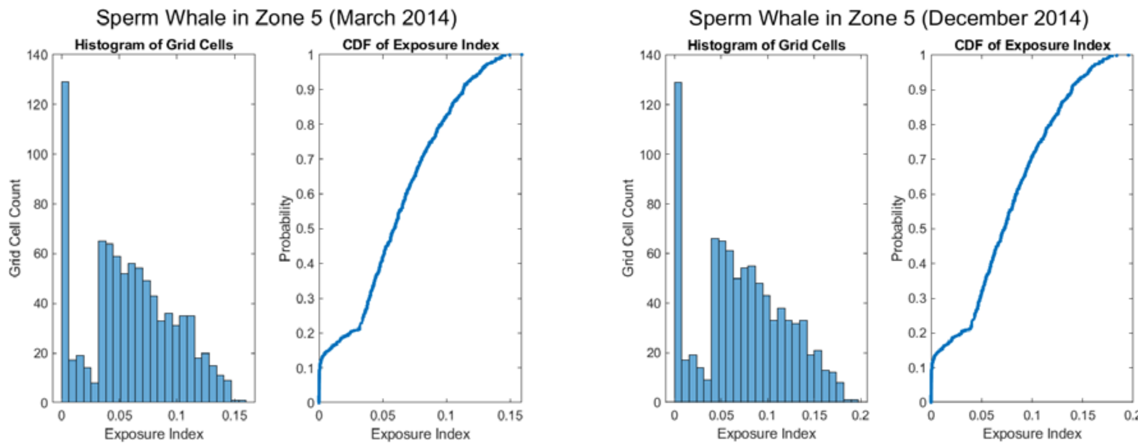

Figure A-53. Exposure index histograms and cumulative distribution functions for sperm whale in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for sperm whale in Zone 5 were 0.0595 (March) and 0.0737 (December). Using these values, the zone-specific population (0.298 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 1.7731 (March) and 2.1963 (December). Consequently, the exposure index risk assessment ratings for sperm whale (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE for both months.

Spinner Dolphin

Relative distribution of spinner dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-54).

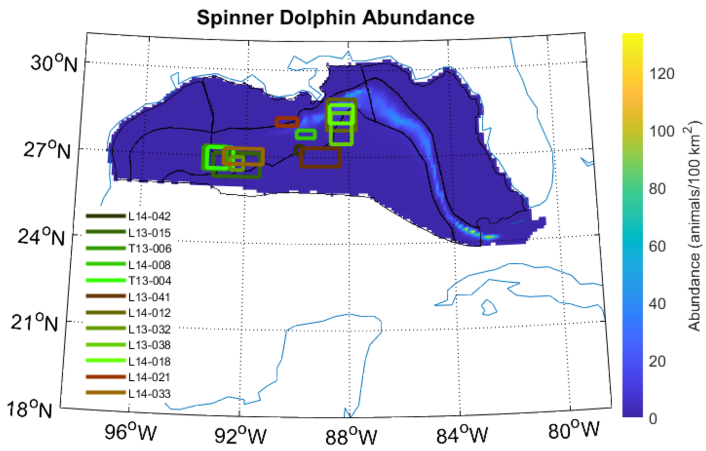

Figure A-54. Spinner dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-55) on an annual basis (2014).

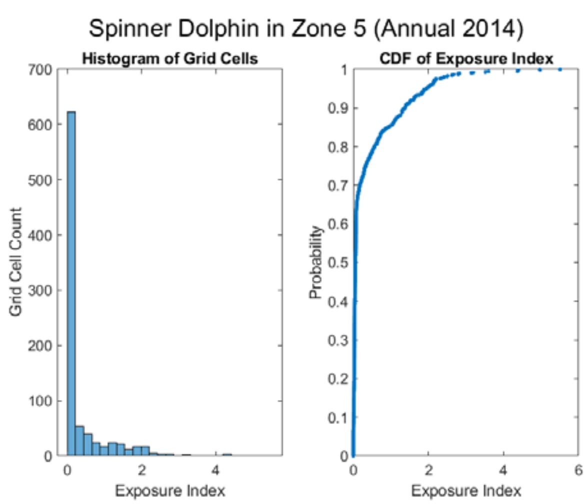

Figure A-55. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for spinner dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-56) for two selected 2014 months (March and December).

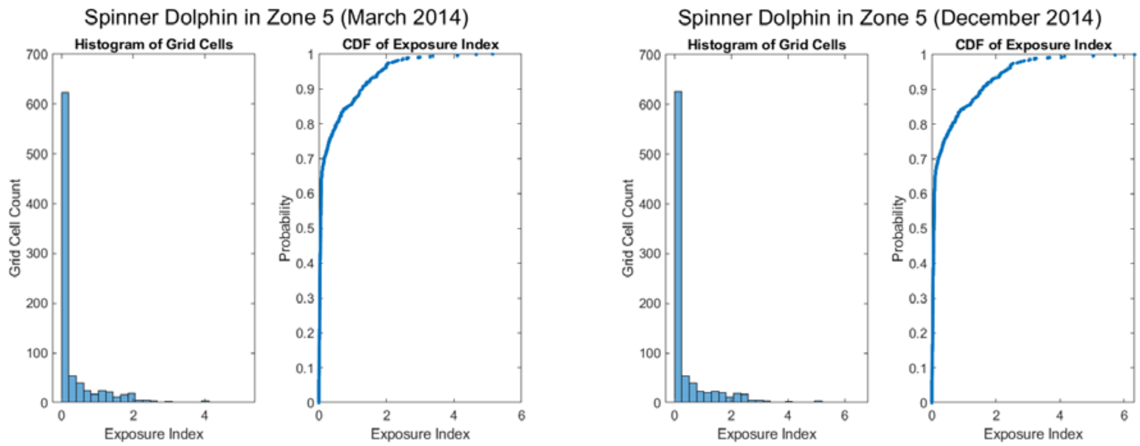

Figure A-56. Exposure index histograms and cumulative distribution functions for spinner dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for spinner dolphin in Zone 5 were 0.3498 (March) and 0.4299 (December). Using these values, the zone-specific population (0.269 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 9.4096 (March) and 11.5643 (December). Consequently, the exposure index risk assessment ratings for spinner dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were VERY HIGH for both months.

Striped Dolphin

Relative distribution of striped dolphin in relation to the 2014 surveys and GoMex zones is shown below (Fig. A-57).

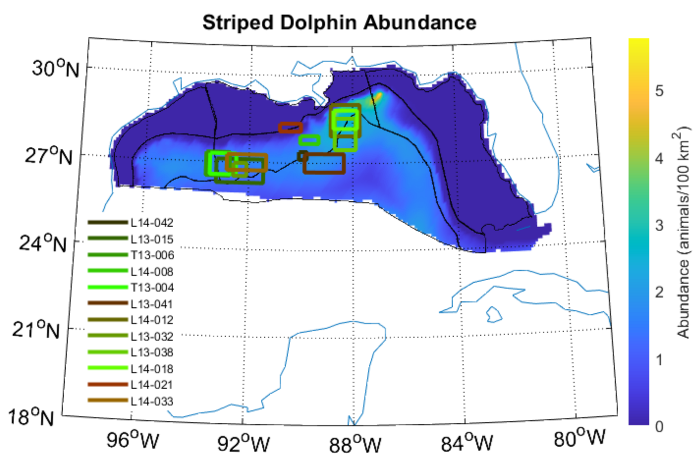

Figure A-57. Striped dolphin abundance distribution and rectangular representation of example surveys for 2014

Resulting exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-58) on an annual basis (2014).

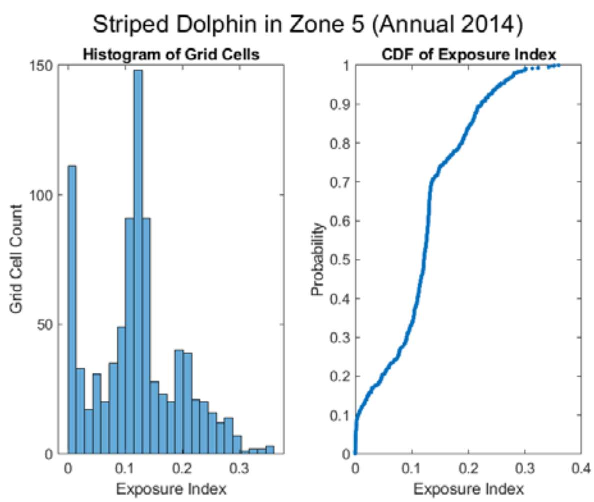

Figure A-58. Annual (2014) exposure histogram and cumulative distribution function for exposure index values for striped dolphin in Zone 5

Monthly exposure index values for Zone 5 are given as histograms and cumulative distribution functions below (Fig. A-59) for two selected 2014 months (March and December).

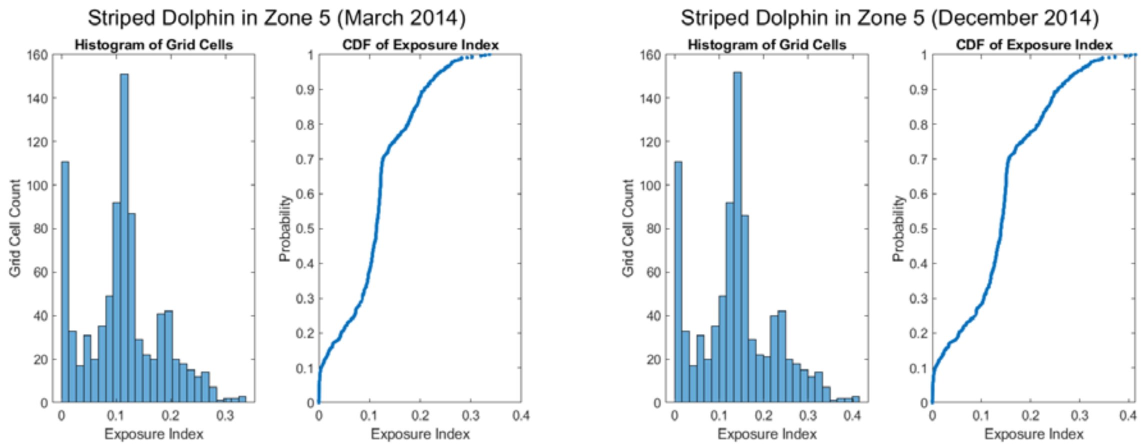

Figure A-59. Exposure index histograms and cumulative distribution functions for striped dolphin in Zone 5 for March (left), and December (right) 2014

Corresponding raw mean index scores for striped dolphin in Zone 5 were 0.1124 (March) and 0.1381 (December). Using these values, the zone-specific population (0.238 of GoMex population within Zone 5), and a scaling factor, the normalized final index scores were 2.6751 (March) and 3.2868 (December). Consequently, the exposure index risk assessment ratings for striped dolphin (using the preliminary rating conversions described in Table 2 above) for March and December 2014 in Zone 5 were MODERATE and HIGH, respectively.

Table A-5. Scaled exposure index values and associated risk assessment scores in Zone 5 for March and December 2014

Species	March, Zone 5		December, Zone 5	
	Normalized Exposure Index	Risk Assessment Score	Normalized Exposure Index	Risk Assessment Score
Atlantic spotted dolphin	0.3145	VERY LOW	0.3863	VERY LOW
Beaked whales (Cuvier/Blainville/Gervais)	2.9536	MODERATE	3.6316	HIGH
Bottlenose dolphin	1.1660	MODERATE	1.4328	MODERATE
Bryde's whale	0.4465	VERY LOW	0.5491	LOW
Clymene dolphin	8.0967	VERY HIGH	9.9489	VERY HIGH
False killer whale	1.1444	MODERATE	1.4058	MODERATE
Fraser’s dolphin	0.5940	LOW	0.7306	LOW
Killer whale	0.0171	VERY LOW	0.0209	VERY LOW
Kogia (dwarf, pygmy sperm whale)	1.6986	MODERATE	2.0862	MODERATE
Melon-headed whale	5.3453	VERY HIGH	6.5693	VERY HIGH
Pantropical spotted dolphin	21.2279	VERY HIGH	26.0868	VERY HIGH
Pygmy killer whale	0.7333	LOW	0.9015	LOW
Risso’s dolphin	2.1680	MODERATE	2.6666	MODERATE
Rough-toothed dolphin	1.5838	MODERATE	1.9467	MODERATE
Short-finned pilot whale	1.4598	MODERATE	1.7920	MODERATE
Sperm whale	1.7731	MODERATE	2.1963	MODERATE
Spinner dolphin	9.4096	VERY HIGH	11.5643	VERY HIGH
Striped dolphin	2.6751	MODERATE	3.2868	HIGH

Zone 5 Example Scenario: Species-Specific Vulnerability Calculations

As described in Southall et al. (2019), the species-specific vulnerability assessment includes four discrete factors: species population; habitat use and compensatory abilities; potential masking; and environmental risk factors. Vulnerability scores for all GoMex species were determined for the acute exposure scenario in an adapted application of the acute risk exposure scenario for the Gulf of Mexico Draft Environmental Impact Statement (DEIS). Here, we simply report those vulnerability scores for species population factor (Table A-6), species habitat use and compensatory abilities (Table A-7), and environmental risk factors (Table A-12). The potential masking factor for each species is derived in greater detail, as this was conducted subsequently. These are given for the Zone 5 example scenario, but for Bryde's whales (LF species for which low-frequency masking noise is presumably more relevant than for odontocetes), examples of this factor calculated for animals in Zone 1 arising from the activities conducted in Zone 5 are also given.

Table A-6. Vulnerability factor 1 scores—species population

Species	Population Status	Population Trend	Population Size	Vulnerability Factor 1 Total Score (out of 7)
Atlantic spotted dolphin	0	1	0	1
Beaked whales (Cuvier/Blainville/Gervais)	0	1	2 (< 2,500)	3
Bottlenose dolphin	0	-1 (increasing)	0	-1
Bryde's whale	3 (endangered)	2 (decreasing)	2 (< 2,500)	7
Clymene dolphin	0	2 (decreasing)	2 (< 2,500)	4
False killer whale	0	1	2 (< 2,500)	3
Fraser's dolphin	0	1	2 (< 2,500)	3
Killer whale	0	2 (decreasing)	2 (< 2,500)	4
Kogia (dwarf, pygmy sperm whale)	0	2 (decreasing)	2 (< 2,500)	4
Melon-headed whale	0	2 (decreasing)	2 (< 2,500)	4
Pantropical spotted dolphin	0	2 (decreasing)	0	2
Pygmy killer whale	0	2 (decreasing)	2 (< 2,500)	4
Risso's dolphin	0	-1 (increasing)	2 (< 2,500)	1

Species	Population Status	Population Trend	Population Size	Vulnerability Factor 1 Total Score (out of 7)
Rough-toothed dolphin	0	2 (decreasing)	2 (< 2,500)	4
Short-finned pilot whale	0	0	2 (< 2,500)	2
Sperm Whale	3 (endangered)	2 (decreasing)	2 (< 2,500)	7
Spinner dolphin	0	0	0	0
Striped dolphin	0	2 (decreasing)	2 (< 2,500)	4

Table A-7. Vulnerability factor 2 scores—species habitat use and compensatory abilities

Species	Habitat Use (% of GoMex total population in Zone 5)	Temporal Factors	Vulnerability Factor 2 Total Score (out of 7)
Atlantic spotted dolphin	0 (4%)	0	0
Beaked whales (Cuvier/Blainville/Gervais)	4 (33%)	1	5
Bottlenose dolphin	0 (4%)	0	0
Bryde's whale	2 (19%)	2	4
Clymene dolphin	2 (27%)	0	2
False killer whale	2 (20%)	0	2
Fraser’s dolphin	2 (20%)	0	2
Killer whale	1 (10%)	0	1
Kogia (dwarf, pygmy sperm whale)	2 (29%)	0	2
Melon-headed whale	2 (29%)	0	2
Pantropical spotted dolphin	2 (16%)	0	2
Pygmy killer whale	2 (19%)	0	2
Risso’s dolphin	2 (27%)	0	2
Rough-toothed dolphin	2 (19%)	0	2
Short-finned pilot whale	2 (29%)	0	2
Sperm Whale	2 (30%)	0	2
Spinner dolphin	2 (27%)	0	2
Striped dolphin	2 (24%)	0	2

Vulnerability Factor 3: Potential Masking Factor

The following is a description of the process used to derive vulnerability scores for each of the four species in terms of potential masking from operations defined in Zone 5. It includes illustrative examples based on the seismic survey activity data for 2014 as provided by BOEM for Zone 5 (Figs. A-1; A-2; Table A-1, above). Here, we follow a simplified analytical approach to evaluate aggregate exposures such that the sound field is static and does not move or change during the period of a seismic airgun survey (see Ellison et al., 2015). It should be noted that the potential masking here is the maximum potential masking associated with the transmissions of seismic airgun pulses. Potential masking during inter-shot intervals will be reduced as the received noise from shots that persists diminishes from individual transmissions, although recent studies have demonstrated that for some scenarios there can be considerable residual noise energy present (e.g., Wiggins et al., 2016).

To illustrate this process for four representative species (Bryde's whale, sperm whale, spotted dolphin, and pygmy sperm whale) representing each of the marine mammal hearing groups (LF, MF, HF), we consider the months of March and December 2014, when four different surveys were conducted in Zone 5. We step through the process of assessing the exposure index for Bryde's whale, sperm whale, spotted dolphin, and pygmy sperm whale. Although these exemplar species are shown here, the final values for all species tested used the respective values for each representative hearing group; all others in the GoMex considered here are MF species and thus share scores with sperm whale and spotted dolphin. Given that low-frequency energy from seismic airguns is known to propagate over considerable distances from the source and into Zone 1 (Estabook et al. 2016, Wiggins et al. 2016), which is the region with the highest concentration of Bryde's whales, we also assess the vulnerability of Bryde's whales in Zone 1 to the aggregate noise condition generated from activities in Zone 5.

The sets of tasks for each of the four primary steps in the aggregate noise, context-specific masking assessment process are as follows:

1. Generate M-weighted, aggregate noise spectrum throughout a region at 10 km x 10 km spatial resolution and one-month time resolution for each of the three M-weighted conditions (M_{lf}, $M_{mf,,}$ and M_{hf}) in Zone 5 and for the M_{lf} condition in Zone 1.
   a. Compute the M-weighted spectrum for each of the three cetacean hearing groups (M_{lf}, M_{mf}, and M_{hf}) (Southall et al. 2007) for a generic sound spectrum from a nominal 4,000 in^3 seismic airgun array (Figure A-60).

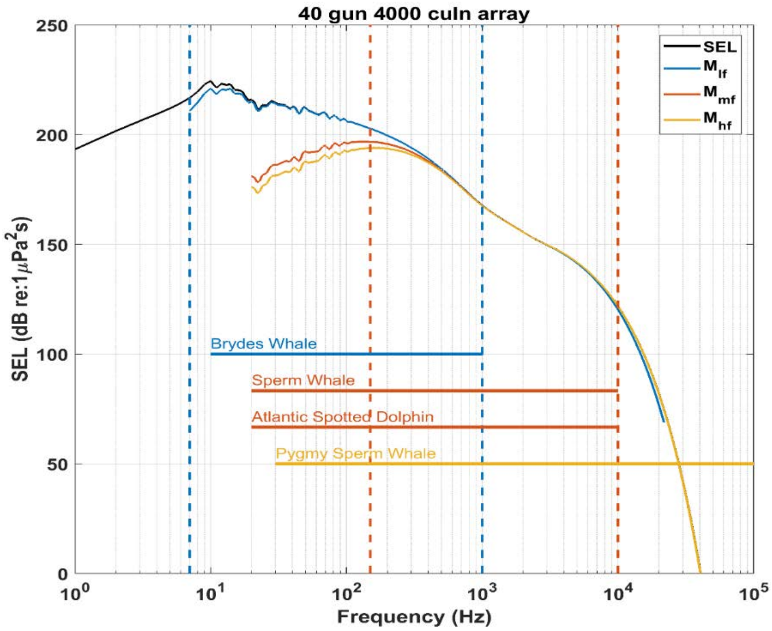

Figure A-60. Different sound spectrum levels for a nominal spectral distribution from a 4,000 in^3 seismic airgun array explosion (black) after the application of the M-weighting functions for low-frequency (M_{lf}, blue), mid-frequency (M_{mf}, orange), and high-frequency (M_{hf}, yellow) cetaceans.[4]

b. For each of the four surveys in each period (month), apply a simple transmission loss (TL) model to estimate the three M-weighted sound spectra in each of the 10 km x 10 km cells within Zone 5 and the M_{lf} condition in Zone 1. The TL model assumes spherical spreading (20Log[range]) out to a range equal to water depth and 17Log[range] for ranges greater than the water depth, and includes an absorption factor. Each survey vessel operates a nominal 4,000 in^3 seismic airgun array placed at the geometric center of each of the 12 sites where surveys were conducted in 2014 (data provided by BOEM) and each survey vessel remains stationary.
c. Calculate the aggregate noise spectrum for the respective month for each of the M_{lf}, M_{mf}, and M_{hf} hearing groups for each of the 10 km x 10 km cells within Zone 5 and for the M_{lf} condition for each of the 10 km x 10 km cells in Zone 1.

2. Calculate ANNR for each of the 10 km x 10 km cells and for each of three defined frequency bands: LF (0.001–1 kHz), MF (1–10 kHz), and HF (>10 kHz).
   a. Calculate the ambient noise spectrum for the 9-knot wind speed condition. We refer to this as the baseline ambient noise condition and assume that it is uniformly distributed throughout the region (Reeder et al. 2011 and Wenz 1962).

[4] The colored horizontal lines with associated common names represent the frequency ranges for the communication (long dashed, LF, 10–1000 Hz), navigation/orientation (short dashed, MF, 1–10 kHz) and foraging (dotted, HF, >10 kHz) masking contexts.

b. Calculate noise spectrum differences between each of the M-weighted, aggregate noise spectra (from step 1c) and the ambient noise spectrum (from step 2a). This is shown in Figs. A-61A and A-61B.

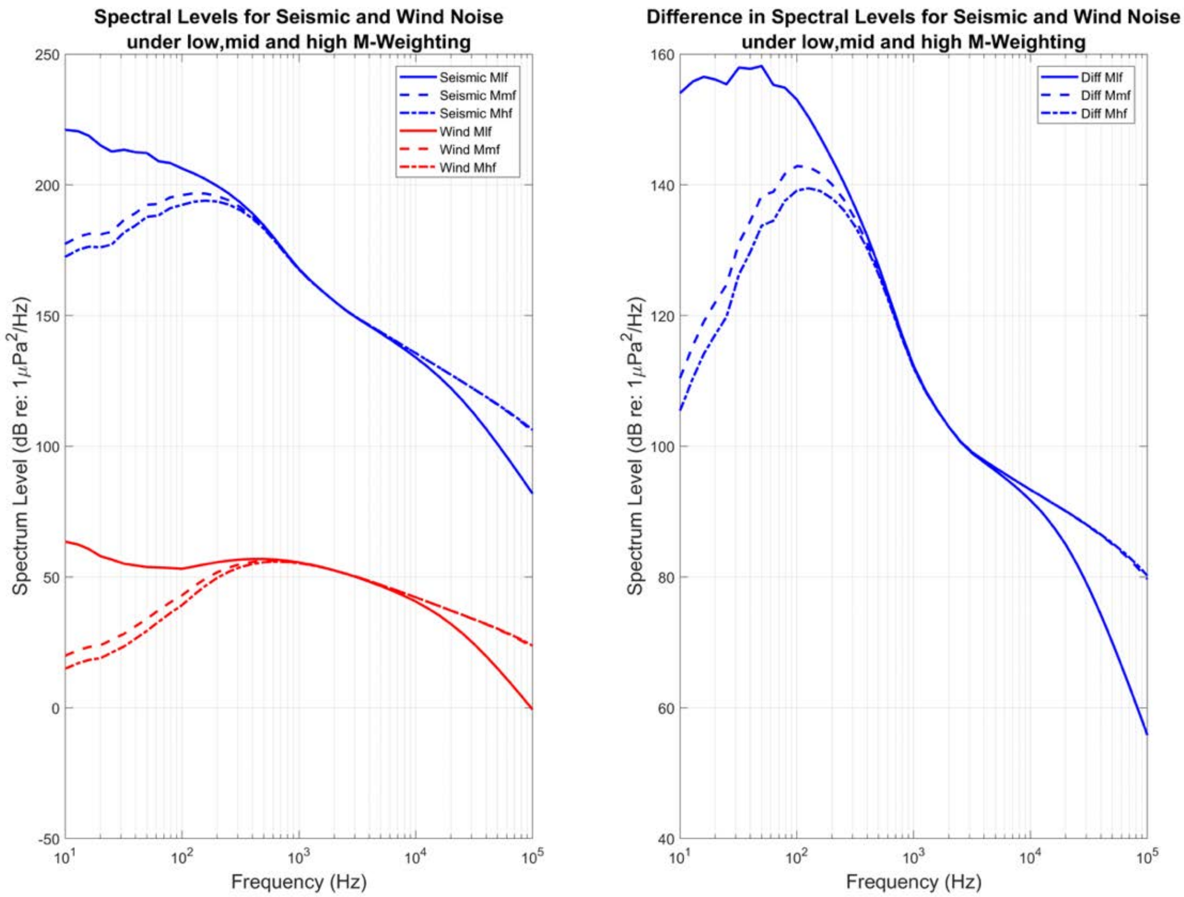

Figure A-61A. Source spectrum levels for seismic and spectrum levels for ambient wind noise (9 kt) for each of the three M-weighted types (left) and M-weighted differences between these seismic and ambient noise spectrum levels (right).

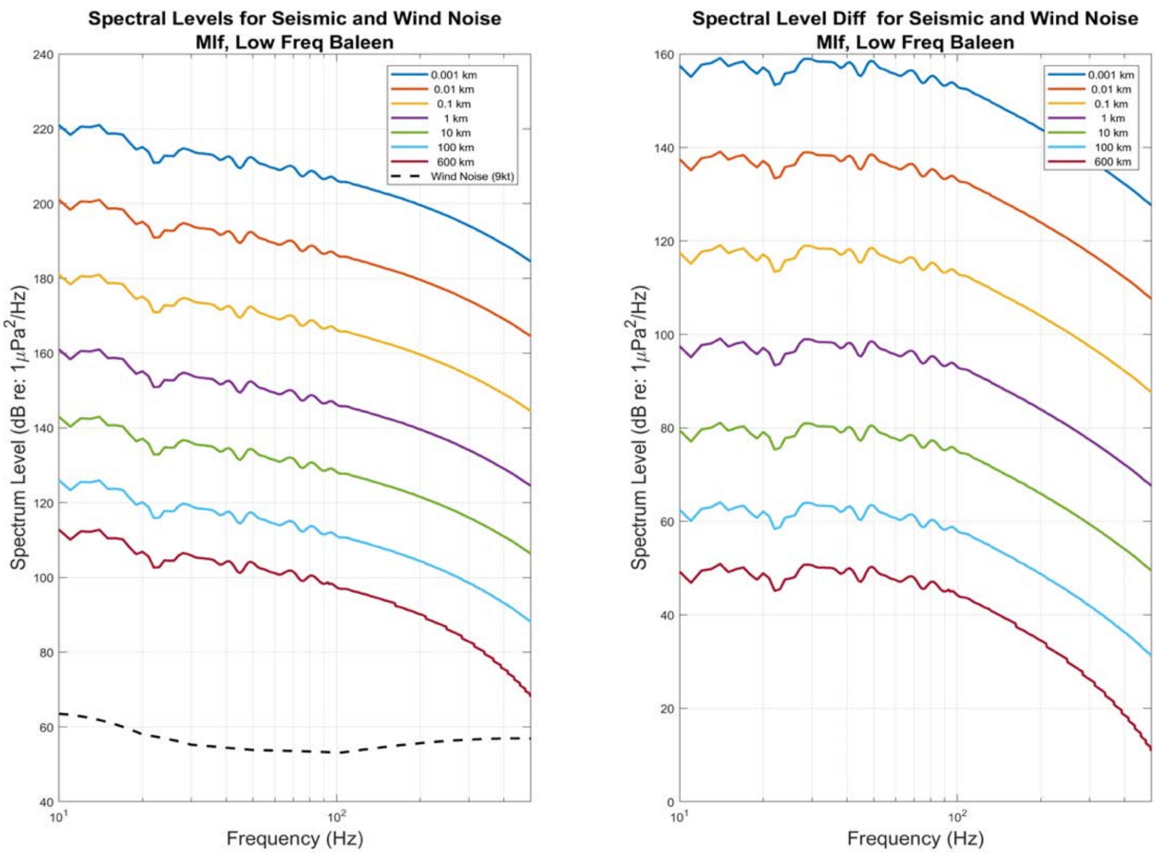

Figure A-61B. Low-frequency, M-weighted (M_{lf}) spectrum levels (left) for a seismic source at different distances from the source (colored lines) and spectrum level for 9 kt ambient wind noise (dashed line) and low-frequency, M-weighted (M_{lf}) spectral differences between seismic and ambient noise spectrum levels (right).

3. Convert M-weighted noise spectrum differences (from step 2b) into sound level differences for each defined frequency bands: LF, MF, and HF. A spectral difference within each respective band is referred to as an ambient noise-to-noise ratio (ANNR), and spectral differences for the three M-weighted frequency bands are referred to as $ANNR_{lf\cdot LF}$ (Fig. A-62), $ANNR_{mf\cdot MF}$ (Fig. A-63) and $ANNR_{hf\cdot HF}$ (Fig. A-64). The ANNR values are also calculated for other frequency band combinations (e.g., lf-MF, hf-LF) and for both March and December 2014 in order to provide all relevant comparisons for step 4. Example histograms showing ANNR values for each of the four species in Zone 5 for March 2014 are given below (Figures A-65 – A-72).

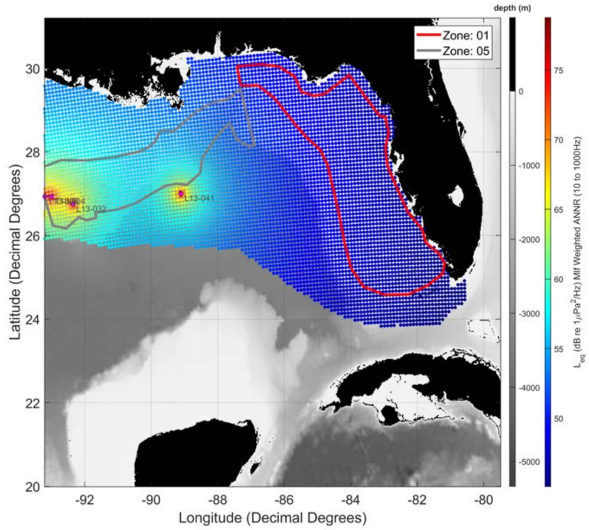

Figure A-62. Map showing the ambient noise-to-noise ratios for the M_{lf} aggregate noise spectrum and communication masking band (LF, 10–1,000 Hz) for the 10 km x 10 km cells inclusive of Zone 1 (red outline) and Zone 5 (grey outline) in March 2014 (i.e., $ANNR_{Mlf\text{-}LF}$).[5]

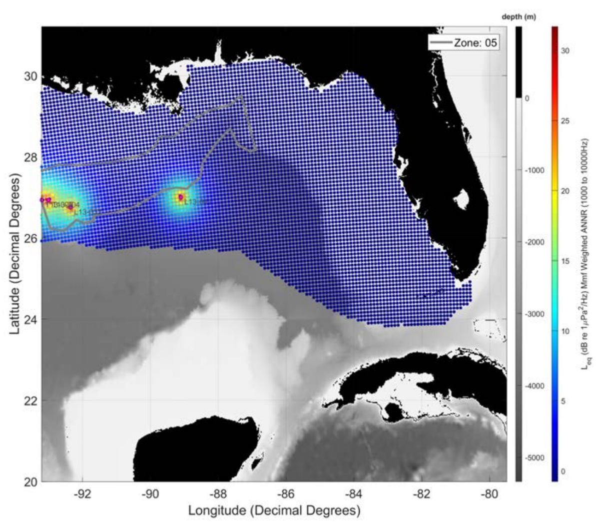

Figure A-63. Map showing the ambient noise-to-noise ratios for the M_{mf} aggregate noise spectrum and navigation/orientation masking band (MF, 1–10 kHz) for the 10 km x 10 km cells in Zone 5 (grey outline) in March 2014 (i.e., $ANNR_{Mmf\text{-}MF}$).

[5] note: There are 1,337 10 km x 10 km cells in Zone 1 and 840 10 km x 10 km cells in Zone 5.

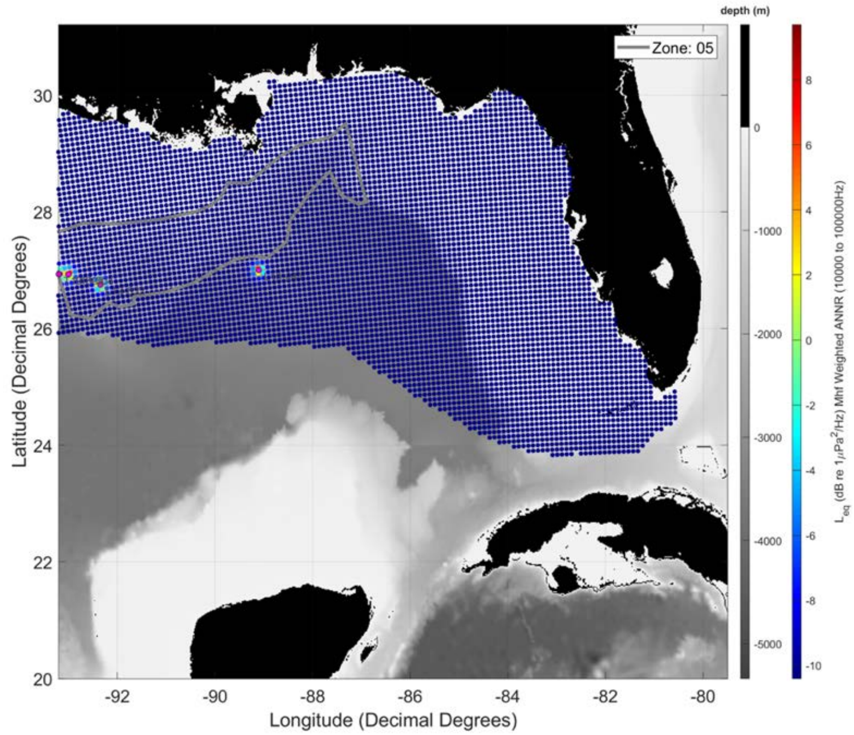

Figure A-64. Map of ambient noise-to-noise ratios for the M_{hf} aggregate noise spectrum and the foraging masking band (HF, >10 kHz) for the 10 km x 10 km cells in Zone 5 (grey outline) in March 2014 ($ANNR_{Mhf \cdot HF}$).

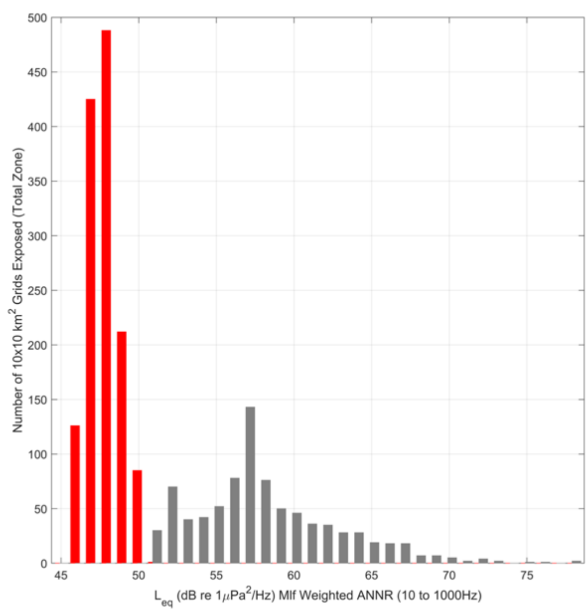

Figure A-65. Distribution of $ANNR_{Mlf \cdot lF}$ values in 10 km x 10 km cells for March 2014 in Zone 1 (red) and Zone 5 (grey) in the M-weighted LF (10–1,000Hz) communication masking band for Bryde's whales.

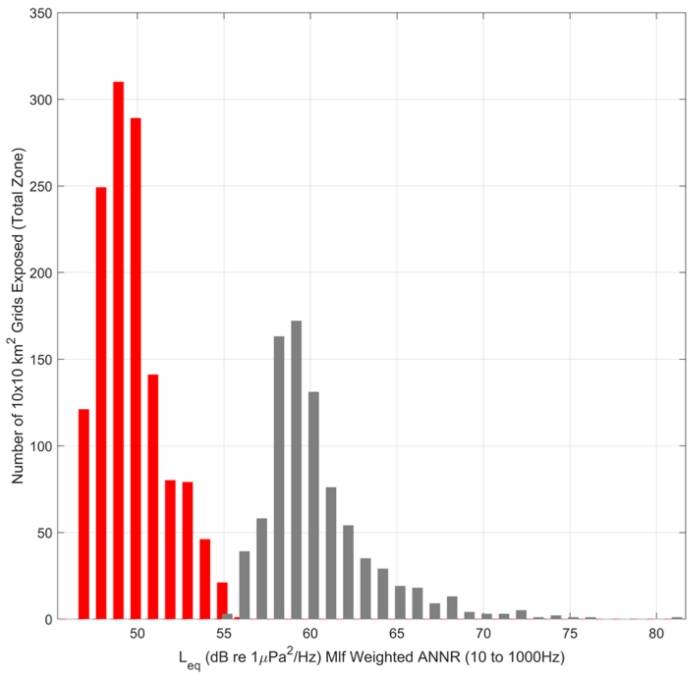

Figure A-66. Distribution of ANNR$_{Mlf•lF}$ values in 10 km x 10 km cells for December 2014 in Zone 1 (red) and Zone 5 (grey) in the M-weighted LF (10–1,000Hz) communication masking band for Bryde's whales.

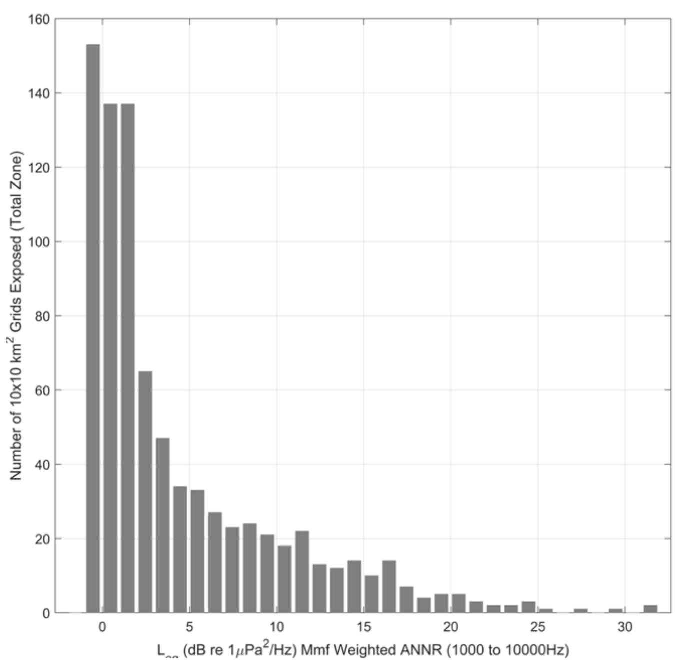

Figure A-67. Distribution of ANNR$_{Mmf•mF}$ values in 10 km x 10 km cells for March 2014 in Zone 5 (grey) in the M-weighted MF (1–10 kHz) masking band for sperm whales.

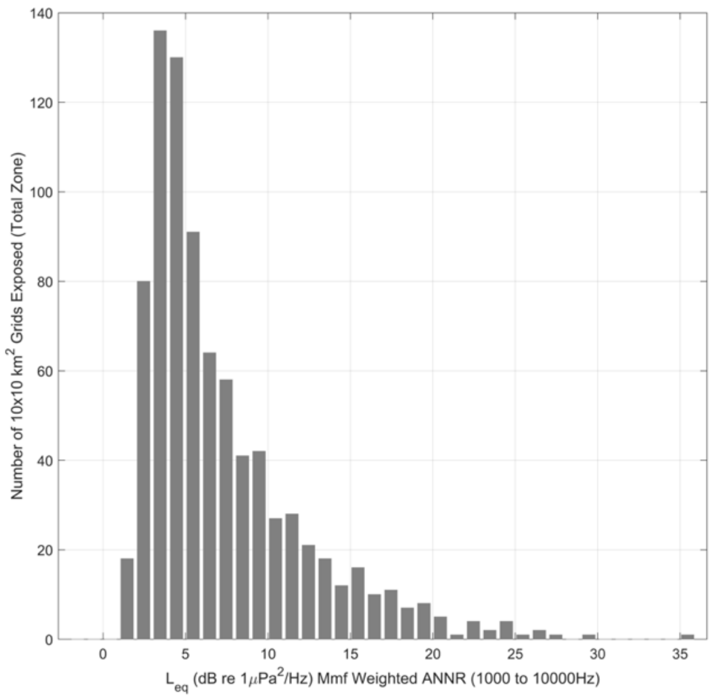

Figure A-68. Distribution of $ANNR_{Mmf\cdot mF}$ values in 10 km x 10 km cells for December 2014 in Zone 5 (grey) in the M-weighted MF (1–10 kHz) masking band for sperm whales.

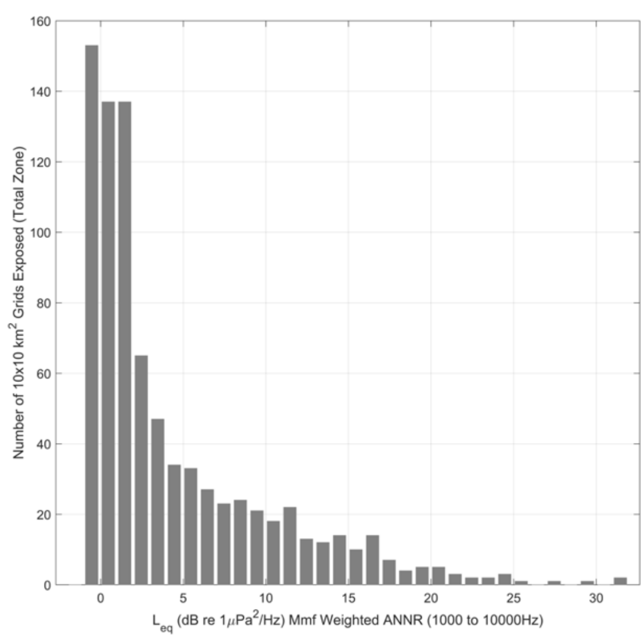

Figure A-69. Distribution of $ANNR_{Mmf\cdot mF}$ values in 10 km x 10 km cells for March 2014 in Zone 5 (grey) in the M-weighted MF (1–10 kHz) masking band for pantropical spotted dolphins.

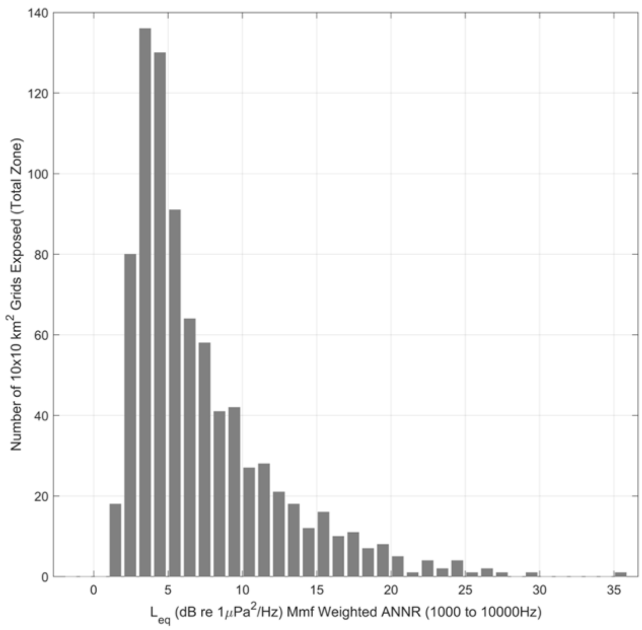

Figure A-70. Distribution of ANNR$_{Mmf\bullet mF}$ values in 10 km x 10 km cells for December 2014 in Zone 5 (grey) in the M-weighted MF (1–10 kHz) masking band for pantropical spotted dolphins.

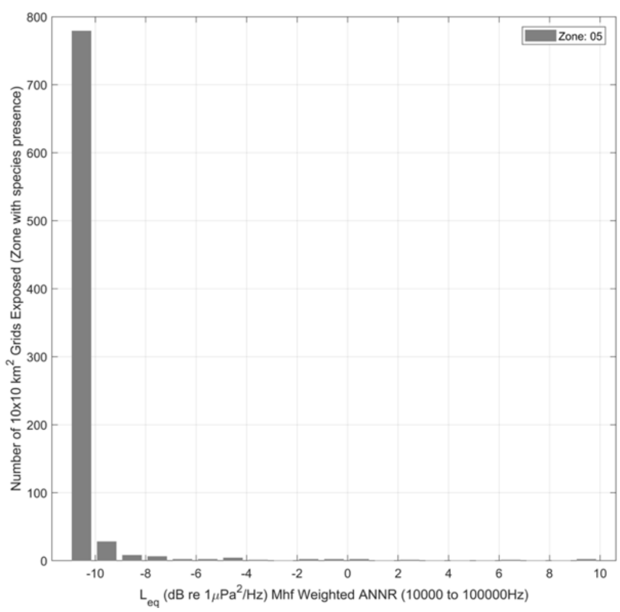

Figure A-71. Distribution of ANNR$_{Mhf\bullet HF}$ values for March 2014 in Zone 5, 10 km x 10 km cells in the M-weighted HF (> 10 kHz) masking band for pygmy sperm whales.

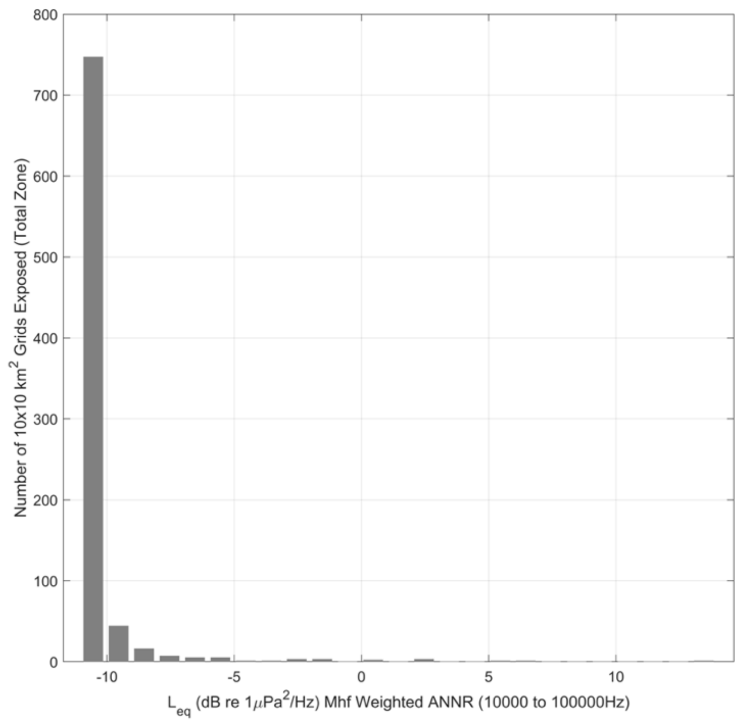

Figure A-72. Distribution of ANNR$_{Mhf-HF}$ values for December 2014 in Zone 5, 10 km x 10 km cells in the M-weighted HF (> 10 kHz) masking band for pygmy sperm whales.

4. For each species of interest, determine the potential masking factor score for each of the M-weighted, activity-specific contexts. This was done based on the respective ANNR values for each frequency band relative to the vulnerability scoring criteria specified in the masking factor description in the main report (above). Median, species-specific ANNR values were calculated for all (LF, MF, and HF) bands, from which both communication and spatial orientation and navigation masking factor scores were determined. These are shown below for March (Table A-8) and December (Table A-9), respectively with the associated masking factor score (maximum possible value is 9). The ANNR values and corresponding masking factor scores that would have been determined for Bryde's whales in Zone 1 based solely on operations hundreds of km away in Zone 5 are also provided for March (Table A-10) and December (Table A-11).

Table A-7. Median ANNR values for Zone 5 for March 2014 for each example species in each of three frequency bands (LF: 0.001–1.0 kHz; MF: 1–10 kHz; HF: 10–100 kHz)[6]

	Median ANNR (LF band)	Median ANNR (MF band)	Median ANNR (HF band)	Communication Masking Factor Score	Spatial Orientation and Navigation Masking Factor Score (LF Band)	Spatial Orientation and Navigation Masking Factor Score (MF Band)	TOTAL MASKING FACTOR SCORE
Bryde's Whale (LF)	56 dB	1 dB	< 0 dB	6	2	0	8
Sperm Whale (MF)	57 dB	2 dB	< 0 dB	1	2	0	3
Spotted Dolphin (MF)	57 dB	2 dB	< 0 dB	1	2	0	3
Pygmy Sperm Whale (HF)	57 dB	2 dB	< 0 dB	0	2	0	2

Table A-8. Median ANNR values for Zone 5 for December 2014 for each example species in each of three frequency bands (LF: 0.001–1.0 kHz; MF: 1–10 kHz; HF: 10–100 kHz)

	Median ANNR (LF band)	Median ANNR (MF band)	Median ANNR (HF band)	Communication Masking Factor Score	Spatial Orientation and Navigation Masking Factor Score (LF Band)	Spatial Orientation and Navigation Masking Factor Score (MF Band)	TOTAL MASKING FACTOR SCORE
Bryde's Whale (LF)	58 dB	4 dB	< 0 dB	6	2	0	8
Sperm Whale (MF)	59 dB	5 dB	< 0 dB	1	2	0	3
Spotted Dolphin (MF)	59 dB	6 dB	< 0 dB	1	2	0	3
Pygmy Sperm Whale (HF)	59 dB	6 dB	< 0 dB	0	2	0	2

Table A-9. Median ANNR values resulting from activities in Zone 5 for whales in Zone 1 for March 2014 Bryde's whales in each of three frequency bands (LF: 0.001–1.0 kHz; MF: 1–10 kHz; HF: 10–100 kHz)[7]

	Median ANNR (LF band)	Median ANNR (MF band)	Median ANNR (HF band)	Communication Masking Factor Score	Spatial Orientation and Navigation Masking Factor Score (LF Band)	Spatial Orientation and Navigation Masking Factor Score (MF Band)	TOTAL MASKING FACTOR SCORE
Bryde's Whale (LF)	48 dB	0 dB	< 0 dB	6	2	0	8

[6] Frequency bands used to determine potential communication masking are highlighted for each species. Potential masking factor scores were assigned based on the vulnerability rating process described within the main section of the report.
[7] The LF band was used as the basis of the communication masking factor score.

Table A-10. Median ANNR values resulting from activities in Zone 5 for whales in Zone 1 for December 2014 Bryde's whales in each of three frequency bands (LF: 0.001–1.0 kHz; MF: 1–10 kHz; HF: 10–100 kHz)

	Median ANNR (LF band)	Median ANNR (MF band)	Median ANNR (HF band)	Communication Masking Factor Score	Spatial Orientation and Navigation Masking Factor Score (LF Band)	Spatial Orientation and Navigation Masking Factor Score (MF Band)	TOTAL MASKING FACTOR SCORE
Bryde's Whale (LF)	48 dB	0 dB	< 0 dB	6	2	0	8

Table A-11. Vulnerability Factor 4 scores—environmental risk factors

Species	Chronic Anthropogenic Noise	Chronic Anthropogenic Risk Factors	Chronic Biological Risk Factors	Vulnerability Factor 4 TOTAL SCORE (out of 7)
Atlantic spotted dolphin	2	2	2	6
Beaked whales (Cuvier/Blainville/Gervais)	2	2	1	5
Bottlenose dolphin	2	2	0	4
Bryde's whale	2	2	0	4
Clymene dolphin	2	2	0	4
False killer whale	2	2	0	4
Fraser’s dolphin	2	2	0	4
Killer whale	2	2	0	4
Kogia (dwarf, pygmy sperm whale)	2	2	0	4
Melon-headed whale	2	2	0	4
Pantropical spotted dolphin	2	2	0	4
Pygmy killer whale	2	2	0	4
Risso’s dolphin	2	2	1	5
Rough-toothed dolphin	2	2	0	4
Short-finned pilot whale	2	2	1	5
Sperm whale	2	2	0	4
Spinner dolphin	2	2	0	4
Striped dolphin	2	2	0	4

Total Vulnerability Scores

Using the vulnerability scores for each species for each masking factor, overall vulnerability risk assessment ratings were determined (based on the criteria specified in the main report; Table 3) for Zone 5 for March (Table A-13) and December (Table A-14).

Table A-12. Species-specific total vulnerability scores and associated vulnerability risk assessment ratings for Zone 5 for March 2014

SPECIES	SPECIES POPULATION FACTOR SCORE	HABITAT USE AND COMPENSATORY ABILITIES FACTOR SCORE	MASKING FACTOR SCORE	OTHER ENVIRONMENTAL RISK FACTOR SCORE	TOTAL VULNERABILITY SCORE (OUT OF 30)	"VULNERABILITY" RISK ASSESSMENT RATING (MARCH 2014)
Atlantic spotted dolphin	1	0	3	6	10	LOW
Beaked whales (Cuvier/Blainville/Gervais)	3	5	3	5	16	MODERATE
Bottlenose dolphin	-1	0	3	4	6	LOW
Bryde's Whale (LF)	7	4	8	4	23	HIGH
Clymene dolphin	4	2	3	4	13	MODERATE
False killer whale	3	2	3	4	12	MODERATE
Fraser's dolphin	3	2	3	4	12	MODERATE
Killer whale	4	1	3	4	12	MODERATE
Kogia (dwarf, pygmy sperm whale)	4	2	2	4	12	MODERATE
Melon-headed whale	4	2	3	4	13	MODERATE
Pantropical Spotted Dolphin	2	2	3	4	11	MODERATE
Pygmy killer whale	4	2	3	4	13	MODERATE
Risso's dolphin	1	2	3	5	11	LOW
Rough-toothed dolphin	4	2	3	4	13	MODERATE
Short-finned pilot whale	2	2	3	5	12	MODERATE
Sperm Whale	7	2	3	4	16	MODERATE
Spinner dolphin	0	2	3	4	9	LOW
Striped dolphin	4	2	3	4	13	MODERATE

Table A-13. Species-specific total vulnerability scores and associated vulnerability risk assessment ratings for Zone 5 for December 2014

SPECIES	SPECIES POPULATION FACTOR SCORE	HABITAT USE AND COMPENSATORY ABILITIES FACTOR SCORE	MASKING FACTOR SCORE	OTHER ENVIRONMENTAL RISK FACTOR SCORE	TOTAL VULNERABILITY SCORE (OUT OF 30)	"VULNERABILITY" RISK ASSESSMENT RATING (MARCH 2014)
Atlantic spotted dolphin	1	0	3	6	10	LOW
Beaked whales (Cuvier/Blainville/Gervais)	3	5	3	5	16	MODERATE
Bottlenose dolphin	-1	0	3	4	6	LOW
Bryde's Whale (LF)	7	4	8	4	23	HIGH
Clymene dolphin	4	2	3	4	13	MODERATE
False killer whale	3	2	3	4	12	MODERATE
Fraser's dolphin	3	2	3	4	12	MODERATE
Killer whale	4	1	3	4	12	MODERATE
Kogia (dwarf, pygmy sperm whale)	4	2	2	4	12	MODERATE
Melon-headed whale	4	2	3	4	13	MODERATE
Pantropical Spotted Dolphin	2	2	3	4	11	MODERATE
Pygmy killer whale	4	2	3	4	13	MODERATE
Risso's dolphin	1	2	3	5	11	LOW
Rough-toothed dolphin	4	2	3	4	13	MODERATE
Short-finned pilot whale	2	2	3	5	12	MODERATE
Sperm Whale	7	2	3	4	16	MODERATE
Spinner dolphin	0	2	3	4	9	LOW
Striped dolphin	4	2	3	4	13	MODERATE

Integrated Risk Assessment

The final stage in the aggregate noise exposure risk assessment process is an integrated assessment of the species-specific and zone-specific exposure index and vulnerability scores using the evaluation grid presented in Table 2 of the main report.

A summary of the normalized exposure index scores with associated risk assessment ratings (from Table A-4) and total vulnerability scores with associated ratings (from Tables A-12, A-13) and the resultant species-specific integrated assessed risk for Zone 5 is given below for the months of March (Table A-14) and December (Table A-15).

Table A-14. Species-specific integrated risk assessed for Zone 5 for March 2014

ZONE 5 INTEGRATED RISK ASSESSMENT: MARCH 2014	Scaled Exposure Index Score	"EXPOSURE" RISK ASSESSMENT RATING	VULNERABILITY SCORE	"VULNERABILITY" RISK ASSESSMENT RATING	OVERALL ZONE 5 INTEGRATED RISK ASSESSED: MARCH 2014
Atlantic spotted dolphin	0.3145	VERY LOW	10	LOW	VERY LOW
Beaked whales (Cuvier/Blainville/Gervais)	2.9536	MODERATE	16	MODERATE	MODERATE
Bottlenose dolphin	1.1660	MODERATE	6	LOW	MODERATE
Bryde's Whale (LF)	0.4465	VERY LOW	23	HIGH	LOW
Clymene dolphin	8.0967	VERY HIGH	13	MODERATE	HIGH
False killer whale	1.1444	MODERATE	12	MODERATE	MODERATE
Fraser's dolphin	0.5940	LOW	12	MODERATE	LOW
Killer whale	0.0171	VERY LOW	12	MODERATE	LOW
Kogia (dwarf, pygmy sperm whale)	1.6986	MODERATE	12	MODERATE	MODERATE
Melon-headed whale	5.3453	VERY HIGH	13	MODERATE	HIGH
Pantropical Spotted Dolphin	21.2279	VERY HIGH	11	MODERATE	HIGH
Pygmy killer whale	0.7333	LOW	13	MODERATE	LOW
Risso's dolphin	2.1680	MODERATE	11	MODERATE	MODERATE
Rough-toothed dolphin	1.5838	MODERATE	13	MODERATE	MODERATE
Short-finned pilot whale	1.4598	MODERATE	12	MODERATE	MODERATE
Sperm Whale	1.7731	MODERATE	16	MODERATE	MODERATE
Spinner dolphin	9.4096	VERY HIGH	9	LOW	HIGH
Striped dolphin	2.6751	MODERATE	13	MODERATE	MODERATE

Table A-15. Species-specific integrated risk assessed for Zone 5 for December 2014

ZONE 5 INTEGRATED RISK ASSESSMENT: DECEMBER 2014	Scaled Exposure Index Score	"EXPOSURE" RISK ASSESSMENT RATING	VULNERABILITY SCORE	"VULNERABILITY" RISK ASSESSMENT RATING	OVERALL ZONE 5 INTEGRATED RISK ASSESSED: DECEMBER 2014
Atlantic spotted dolphin	0.3863	VERY LOW	10	LOW	VERY LOW
Beaked whales (Cuvier/Blainville/Gervais)	3.6316	HIGH	16	MODERATE	HIGH
Bottlenose dolphin	1.4328	MODERATE	6	LOW	MODERATE
Bryde's Whale (LF)	0.5491	LOW	23	HIGH	MODERATE
Clymene dolphin	9.9489	VERY HIGH	13	MODERATE	HIGH
False killer whale	1.4058	MODERATE	12	MODERATE	MODERATE
Fraser's dolphin	0.7306	LOW	12	MODERATE	LOW
Killer whale	0.0209	VERY LOW	12	MODERATE	LOW
Kogia (dwarf, pygmy sperm whale)	2.0862	MODERATE	12	MODERATE	MODERATE
Melon-headed whale	6.5693	VERY HIGH	13	MODERATE	HIGH
Pantropical Spotted Dolphin	26.0868	VERY HIGH	11	MODERATE	HIGH
Pygmy killer whale	0.9015	LOW	13	MODERATE	LOW
Risso's dolphin	2.6666	MODERATE	11	MODERATE	MODERATE
Rough-toothed dolphin	1.9467	MODERATE	13	MODERATE	MODERATE
Short-finned pilot whale	1.7920	MODERATE	12	MODERATE	MODERATE
Sperm Whale	2.1963	MODERATE	16	MODERATE	MODERATE
Spinner dolphin	11.5643	VERY HIGH	9	LOW	HIGH
Striped dolphin	3.2868	HIGH	13	MODERATE	HIGH

Risk Assessment Synthesis

It should be noted that the exposure index scores differ slightly for the four species (Bryde's whale, Kogia, pantropical spotted dolphin, and sperm whale) included in Southall et al. (2019) because of improvements in the exposure index calculations. Additionally, all GoMex marine mammal species are assessed here. With regard to the risk assessment results here, several observations may be made.

First, the resulting exposure index values are respectively high for species with relatively high numbers of individuals present in the focal area (Zone 5) and/or high percentages of their overall GoMex population within this zone (e.g., Clymene, pantropical spotted, spinner dolphin). This is a function of the relatively high spatial overlap with their habitat use and potential disturbance. For these species, relatively low vulnerability scores could reduce the overall assessed risk to a variable—but somewhat limited—extent, and these species generally remain in the high assessed risk accordingly. The presumed activity would not necessarily pose a high probability of disturbance having population consequences, particularly for robust populations; however, based on the co-occurrence of large numbers of these species with concentrations of disturbance, the assessed potential for risk is relatively high.

Conversely, species with relatively high vulnerability scores (e.g., Bryde's whales) resulting from various factors (in this case, very small population size, high spectral overlap between noise disturbance and sounds/hearing of importance) can have relatively higher resulting assessed risk even with low exposure index scores. This observation indicates that these species are of reasonably moderate concern (and corresponding mitigation measures) despite the more limited probable exposure across the entire zone because of factors related to their population and life history.

Finally, it is notable that the majority of overall assessed risk observed in this study are moderate or high following the integrated risk assessment. This zone includes continental shelf habitat areas that are relatively high-density areas for many species relative to coastal or pelagic areas with more limited species prevalence. Further, this zone is an area of relatively high concentration for G&G activities, and the level of such activities present in the scenario here is higher than many other such habitats. It should be noted that these activities have been commonly present in these habitats for decades, and species here may be concomitantly more habituated to their presence than less frequently explored regions. Applications of the risk assessment of aggregate activities in other areas may be expected to generally result in lower average integrated risk scores, but factors such as relative presence of activities should be considered in interpreting results.

Appendix B: References

Ellison, W.T., Southall, B.L., Frankel, A.S., Vigness-Raposa, K. and Clark. C. (2018). An Acoustic Scene Perspective on Spatial, Temporal, and Spectral Aspects of Marine Mammal Behavioral Response to Noise. *Aquatic Mammals* 44, 239-243, DOI 10.1578/AM.44.3.2019.239.

Ellison, W.T., Racca, R., Clark, C.W., Streever, B., Frankel, A.S., Fleishman, E., Angliss, R., Berger, J., Ketten, D., Guerra, M., Leu, M., McKenna, M., Sformo, T., Southall, B., Suydam, R., and Thomas, L. (2016). Modeling the aggregated exposure and responses of bowhead whales Balaena mysticetus to multiple sources of anthropogenic underwater sound. *Endangered Species Research* 30, 95-108.

Ellison, W.T., Clark, C.W., Mann, D.A., Southall, B., and Tollit, D.J. (2015). A risk assessment framework to assess the biological significance of noise exposure on marine mammals. *21st Biennial Conference on the Biology of Marine Mammals*, San Francisco, CA, USA, 13-18 December.

Ellison, W.T., Southall, B.L., Clark, C.W. and Frankel, A.F. (2012). A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology* 26, 21-28.

Reeder, D.B., Sheffield, E.S., and Mach, S.M. (2011). Wind-generated ambient noise in a topographically isolated basin: A pre-industrial era proxy. The Journal of the Acoustical Society of America 129, 64-73.

Roberts J.J., Best, B.D., Mannocci, L., Fujioka, E., Halpin, P.N., Palka, D.L., Garrison, L.P., Mullin, K.D., Cole, T.V.N., Khan, C.B., McLellan, W.M., Pabst, D.A., and Lockhart, G.G. (2016). Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Scientific Reports 6*: 22615. doi: 10.1038/srep22615.

Roberts J.J., Best B.D., Mannocci, L., Fujioka, E., Halpin, P.N., Palka, D.L., Garrison, L.P., Mullin, K.D., Cole, T.V.N., Khanc, C.B., McLellan, W.A., Pabst, D.A., Lockhart, G.G. (2015). Density model for Bryde's whale (*Balaenoptera edeni*) in the U.S. Gulf of Mexico: Supplementary Information, Version 3.1, 2015-11-06. Marine Geospatial Ecology Lab, Duke University, Durham, North Carolina.

Southall, B., Ellison, W., Clark, C., Tollit, D. (2019). Aggregate (chronic) noise exposure risk assessment report (task 5, Part 1). Aptos (CA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 20xx-xx. 66 p.

Southall, B.L., Amaral, J., Clark, C.W, Ellison, W., Joy, R., Tollit, D., and Ponirakis, D.W. (2018). A Risk Assessment Framework to Evaluate the Potential Relative Effects of Noise on Marine Mammals. *6th Conference on the Effects of Sound on Marine Mammal*, Den Haag, Netherlands, 10-14 September.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Jr., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P.L. (2007). Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals* 33, 411-521.

Wenz, G.M. (1962). Acoustic ambient noise in the ocean: spectra and sources. *The Journal of the Acoustical Society of America* 34, 1936-1956.

Wiggins, S.M., Hall, J.M., Thayre, B.J., and Hildebrand, J.A. (2016). Gulf of Mexico low-frequency ocean soundscape impacted by airguns. *The Journal of the Acoustical Society of America* 140, 176-183.

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).