International Association
IAGC
of Geophysical Contractors

October 15, 2018

VIA EMAIL AND U.S. MAIL

RDML Timothy Gallaudet, Ph.D., USN Ret.
Assistant Secretary of Commerce for Oceans and Atmosphere and
Acting Under Secretary of Commerce for Oceans and Atmosphere
National Oceanic and Atmospheric Administration
1401 Constitution Avenue N.W., Room 5128
Washington, D.C. 20230

Re: Marine Mammal Incidental Take Authorization Concerns

Dear Admiral Gallaudet:

Thank you for taking the time to meet last week to discuss the long-pending incidental harassment authorization (IHA) applications for seismic surveys on the Atlantic Outer Continental Shelf (OCS). As you know, these applications—filed by members of the International Association of Geophysical Contractors (IAGC)—have been pending with the National Marine Fisheries Service (NMFS) for over three years. Although I very much appreciate your assurance that the pending IHA applications will be decided upon in a couple of weeks, I'd like to provide some additional context for the IAGC and its members' frustrations with this regulatory process. Below, I also address some key follow-up points from last week's meeting.

NMFS's handling of the pending IHA applications has undermined both the Outer Continental Shelf Lands Act, which mandates the "expeditious and orderly development" of the OCS, and the Administration's policy "to encourage energy exploration and production, including on the Outer Continental Shelf . . . while ensuring that any such activity is safe and environmentally responsible."[1] That policy expressly requires the Secretary of Interior to "develop and implement, in coordination with the Secretary of Commerce and to the maximum extent permitted by law, a streamlined permitting approach for privately funded seismic data research

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[1] 43 U.S.C. § 1332; Executive Order 13795—Implementing an America-First Offshore Energy Strategy ("EO 13795"), Sec. 2, http://www.presidency.ucsb.edu/ws/index.php?pid=123867.

and collection aimed at *expeditiously determining* the offshore energy resource potential of the United States within the Planning Areas."[2]

NMFS's continued delay in processing the IAGC's members' Atlantic IHA applications cannot be reconciled with these express legislative and executive mandates. Through this delay, NMFS's Office of Protected Resources—a division whose responsibility is narrowly focused on the management of protected species—has become the lynchpin to the exploration of the Atlantic OCS and the primary obstacle to fulfillment of important federal offshore energy policies. Indeed, those who are opposed to Atlantic OCS seismic surveying have proclaimed that "[e]very day that goes by where those seismic IHAs don't issue is a victory."[3] This continuing "victory" for those opposed to U.S. energy policies also represents a continuing loss for the United States in the international arena.[4]

Moreover, NMFS's delay is neither a reasonable exercise of administrative discretion nor attributable to a lack of agency resources. The Marine Mammal Protection Act (MMPA) expressly requires NMFS to issue its decision on an IHA application within 120 days.[5] NMFS has no discretion to ignore this statutory deadline and its continuing delay in processing the Atlantic IHA applications undeniably violates the MMPA. In addition, during the time that the IAGC's members' applications have been pending, NMFS has issued *four* other IHAs for seismic surveys conducted by the United States Geological Survey and research institutions on the Atlantic OCS.[6] The IHA applications for these four Atlantic surveys were processed in an

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[2] EO 13795, Sec. 3(c) (emphasis added).

[3] *Trump lease plan sparks 'storm surge' of fear in S.C.*, Energywire, https://www.eenews.net/stories/1060100373 (Oct. 3, 2018). This statement was recently made by the South Carolina Environmental Law Project, which has publicly stated its intent to file a lawsuit challenging any seismic survey authorizations for the Atlantic OCS. That group and others plan to file a lawsuit—no matter the content or conditions of any IHAs—because they are opposed to any and all exploration of the Atlantic OCS and to legislative and executive offshore energy mandates.

[4] As described in the first enclosure with this letter, in the last four years, Mexico has issued *14* marine exploration permits through February 2018 while the U.S. has issued *zero* exploration permits for the Atlantic OCS.

[5] 16 U.S.C. § 1371(a)(5)(D)(iii).

[6] *See* 83 Fed. Reg. 39,692 (Aug. 10, 2018) (IHA issued to United States Geological Survey for seismic survey to be conducted in Northwest Atlantic Ocean); 83 Fed. Reg. 27,954 (June 15, 2018) (IHA issued to Scripps Institution of Oceanography for marine seismic survey in Northwest Atlantic Ocean); 81 Fed. Reg. 2174 (Jan. 15, 2016) (IHA issued to Lamont-Doherty Earth Observatory for seismic survey in South Atlantic Ocean); 80 Fed. Reg. 27,635 (May 14, 2015) (IHA issued to Lamont-Doherty Earth Observatory for seismic survey in Northwest Atlantic Ocean).

average of approximately 138 days. Accordingly, NMFS plainly has the resources to process Atlantic IHA applications. NMFS has simply de-prioritized the applications of the IAGC's members, despite federal mandates requiring agencies to prioritize and expedite the exploration of the OCS.

In short, NMFS's continuing delay has no legal or practical justification. The IAGC requests—again—that NMFS complete its process and issue its decisions on the pending IHA applications. I appreciate your attention to this matter and your consideration of these frustrations. In addition to our timing concerns, I address below two specific issues that we discussed in our meeting last week.

First, the IAGC has for years stated its objections to the overly conservative modeling approach used by NMFS to forecast marine mammal takes incidental to oil and gas seismic surveys on the Atlantic OCS and in the Gulf of Mexico (GOM). The gist of the IAGC's objections is that NMFS's approach to take estimation is based upon a modeling exercise that uses conservatively biased assumptions for many model variables. These conservatively biased assumptions, each contributing relatively modest overestimates of effect, lead to multiplicatively accumulating bias as the conservative assumptions interact with each other to multiply uncertainty toward unlikely statistical probabilities. Consequently, the modeled take estimates are not representative of actual or expected conditions.

In an effort to illustrate these modeling problems, the IAGC and the American Petroleum Institute requested and received permission from the Bureau of Ocean Energy Management (BOEM) and NMFS to engage the same contractor that performed the modeling (JASCO Applied Sciences) to run the same model, with the same data, but with certain alterations. This new analysis included alterations to only four or five variables to illustrate the dramatic consequences of redundantly applied precaution in a large, complex, multivariate model. We provided this analysis to BOEM and NMFS on August 25, 2017. However, in its proposed incidental take regulation for oil and gas exploration activities in the Gulf of Mexico, issued on June 22, 2018, NMFS stated that the analysis was "not made available to NMFS in time to fully consider [it] in preparing [the] proposed regulations."[7]

I have enclosed a copy of the modeling analysis described above and would appreciate your review of the document. I propose that we schedule a meeting to discuss the analysis and NMFS's modeling in more depth with experts from NOAA, BOEM, and IAGC. The IAGC strongly believes that NOAA's commitment to excellence in weather modeling should apply equally to NMFS's modeling of marine mammal incidental take.

Second, as we explained last week, the best available science does not support the imposition of shutdown or power-down requirements for any dolphin observations in an exclusion zone. Although the IAGC agrees that small dolphins are more likely to bow-ride than large dolphins, substantial data indicate that dolphins transiting survey vessels at full power do not exhibit

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[7] 83 Fed. Reg. 29,212, 29,259 (June 22, 2018).

behavior that would indicate a disturbance, regardless of their size. In short, the best available science shows that seismic surveys do not have any meaningful adverse effects on dolphin species.[8] The IAGC has addressed this issue extensively in public comments submitted in the ongoing regulatory processes associated with NMFS's consideration of IHA applications for seismic surveys on the Atlantic OCS and BOEM's petition for incidental take regulations for seismic surveys in the GOM.[9]

Additionally, the imposition of a power-down requirement for large or small dolphin observations is just as unnecessary and presents the same practicability concerns as a shutdown requirement. As described on our comments on the proposed rule for GOM incidental take regulations, powering down for dolphin presence is operationally difficult and commercially devastating, and would only delay and prolong survey work. As our comments explain, the

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[8] *See* 82 Fed. Reg. 26,244, 26,253 (June 6, 2017) ("auditory injury is extremely unlikely to occur for mid-frequency cetaceans (*e.g.*, delphinids) as this group is relatively insensitive to sound produced at the predominant frequencies in an airgun pulse while also having a relatively high threshold for the onset of auditory injury (*i.e.*, permanent threshold shift)"); *id*. ("Although other mid-frequency hearing specialists (*e.g.*, large delphinids) are no more likely to incur auditory injury than are small delphinids, they are much less likely to approach vessels."); *id*. at 26,298 (NMFS recognition that the expected effects from the proposed activities "are considered low for most delphinids, as it is unlikely that disturbance due to survey noise would entail significant disruption of normal behavioral patterns, long-term displacement, or significant potential for masking of acoustic space"); *see also* Finneran et al. 2015. *Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior*. 137 J. Acoust. Soc. Am. 1634-46 (no evidence of TTS when bottlenose dolphins exposed to seismic air pulse at cumulative sound exposure levels of 185-196 dB re 1 μPa^2-s); Schlundt et al. 2016. *Auditory effects of Multiple Impulses from a Seismic Air Gun on Bottlenose Dolphins* (Tursiops truncates), Adv. Exp. Med. Biol. 875:987-91 ("Bottlenose dolphins exposed to impulses from seismic airguns show that the potential for seismic surveys using air guns to cause auditory effects are lower than previously predicted. No injury took place and no significant behavioral reaction was observed."); Barkaszi et al. 2012. *Seismic survey mitigation measures and marine mammal observer reports*. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2012-015 (observation reports indicate no significant difference between the frequency of dolphin sightings and acoustic detections, regardless of whether the seismic source is active or silent).

[9] *See* August 21, 2018, Letter from Nikki Martin et al. to Jolie Harrison re *Comments on Proposed Marine Mammal Incidental Take Regulations for Geophysical Surveys in the Gulf of Mexico*; July 21, 2017, Letter from Nikki Martin et al. to Jolie Harrison re *Comments on Proposed Incidental Harassment Authorizations for the Incidental Taking of Marine Mammals During Geophysical Surveys in the Atlantic Ocean*; August 28, 2015, Letter from Nikki Martin et al. to Jolie Harrison re *Comments on Incidental Harassment Authorization Applications for the Incidental Taking of Marine Mammals During Geophysical Surveys in the Atlantic Ocean*.

inclusion of a power-down requirement for dolphins will result in millions of dollars of additional survey costs and significantly longer surveys.

I look forward to continued productive discussion on these important issues. In the meantime, if you have any questions or need additional information, please do not hesitate to contact me at 713.957.8080.

Sincerely,

Nikki C. Martin

Nikki Martin
President
International Association of Geophysical Contractors

Enclosures

cc: The Honorable Ryan Zinke, Secretary of the Interior
The Honorable Lisa Murkowski, U.S. Senator
The Honorable Dan Sullivan, U.S. Senator
The Honorable Steve Scalise, U.S. Representative
Chris Oliver, Assistant Administrator for NOAA Fisheries
Francis Brooke, Special Assistant to the President for Economic Policy

International Association IAGC of Geophysical Contractors ENERGY STARTS HERE™

INFOGRAPHIC

Time to Modernize the Marine Mammal Protection Act

The U.S. is falling behind in seismic information gathering, exploration activity and energy development due to unnecessary bureaucratic delays caused by the vague language and broken regulatory processes in the Marine Mammal Protection Act (MMPA).

This regulatory inefficiency means investment that was once allocated in the United States is going elsewhere. The Mexican government has generated almost **$1.3 billion USD** from offshore energy development since 2014. Meanwhile, the United States has lost potential jobs and revenue.

The Marine Mammal Protection Act (MMPA) was created to protect marine mammals, not to be used as a tool by anti-energy groups to prevent exploration activities. Help bring the MMPA into the 21st century by supporting common sense reforms that ensure investments stay in the United States.

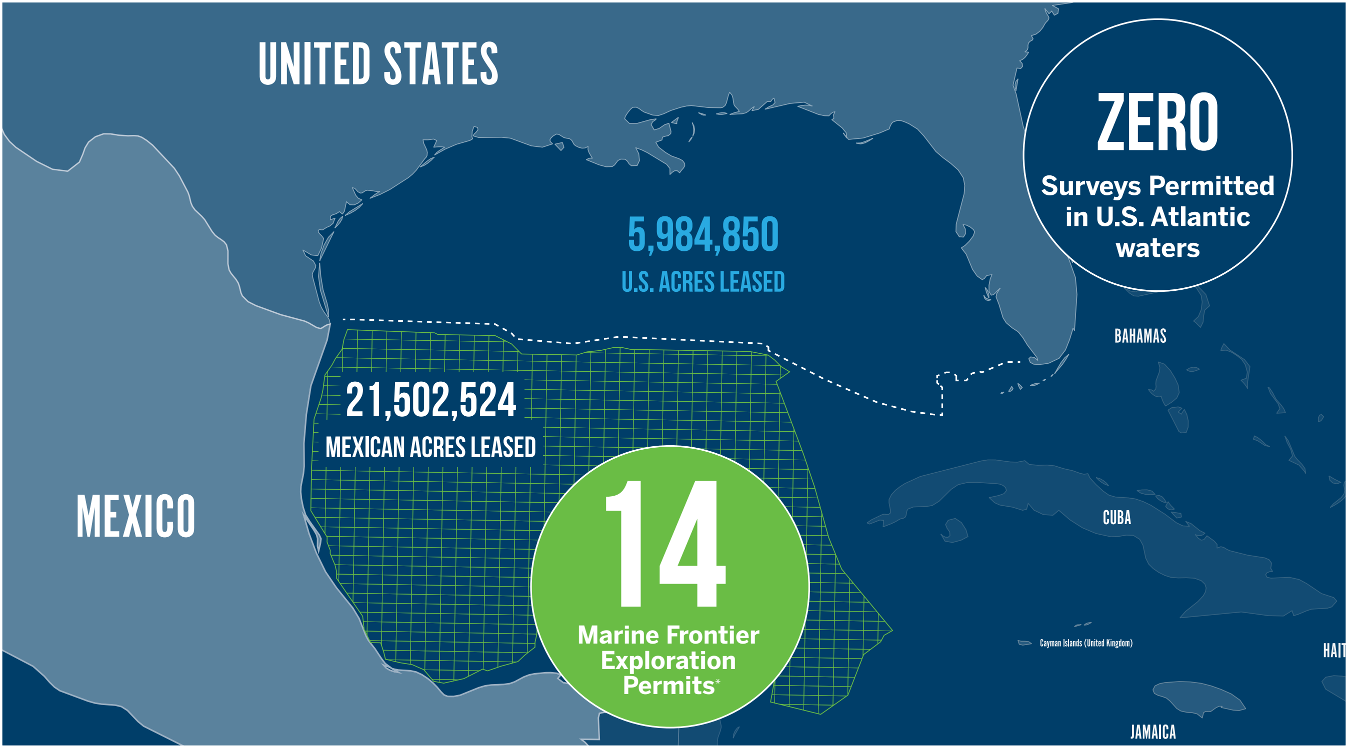
U.S. Regulators have failed to rule on permits in Atlantic waters for over

4 YEARS

$1.3 BILLION USD

Mexico earned from offshore energy development since 2014

U.S. Losing to Mexico in Offshore Development



ZERO

Surveys Permitted in U.S. Atlantic waters

14

Marine Frontier Exploration Permits*

* 2014 through February, 2018

For more information, go to **https://www.iagc.org/dc-fly-in.html**

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August 25, 2017

Dr. Walter Cruickshank
Acting Director
Bureau of Ocean Energy Management
1849 C Street, NW
Washington, D.C. 20240

Mr. Chris Oliver
Assistant Administrator
NOAA Fisheries
1315 East-West Highway
Silver Spring, MD 20910

Re: Modeling Analysis for Final Programmatic Environmental Impact Statement for Geological & Geophysical Activities on Gulf of Mexico Outer Continental Shelf

Dear Dr. Cruickshank and Mr. Oliver:

The International Association of Geophysical Contractors and the American Petroleum Institute (the "Associations") respectfully provide the enclosed report, titled "Gulf of Mexico Acoustic Exposure Model Variable Analysis" ("Model Analysis"), for your consideration. We request that the Bureau of Ocean Energy Management ("BOEM") include the Model Analysis in its administrative record for the forthcoming record of decision related to BOEM's Programmatic Environmental Impact Statement evaluating the potential environmental effects of geological and geophysical activities on the Gulf of Mexico Outer Continental Shelf ("PEIS"). We also request that the National Marine Fisheries Service ("NMFS") include the Model Analysis in its administrative record for its Marine Mammal Protection Act ("MMPA") Section 101(a)(5)(a) rulemaking for the Gulf of Mexico. Below, we provide some important context for the Model Analysis.

As explained in our comments on the Draft PEIS, the Associations are very concerned with the repeated application of precautionary assumptions across many variables within the model that was used for the PEIS to estimate marine mammal exposures to certain sound levels. Models are tools, but it is important to remember that models are simplifications of the real world and the parameters of a model are assumptions made by the decision-maker(s). It is the assumptions that lead to overestimates or underestimates of the results. By design, a multivariate model incorporates numerous variables to produce a single predicted result. When "precautionary" values are used for each of those variables—instead of the best available or most likely (*e.g.*, mean or median) values—and the uncertainty, or error (*i.e.*, standard deviation), is not adequately quantified, the predicted outcome from the multivariate model can be inflated by significant orders of magnitude larger than a result based upon the input of the most likely or best available values for each variable. In certain cases, such as marine mammal take modeling, this can be on order of thousands or millions higher. The reason for this phenomenon is that the variables are multiplied within the model and when each variable is given a seemingly innocuous "precautionary" value not supported by proper analysis of variance or error, the multiplicative effect of compounding all those variables produces an extraordinarily unrealistic result.

To illustrate this problem, the Associations requested and received permission from BOEM and NMFS to engage the same contractor that performed the modeling for the PEIS (JASCO Applied Sciences) to run that same model, with the same data, but with alterations to four variables. The alternate values used for these four variables were chosen to attempt to reflect the central or most likely tendency for each value, based upon the best available information or practice. The four altered variables are described as follows:

- Sound Source Size. In the Draft PEIS, an artificial sound source was applied to all surveys, roughly comparable to the largest sound source used in the Gulf of Mexico (8,000 cubic inches). In contrast, the Model Analysis assumes an array of 4,130 cubic inches—a survey sound source used frequently in the Gulf that is near the mean or median size range of arrays used in the Gulf over the past decade. This single change results in a four-fold decrease in exposure estimates. *See* Model Analysis at Tables 15-16 and Appendix B.

- Population Density. The Draft PEIS applies a novel method for estimating animal distribution and abundance (Roberts et al. 2016).[1] The approach used in Roberts et al. (2016) ("Roberts Model") is new and untested, and differs significantly from the official, MMPA-required population data produced by NMFS (NOAA Stock Assessment Reports or "SARs," http://www.nmfs.noaa.gov/pr/sars/species.htm). For some species, SAR values and Roberts Model values have little difference, but for other species, the Roberts Model predicts abundance estimates 8, 16, or even 30 times greater than the SAR estimates. The Roberts Model abundance estimate was smaller than the SAR estimate for only one species. Appendix H of the Model Analysis provides a detailed explanation of how the intermediate values were generated for the analysis. The impact of a slight alteration of animal density data is a decrease in takes of less than 50% by itself, but when combined with the other changes, the more central estimates of population parameters contribute to a much larger reduction to the total take estimates, as illustrated by Tables 15-19 in the Model Analysis.

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[1] Roberts J.J., B.D. Best, L. Mannocci, E. Fujioka, P.N. Halpin, D.L. Palka, L.P. Garrison, K.D. Mullin, T.V.N. Cole, C.B. Khan, W.A. McLellan, D.A. Pabst, G.G. Lockhart. 2016. Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. Nature: Scientific Reports: 6:22615 | DOI: 10.1038/srep22615. www.nature.com/scientific reports/.

- Aversion. In the Draft PEIS, behavioral avoidance or movement away from the source was acknowledged to be a well-documented and significant factor influencing the number of potential "takes," especially "Level A" takes (as defined under the MMPA). In essence, the animals avoid coming within the zone containing sound levels that may cause Level A take. Avoidance or "aversion" is a well-documented phenomenon across many, if not all, marine mammal species. However, the PEIS modeling did not account for aversion. The Model Analysis includes a relatively slight degree of aversion—a few degrees deviation from course for a few seconds (*see* Model Analysis, Appendix F). Even incorporating a conservatively small amount of aversion results in a predicted reduction of Level A exposures of 40-80%. Stronger aversion that is more consistent with research studies and observer data would further reduce the estimated Level A exposures.

- Mitigation. Although visual and acoustic monitoring and mitigation measures have been required of industry vessels for decades, the Draft PEIS models give zero value to the benefits of these monitoring and mitigation measures. However, mitigation effectiveness likely varies by species and observing conditions, from as low as 5-10% at times to close to 100% for certain species and observing conditions. The Model Analysis includes a modest set of species-dependent mitigation factors (Model Analysis, Section 4.5, Tables 18-19). This has a straightforward impact on reducing predicted takes that scales to the assumed probability of observers detecting the animals, but which, we reiterate, interacts in a multiplicative manner with the other variables to create the highly inflated totals seen in the PEIS.

A fifth variable, the risk threshold criteria, was re-modeled by JASCO under contract to NMFS. This variable has been included along with the four variables selected by IAGC and API, with permission from NMFS, and is consistent with the points made by the other four changed variables: that small movements toward best available science have a greater impact on final model outcome than might be expected from the relatively small change to a single variable, through the multiplicative interactions with the other variables. We note, however, that the NOAA 2016 criteria, while a significant improvement over the criteria used in the Draft PEIS, still contain precautionary assumptions above and beyond the best available science.

We provide the Model Analysis solely to illustrate the substantial overestimation that can result from compounding precautionary assumptions in a multivariate model and to provide quantitative support for the qualitative comments we provided on the Draft PEIS.[2] It is not the structure of the model that is necessarily problematic, but it is the precautionary assumptions allocated to particular variables in the model by BOEM and NMFS that are problematic. The evaluation of alterations to only four of these variables sufficiently demonstrates the significant consequences of redundantly applied precaution in a complex multivariate model. As shown in

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[2] *See* Letter from the Associations to Dr. Jill Lewandowski, dated November 29, 2016.

the Model Analysis, these alterations produce marine mammal exposure estimates that are substantially lower than what are predicted by the model used for the PEIS.

The alternative values used for the Modeling Analysis do not reflect a position by industry about what is or should be considered the best available or most likely values for given variables. Rather, our intent is to demonstrate the importance of having a more thorough and inclusive expert discussion about what are the best available or most likely values for the different variables used in the PEIS model. Additionally, the Model Analysis should not be interpreted as the Associations' agreement with the model generally or a belief that the re-modeled results are indicative of actual effects. For example, we believe the re-modeled results presented in the Model Analysis still substantially overestimate the number of potential "Level B" exposures due to, among other factors, precautionary conservatism applied to the values used for Level B thresholds. Finally, we reiterate that the Model Analysis does not address all of the beneficial effects of mitigation, including benefits that may be qualitatively analyzed. We continue to believe, based upon many years of supporting experience and data, that mitigation measures substantially reduce, if not eliminate, potential takes.

We appreciate your consideration of the Model Analysis and respectfully invite further discussion on this issue. We will contact each of you to schedule a meeting so that we may discuss the Model Analysis in more detail and answer any questions that you or your respective colleagues may have.

Sincerely,

Nikki C. Martin

Nikki Martin
International Association of Geophysical Contractors
President

Andy Radford

Andy Radford
American Petroleum Institute
Sr. Policy Advisor – Offshore

Attachment

cc: David Bernhardt, Deputy Interior Secretary
Kate MacGregor, Deputy Assistant Secretary for Land and Minerals
Vincent DeVito, Counselor to the Secretary for Energy Policy
Chairman Rob Bishop, House Committee on Natural Resources
Chairman John Thune, Senate Commerce Committee
Chairman Lisa Murkowski, Senate Energy and Natural Resources Committee

Gulf of Mexico Acoustic Exposure Model Variable Analysis

Submitted to:

Robert Gisiner
Director, Marine Environmental Science/Biology
International Association of Geophysical Contractors
and
Andy Radford
Sr. Policy Advisor – Offshore
American Petroleum Institute
Contract: 2017-111331

Authors:

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25 August 2017

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Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Executive Summary

The International Association of Geophysical Contractors (IAGC) and the American Petroleum Institute (API), representing their member companies, are interested in better understanding the effect that various acoustic model parameters or inputs have on the outputs used to estimate numbers of animals exposed to threshold levels of sound from geophysical sources used in the Gulf of Mexico (GoM). JASCO conducted acoustic modeling for the 2016 GoM Outer Continental Shelf Proposed Geological and Geophysical (G&G) Activities Draft Programmatic Environmental Impact Statement (PEIS). One output of the models used in the PEIS work is an estimate of the number of potential animal exposures to a pre-determined acoustic threshold. A number of parameters were used in the model to calculate this estimate for the PEIS.

For this analysis, JASCO was tasked with adjusting several parameters to test their impact on model outcomes, and comparing these outcomes to those found in the PEIS. This comparison provides insight into the relative importance of several variables, individually and in combination, as influencers on model outputs. The parameters discussed in the analysis include:

- seismic sound source array size (including total volume, number of array elements, element air pressure, array geometry and spacing) used in source and propagation models,
- acoustic threshold criteria and associated weighting used to calculate exposures,
- animal densities used for adjusting simulated computer model exposures to potential real-world animal exposures,
- natural aversive behaviors of marine mammals, and
- the addition of mitigative measures that lessen the potential for animals' exposure to threshold levels of seismic sound.

The models and processes used in this analysis are the same, or comparable to those used in the modeling effort for the PEIS. This ensures that comparisons are relevant and meaningful for those parameters tested. The adjusted parameters used in this study for comparison with work completed as part of the PEIS are summarized in the table below.

Parameter	BOEM GOM G&G PEIS		IAGC/API GoM Model Analysis
	Draft PEIS	Final PEIS	
Airgun array volume	8000 in^3	8000 in^3	4130 in^3
Acoustic criteria: injury	180 dB rms SPL re 1 µPa	NOAA Technical Guidance (NMFS 2016)	NOAA Technical Guidance (NMFS 2016)
Acoustic criteria: behavior	160 dB rms SPL re 1 µPa	160 dB rms SPL re 1 µPa	Wood et al. (2012) step function
Frequency weighting	unweighted	Injury: NOAA Technical Guidance (NMFS 2016) Behavior: unweighted	Injury: NOAA Technical Guidance (NMFS 2016) Behavior: Type I (Southall et al. 2007)
Animal density source	PEIS (Roberts et al. 2016a)	PEIS (Roberts et al. 2016a)	PEIS (Roberts et al. 2016a) & Alternate Densities
Animal aversion	not included	not included	included
Mitigation	not applied	not applied	evaluated

For most species, assessment using NOAA's Technical Guidance (NMFS 2016) leads to a substantial decrease in predicted injurious exposures compared to the Draft PEIS. The exception is high-frequency species whose predicted injury rates remain about the same. The Technical Guidance was not available when the Draft PEIS was completed, but injurious exposure estimates using the Technical Guidance are included in the Final PEIS. Exposure estimates from the Final PEIS modeling were used as the baseline values to understand the effects of adjusting the parameters shown in the table.

The reduction in array volume, inclusion of aversion, and use of alternate densities that were introduced in consultation with IAGC, lowered injurious and behavioral exposure estimates for all species. Use of a smaller airgun array volume with lower source level creates a smaller ensonified area resulting in fewer numbers of animals expected to exceed exposure thresholds. Programming simulated animals to avoid loud sounds reduces the number of injurious exposures, though the magnitude of the effect is variable because of statistical variability in re-running the simulations. Use of alternate density estimates changes the exposure rate by the same proportion as the change in the density estimate. Mitigation procedures could further reduce the potential for injury roughly in proportion to the rate at which animals are detected within an exclusion zone.

Contents

Figures

Tables

1. Introduction

The International Association of Geophysical Contractors (IAGC) and the American Petroleum Institute (API), representing their member companies, are interested in better understanding the effect that various acoustic model parameters or inputs have on the outputs used to estimate numbers of animals exposed to threshold levels of sound from geophysical sources used in the Gulf of Mexico (GoM). JASCO conducted acoustic modeling for the 2016 GoM Outer Continental Shelf Proposed Geological and Geophysical (G&G) Activities Draft Programmatic Environmental Impact Statement (PEIS; BOEM 2016). One output of the models used in the PEIS work is an estimate of the number of potential animal exposures to a pre-determined acoustic threshold. A number of parameters were used in the model to calculate this estimate for the PEIS.

For this analysis, JASCO was tasked with adjusting several parameters to test their impact on model outcomes, individually and in combination, and comparing these outcomes to those found in the PEIS. This comparison provides insight into the relative importance of several parameters as influencers on acoustic model outputs. The parameters discussed in the analysis include:

- Seismic sound source array size (including total volume, number of array elements, element air pressure, array geometry and spacing) used in source and propagation models,
- Acoustic threshold criteria and associated weighting used to calculate exposures,
- Animal densities used for adjusting simulated computer model exposures to potential real-world animal exposures,
- Natural aversive behaviors of marine mammals, and
- The addition of mitigative measures that lessen the potential for animals’ exposure to threshold levels of seismic sound.

The models and processes used in this analysis are the same, or comparable to those used in the modeling effort for the PEIS. This ensures that comparisons are relevant and meaningful for those variables tested. Both the PEIS and this analysis also use the same time period, which provides estimates of the annual potential marine mammal acoustic exposure from geological and geophysical exploration sound source activity in the GoM for years 2016 to 2025. Exposure estimates are computed from modeled sound levels received by simulated animals (animats). Because animals and noise sources move relative to the environment and each other, and the sound fields generated by the sound sources are shaped by various physical parameters, the sound levels received by an animal are a complex function of location and time. Acoustic models are used to compute three-dimensional (3-D) sound fields that vary with time. The simulated realistic movements of animats within these fields sample the sound levels in a manner representing how real animals would experience this sound. From the time history of the received sound levels, the number of animats exposed to levels exceeding threshold criteria are determined and then adjusted by the number of animals in the area to estimate the potential number of real animals likely to receive the pre-determined sound levels.

In this analysis, the GoM is divided into seven modeling zones, with four (4) survey types simulated within each zone used to estimate the potential exposures from each survey. The results from each zone were summed to provide Gulf-wide estimates of the potential number of animals exposed to threshold levels of sound capable of causing injurious effects or behavioral disturbance for each marine mammal species, survey type, and year, based on specific assumed levels of survey activities.

2. Project Description and Methods

The Draft GOM PEIS modeling to estimate potential marine mammal exposures to levels of sound capable of causing injury or behavioral disturbance was conducted prior to the release of the final NOAA Technical Guidance (NMFS 2016). Potential injury (Level A) from acoustic exposure in the Draft PEIS was therefore calculated using a National Marine Fisheries Service (NMFS) criteria with a threshold of 180 dB rms SPL (re 1 µPa) (HESS 1999). Modeling for the PEIS used an array volume of 8000 in^3 as the sound source for seismic surveys, and did not include animal aversions to loud sounds or mitigation procedures. Marine mammal density estimates used in the PEIS were the newly-available habitat-based estimates from Duke University's Marine Geospatial Ecology Laboratory (MGEL) (referenced as PEIS densities hereafter) model (Roberts et al. 2016b).

The objective of this study is to assess the level of influence several variables have on predicted, potential animal exposures, which are a key output of acoustic exposure models. To do this, source, propagation and acoustic exposure models were run using inputs provided by IAGC and API. These inputs are then compared to those modeled for the PEIS. Table 1 provides descriptions of model input assumptions used in this analysis and the PEIS.

Table 1. Summary of model inputs used for comparison and analysis of variable influence on predicted potential animal exposures.

Parameter	BOEM GOM G&G PEIS		IAGC/API GoM Model Analysis
	Draft PEIS	Final PEIS	
Airgun array volume	8000 in^3	8000 in^3	4130 in^3
Acoustic criteria: injury	180 dB rms SPL re 1 µPa	NOAA Technical Guidance (NMFS 2016)	NOAA Technical Guidance (NMFS 2016)
Acoustic criteria: behavior	160 dB rms SPL re 1 µPa	160 dB rms SPL re 1 µPa	Wood et al. (2012) step function
Frequency weighting	unweighted	Injury: NOAA Technical Guidance (NMFS 2016) Behavior: unweighted	Injury: NOAA Technical Guidance (NMFS 2016) Behavior: Type I (Southall et al. 2007)
Animal density source	PEIS (Roberts et al. 2016a)	PEIS (Roberts et al. 2016a)	PEIS (Roberts et al. 2016a) & Alternate density
Animal aversion	not included	not included	included
Mitigation	not applied	not applied	included

An overview of potential reduction of injurious exposures when mitigation procedures are employed will also be addressed.

2.1. Survey Locations

2.1.1. Choice of zone boundaries

The size and shape of acoustic footprints from exploration surveys in the Gulf of Mexico are influenced by many parameters, but the strongest influencers are water depth and seabed slope. We divided the project area into three main bathymetric areas Shelf, Slope, and Deep. The Shelf extends from shore to 100–200 m depths, where bathymetric relief is gradual; water depths on the continental shelf off Florida's eastern coast are less than 200 m deep out to ~ 150 km from shore. The Slope starts at the Shelf's outer boundary and extends into deeper water where the seabed relief is steeper and water deepens from 100–

200 m to 1500–2500 m over as little as 50 km horizontal distance. The Slope ends at the Deep area, where, although water depths are more consistent than in the other areas, depths can vary from 2000–3300 m. The subdivision depth definitions are Shelf: 0–200 m, Slope 200–2000 m, and Deep: > 2000 m.

For this analysis, and to maintain consistency with the PEIS, the Gulf was divided into 7 zones: 3 Shelf zones, 3 Slope zones, and 1 Deep zone [see Section 7.2.3 of Appendix D in Volume II of the Draft PEIS (BOEM 2016) for more detail]. These divisions are based on the physical properties of the area and the distribution of its marine inhabitants, The southern edge of the Deep zone is defined by the U.S. Exclusive Economic Zone (EEZ) boundary. The zones boundaries were defined by the 200 and 2000 m depth contours and the east-west boundary lines of BOEM's Planning Areas (except for the Deep zone 7, which included portions of all three Planning Areas). The seven modeling zones, labelled "zones" are shown in Figure 1 along with the seven representative simulation locations (numbered rectangles) discussed below.

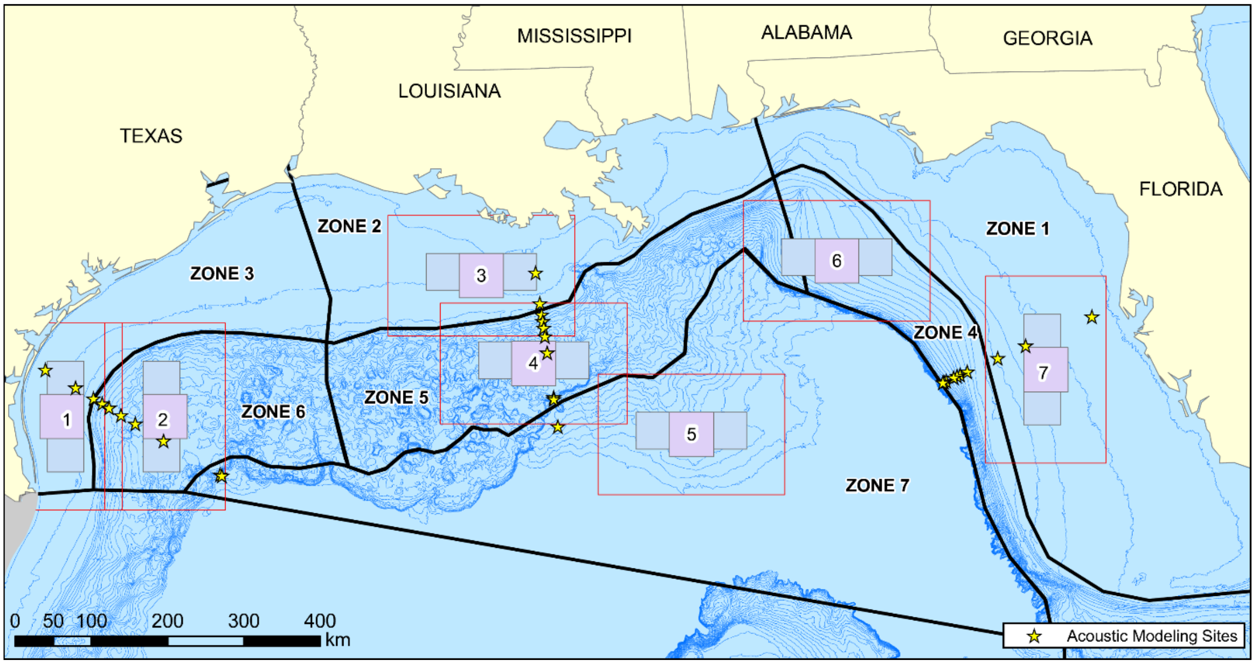

Figure 1. Gulf of Mexico project area. Black lines delineate the zones. Large, red rectangular boxes show the animal simulation extents for seismic surveys. Gray rectangles are the survey area extents for the 2-D and 3-D surveys. Pink squares are the survey extents of coil surveys. Yellow stars show the acoustic modeling sites are along West, Central, and East transects.

2.1.1.1. Survey and simulation locations

Within each of the seven zones, representative survey locations were defined (filled rectangles in Figure 1) for four different survey types described in Section 2.2. During the simulations, the source is moved within these rectangles. The sound produced ensonifies an area larger than the survey rectangle, so the extent of the corresponding animat simulation extents (red boxes in Figure 1) are larger. The animat simulation areas are determined by first finding the range to the lowest sound level which could result in disturbance, or 50 km, (whichever is smaller), and setting a buffer around the survey area of at least this range.

2.1.1.2. Acoustic Modeling Sites

As the acoustic energy from a source propagates, it is subject to a number of marine acoustic effects that depend on the ocean and bottom environment. We selected a set of 30 sites to calculate acoustic propagation loss grids as functions of source, range from the source, azimuth from the source, and receiver depth. We then used these grids as inputs to the acoustic exposure model. The 30 modeling sites (yellow stars in Figure 1) were grouped into three transects—Western, Central, and Eastern. Even though these 30 modeling sites were not all located within the survey extents (boxes) discussed in the previous section, and Boxes 5 and 6 do not contain any individual modeling sites, the environmental parameters and acoustic propagation conditions represented by these 30 modeling sites were chosen to be representative of the prevalent acoustic propagation conditions within the survey extents (boxes). (See Section 7.2.3.2 of Appendix D in Volume II of the Draft PEIS (BOEM 2016) for more detail.)

2.2. Survey Types

Four types of surveys that were included in the PEIS were also modeled for this analysis. These include 2-D, 3-D narrow azimuth (NAZ), 3-D wide azimuth (WAZ), and Coil. Each survey type is described below.

2.2.1. 2-D seismic survey

The 2-D seismic survey is performed with a single vessel towing a single seismic array. The lateral spacing of the production lines is consistent with that modeled in the PEIS, at 4.8 km (Figure 2). The production lines were generated using racetrack infill method, skipping two tracks on the left side turn (15 km wide turn) and transitioning onto the adjacent line on the right side turn (5 km wide turn). Seven days of survey were simulated. The vessel speed was 4.5 kts (2.3 m/s). The shot interval was 21.6 s (50 m). The total length of the simulated track was ~ 1400 km. The number of simulated pulses was ~ 28,000. Constant towing azimuth, parallel to the long side of the survey box, was modeled for all shots.

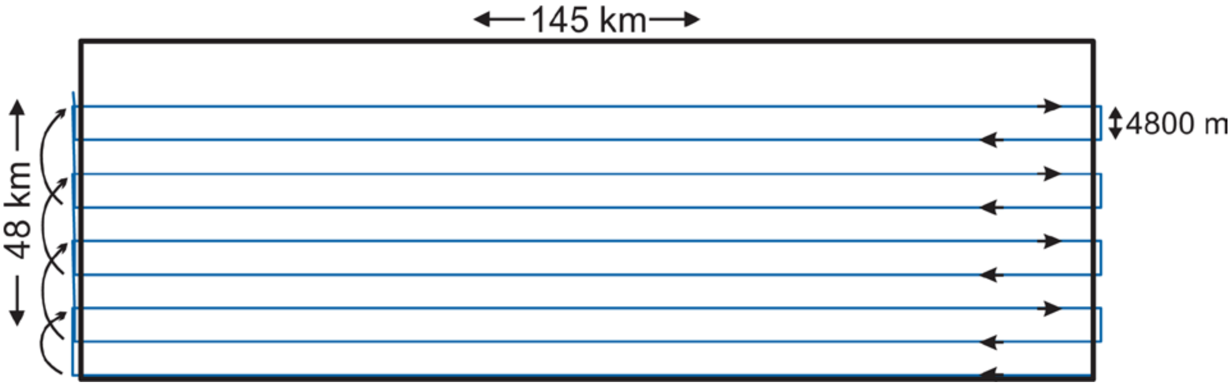

Figure 2. Simulated portion of the track for the 2-D seismic survey.

2.2.2. 3-D narrow azimuth seismic survey

3-D NAZ seismic surveys can be performed with one or two vessels towing two identical seismic source arrays. The source array towed by the same vessel is operated in a flip-flop mode, i.e., for each shot position only one of the two arrays produces a seismic pulse. In the two-vessel option, sources at each vessel produce seismic pulses simultaneously. The two-vessel option was simulated for this analysis. Both vessels follow the same track, separated along the track by 6,000 m. The production lines were laterally spaced by 1 km (Figure 3). The production lines were generated using a racetrack infill-in method with eight loops in each racetrack (7–8 km wide turn). Forty-nine lines were required to fully cover the survey area. The 7-day simulation covered ~ 20% of the complete survey. The vessel speed was 4.9 kts (2.5 m/s). The shot interval was 15 s (37.5 m) for each vessel. The total length of the simulated track is ~ 1500 km, with ~ 80,000 simulated pulses.

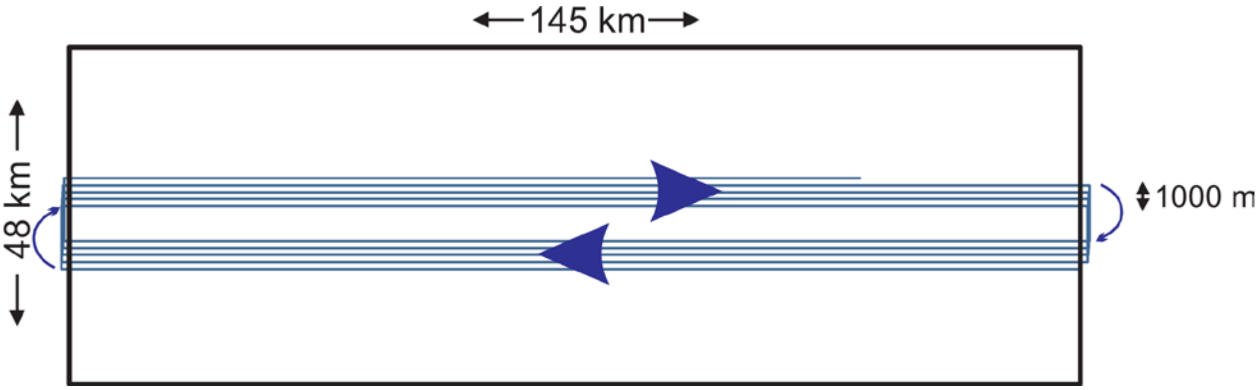

Figure 3. Simulated portion of the track for the 3-D NAZ seismic survey.

2.2.3. 3-D wide azimuth seismic survey

The 3-D WAZ seismic survey was performed with multiple vessels traveling along parallel tracks with some lateral and along the track offsets. The four-vessel option with seismic sources firing sequentially is simulated. The tracks of each vessel have the same geometry with a 1,200 m lateral offset. The vessels also have a 500 m offset along the track. The lateral spacing of the same vessel's production lines is 4.8 km and 1.2 km for the group (Figure 4). The production lines were generated with a racetrack infill method with two loops in each racetrack (9.6 km wide turn). Forty lines are required to fully cover the survey area with the vessel moving at 4.5 kts (2.3 m/s). The 7-day simulation covered ~ 85% of the complete survey. The shot interval was set to 86.4 s (200 m) for each vessel or 21.6 for the group. The total length of the simulated track is ~ 1400 km, with ~ 28,000 simulated pulses.

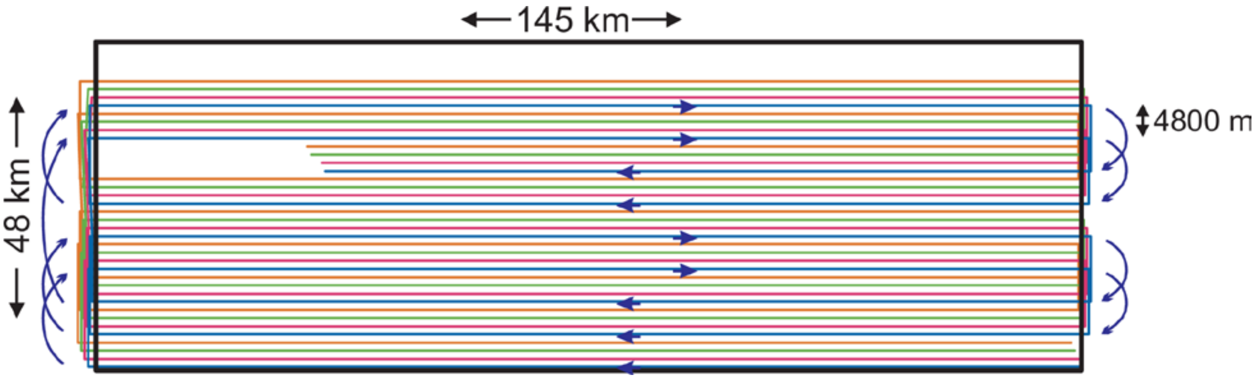

Figure 4. Simulated portion of the track for the 3-D WAZ seismic survey.

2.2.4. Coil seismic survey

The coil seismic survey modeled in both the PEIS and this analysis, is performed by multiple vessels that sail a series of circular tracks with some angular separation while towing sources. The four-vessel option was simulated assuming simultaneous sourcing around a track consisting of a series of circles with 12.5 km diameter (Figure 5). Once the vessel completes a full circle, it advances to the next one along a tangential connection segment. The offset between the center of one circle and the next, either along-swath or between swaths, is 5 km. The full survey geometry consists of two tracks with identical configuration with 1,200 m and 600 m offsets along X and Y directions, respectively. Two of the four vessels follow the first track with 180° separation; the other two vessels follow the second track with 180° separation relative to each other and 90° separation relative to the first pair. One hundred circles per vessel pair were required to fully cover the survey area. The 7-day simulation covered ~ 30% of the complete survey. The vessel speed was 4.9 kts (2.5 m/s). The shot interval was 20 s (50 m) for each vessel. The total length of the simulated track is ~ 1,500 km, with ~ 120,000 simulated pulses.

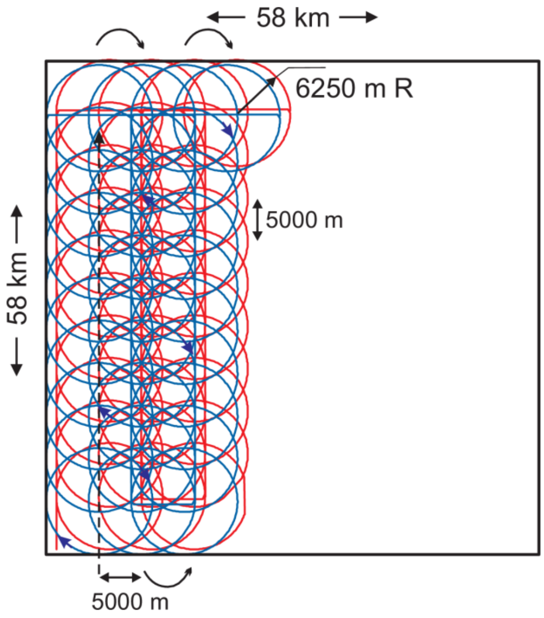

Figure 5. Simulated portion of the track for the coil seismic survey.

2.3. Acoustic Analysis Methods

Acoustic analysis methods used in this study are the same, or similar to those used in the modeling completed for the Draft PEIS, with only model inputs adjusted for comparison as shown in Table 1. To estimate potential direct effects (e.g., injury, behavioral disturbance) to marine life within the sound fields produced by the 4130 in^3 source array in various types of surveys, JASCO performed the following modeling and analysis procedures:

1. Modeled the spectral and temporal characteristics of the sound output from the proposed seismic source using the Airgun Array Source Model (AASM). Model set-up and initialization data for the 4130 in^3 airgun array configuration was provided by IAGC.
2. Acoustic propagation modeling using the Marine Operations Noise Model (MONM) that combines the outputs of the source model with the spatial and temporal environmental context (e.g., location, oceanographic conditions, seabed type) to estimate sound fields (converted to exposure radii for monitoring and mitigation). The lower frequency bands were modeled using MONM-RAM, which is based on the parabolic equation method of acoustic propagation modeling, and the higher

frequencies were modeled using MONM-Bellhop, which is a Gaussian-beam ray-theoretic acoustic propagation model.

3. Integrated the estimated sound fields with species-typical behavioral parameters (e.g., dive patterns, aversion), to estimate received sound levels for the animals that may occur in the operational area using the JASCO Animal Simulation Model Including Noise Exposure (JASMINE).
4. Estimated the number of potential injurious and behavioral level exposures based on pre-defined acoustic thresholds/criteria (NMFS 2016) and density estimates provided by IAGC and API.

Details of the acoustic analysis are provided in Appendix B and Appendix F.

2.3.1. Sound source and sound propagation

Seismic airguns generate pulsed acoustic energy by releasing into the water highly compressed air, which forms air bubbles that undergo a damped volume oscillation and emit an acoustic pressure wave that follows the bubble's oscillating internal pressure. Seismic airguns produce sounds primarily at frequencies from a few hertz to a few kilohertz, but also produce lower level sounds at higher frequencies. Larger airguns with larger internal air volume, produce higher broadband sound levels with sound energy spectrum shifted toward the lower frequencies. Single airguns or multiple airguns arranged in a spatial pattern (referred to as an airgun array) are typically towed by a survey vessel, with shots or impulses generated every 5 to 30 s along survey track lines.

A single airgun produces an approximately omnidirectional sound field, with the acoustic energy initially emitted equally in all directions. The sound signal then reflects from the water's surface and interacts with sounds that travel directly from the airgun. The result of this interaction is that, on average, more sound energy is focused downwardly than horizontally, an effect that is more prominent for lower frequencies. Larger seismic surveys usually use multiple airguns arranged in arrays, with most of the airguns in a horizontal plane. This configuration, combined with the effect of the surface reflection, focuses more sound energy downward, while emitting lower levels of sound horizontally. Airgun arrays generally show significant horizontal directionality patterns due to the phase delay between pulses from horizontally separated lines of airguns.

Sound propagates unevenly through water as it radiates away from the acoustic source due to source characteristics, and variation in area-specific environmental parameters such as water temperature and density (affecting sound velocity), and bottom type and bathymetry. The source characteristics and environmental parameters are all considered in the propagation model. The propagation model is described in Appendix C and the environmental parameters detailed in Appendix D.

For this project a seismic source array with a 4130 in^3 volume was used as the sound source. The source levels and directivity pattern calculations are shown Appendix B.1. The results of the source and propagation model for this array volume are compared to the larger source array (8000 in^3) model results included in the Draft PEIS (Section 6.3.1.1 of Appendix D in Volume II of the Draft PEIS (BOEM 2016)).

2.3.2. Animal movement and exposure modeling

The JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was used to predict the exposure of animats (virtual marine mammals) to sound arising from the surveys. Sound exposure models like JASMINE integrate the predicted sound field with biologically meaningful movement rules for each marine mammal species that result in an exposure history for each animat in the model. Inside JASMINE, the sound source mimics the proposed survey pattern (as described above). As shown in Figure 6, animats are programmed to behave like the marine animals that may be present in the survey area. The parameters used for forecasting realistic behaviors (e.g., diving, foraging, aversion, surface times etc.) are determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species (see Appendix F for a more detailed explanation of JASMINE and the parameters used in modeling marine mammal movement).

Individual animat's sound exposure levels are summed over the total simulation duration or a shorter time period, such as 24 hours, to determine its total received energy. The maximum exposure sound pressure level during the time period is also determined from the exposure history, and both total energy received and maximum pressure are compared to the pre-determined thresholds (Section 2.4).

The Marine Mammal Movement and Behavior (3MB) model (Houser 2006) was used in the modeling for the PEIS (Section 5.3 of Appendix D in Volume II of the Draft PEIS (BOEM 2016)). JASMINE was used for this study so that behavioral aversion could be included. JASMINE was written by JASCO and is based on the 3MB model. The performance of JASMINE and 3MB are the same except that JASMINE allows for animats to change behavioral states in response to specified received levels, which is necessary for implementation of behavioral aversion (see below).

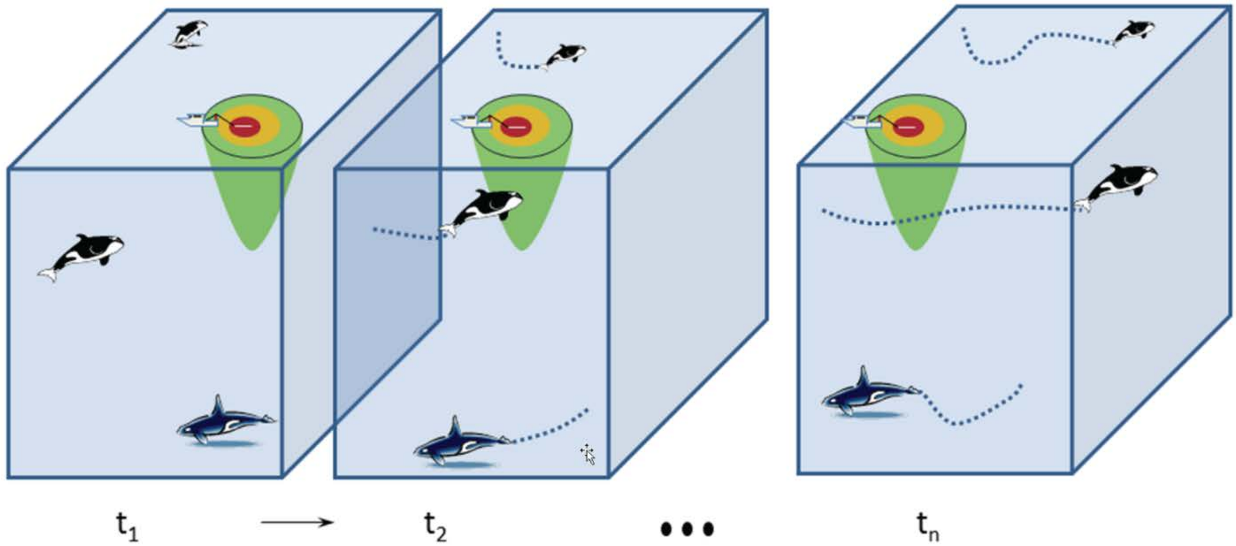

Figure 6. Cartoon of animats in a moving sound field. The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time. In this cartoon the vessel and sound source are moving from right to left, as is the deepest animat. The two upper animats move from left to right. Because the upper and lower animats are far from the source, low levels of sound exposure are expected. The middle animat is nearer the sound source, so its acoustic exposure is expected to be higher than the other two animats, and its highest exposure occurs closest to the sound source at the second time step (t_2).

2.3.2.1. Aversion

Aversion is a common response of animals to sound, particularly at relatively high sound exposure levels (Ellison et al. 2012). As received sound level generally decreases with distance from a source, this aspect of natural behavior can strongly influence the estimated maximum sound levels an animal is predicted to receive and significantly affects the probability of more pronounced direct or subsequent behavioral effects. As part of the revised analysis approach recommended by Southall et al. (2016) aversion parameters to sound level were implemented for all selected acoustic criteria. A scaled aversion response function was created, with the magnitude and probability of an aversion response increasing with increased received sound levels. At the end of each time step, each animat "evaluates" its received sound level and applies the aversion rules. At a given received level, there is a specified probability that an aversion would occur for a specified duration and corresponding course change away from the source. Details of the aversion approach used in JASMINE are provided in Appendix F.1.4. Aversion rules applied in simulation models assume that all animals respond the same way to pre-determined sound levels. Behavioral response of animals is extremely variable (see Southall et al. 2007) and aversion behavior is insufficiently documented in most species.

2.4. Details of Acoustic Criteria Used in this Analysis

To assess the potential impacts, it is necessary to first establish exposure criteria for which sound levels may be expected to have a negative impact on animals. In 2016, after the publication of the Draft PEIS, NOAA issued a Technical Guidance document that provides acoustic thresholds for onset of PTS and TTS in marine mammal hearing for all sound sources (NMFS 2016). NOAA also provided guidance on the use of weighting functions when applying injury criteria. The NOAA Guidance recommends the use of a dual criteria for assessing injurious exposures, including a peak, unweighted sound pressure level metric ($\mathrm{SPL_{pk}}$) and a cumulative sound exposure level (SEL) metric with frequency weighting. Both acoustic criteria and weighting function application are specified by hearing group.

2.4.1. Marine mammal hearing groups

Current data and predictions indicate that not all marine mammal species have equal hearing capabilities, either in absolute hearing sensitivity or frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007, Au and Hastings 2008). While hearing measurements are available for a small number of species based on captive animal studies, direct measurements of many odontocetes and all mysticetes do not exist. As a result, hearing ranges for many odontocetes are grouped with similar species, and predictions for mysticetes are based on other methods including: anatomical studies and modeling (Houser et al. 2001, Parks et al. 2007, Tubelli et al. 2012, Cranford and Krysl 2015); vocalizations (see reviews in Richardson et al. 1995, Wartzok and Ketten 1999, Au and Hastings 2008); taxonomy; and behavioral responses to sound (Dahlheim and Ljungblad 1990, see review in Reichmuth et al. 2007) In 2007, Southall et al. proposed that marine mammals be divided into hearing groups. This division was updated in 2016 by NMFS using more recent best available science (Table 2).

Table 2. Marine mammal hearing groups (NMFS 2016).

Hearing group	Generalized hearing range*
Low-frequency (LF) cetaceans (mysticetes or baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (odontocetes)	275 Hz to 160 kHz

*The generalized hearing range for all species within a group. Individual hearing will vary.

2.4.2. Marine mammal weighting functions

The potential for anthropogenic sounds to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well, unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound. Sound spectra are weighted at particular frequencies in a manner that reflects an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS acoustic thresholds expressed in metrics that consider what is known about marine mammal hearing (e.g., SEL) (Southall et al. 2007, Erbe et al. 2016, Finneran 2016). Marine mammal auditory weighting functions published by Finneran (2016) are included in the NMFS 2016 Technical Guidance for use in conjunction with corresponding SEL PTS (injury) onset acoustic criteria (Table 3). The auditory weighting functions used in this study are described in Appendix E.

The application of marine mammal auditory weighting functions emphasizes the importance of making measurements and characterizing sound sources in terms of their overlap with biologically-important frequencies (e.g., frequencies used for environmental awareness, communication or the detection of predators or prey), and not only the frequencies of interest or concern for the completion of the sound-producing activity (i.e., context of sound source; NMFS 2016).

2.4.3. Injury exposure criteria

Loud and/or sustained sounds may injure the hearing apparatus of animals, resulting in a permanent shift in hearing thresholds. There are no published data on the sound levels that cause PTS in marine mammals. There are data that indicate the received sound levels at which TTS occurs, and PTS onset is typically extrapolated from TTS onset and growth. NMFS 2016 criteria incorporate best available science that indicates injury (PTS) in marine mammals is correlated with both sound exposure level (SEL) that accumulates over time, or very loud, instantaneous peak pressure levels. These dual threshold criteria of SEL and peak SPL are used to calculate marine mammal exposures (Table 3).

Table 3. Summary of relevant PTS and TTS onset acoustic thresholds (NMFS 2016) used in this analysis

Hearing group	PTS onset thresholds* (received level)		TTS onset thresholds* (received level)	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
Low-frequency (LF) cetaceans	SPL_{pk}, flat: 219 dB SEL_{LF}, 24h: 183 dB	SEL_{LF}, 24h: 199 dB	SPL_{pk}, flat: 213 dB SEL_{LF}, 24h: 168 dB	SEL_{LF}, 24h: 179 dB
Mid-frequency (MF) cetaceans	SPL_{pk}, flat: 230 dB SEL_{MF}, 24h: 185 dB	SEL_{MF}, 24h: 198 dB	SPL_{pk}, flat: 224 dB SEL_{MF}, 24h: 170 dB	SEL_{MF}, 24h: 178 dB
High-frequency (HF) cetaceans	SPL_{pk}, flat: 202 dB SEL_{HF}, 24h: 155 dB	SEL_{HF}, 24h: 173 dB	SPL_{pk}, flat: 196 dB SEL_{HF}, 24h: 140 dB	SEL_{HF}, 24h: 153 dB

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

SPL_{pk}, flat–peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa

SEL - denotes cumulative sound exposure over a 24-hour period and has a reference value of 1 µPa^{2}s

The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting.

2.4.4. Behavioral exposure criteria

Numerous studies on behavioral response have not resulted in consensus in the scientific community on the appropriate sound exposure metric for assessing behavioral reactions, and it is recognized that many variables other than received sound level affect the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012). Because of the complexity and variability of marine mammal behavioral responses to acoustic exposure, NMFS has not yet released technical guidance on behavior thresholds for use in calculating animal exposures (NMFS 2016). Based on observations of mysticetes (Malme et al. 1983, Malme et al. 1984, Richardson et al. 1986, Richardson et al. 1990), the NMFS currently uses SPL thresholds for behavioral response of 160 dB re 1 µPa for impulsive sounds and 120 dB re 1 µPa for non-impulsive sounds for all marine mammal species (NMFS 2016). It was noted in early workshops that behavioral responses to sound may occur at lower levels, but significant responses were most likely to occur above an rms SPL of 140 dB re 1 µPa (HESS 1999). An extensive review of behavioral responses to sound was undertaken by Southall et al. (2007, their Appendix B), who found varying responses for most marine mammals between an rms SPL of 140 and 180 dB re 1 µPa, consistent with the HESS (1999) report, but lack of convergence in the data prevented them from suggesting explicit thresholds. Absence of controls, precise measurements, appropriate metrics, and context dependency of responses (including the activity state of the animal) all contribute to variability.

In 2012, Wood et al. proposed a graded probability of response for impulsive sounds using a frequency weighted rms SPL metric. Wood et al. (2012) also designated behavioral response categories for sensitive species (including harbor porpoise and beaked whales) and for migrating mysticetes. For this analysis, the Wood et al. (2012) criteria is used to assess behavioral response to impulsive sounds (Table 4).

Table 4. Behavioral exposure criteria used in this analysis (porpoise and migrating mysticetes are not present in the GoM so are excluded from the table). Probability of behavioral response frequency-weighted sound pressure level (rms SPL dB re 1 µPa). Probabilities are not additive. Adapted from Wood et al. (2012).

Marine mammal group	Probability of response to frequency-weighted rms SPL (dB re 1 µPa)			
	120	140	160	180
Beaked whales and porpoises	50%	90%		
All other species		10%	50%	90%

2.5. Species that May be Present in the Survey Area

Of the approximately 125 species of known marine mammals, 32 cetaceans and one sirenian species are thought to occur in the Gulf of Mexico (Wursig et al. 2000, Jefferson et al. 2008). Seven of the cetacean species are baleen whales (mysticetes) and 25 are toothed whales (odontocetes). Of the seven mysticete species, only the Bryde’s whale is resident in the GoM, but its observed range is in the De Soto Canyon area, over 300 km from the proposed survey area. The other six mysticetes, the North Atlantic right whales, and the humpback, minke, sei, fin, and blue whales, are all considered rare or extralimital strays in the GoM. Four of the odontocetes are considered extralimital or rare visitors in the Gulf of Mexico: Sowerby’s beaked whales, the long-finned pilot whales, the long-beaked common dolphins, and short-beaked common dolphins (Davis and Fargion 1996, Jefferson and Schiro 1997, Davis et al. 2000). Species that are rare, or are unlikely to occur in the GoM, are not considered further in the environmental analysis. The low frequency Bryde’s whales are included in the analysis because the calculated range for behavioral response is larger than that of mid-or high-frequency species.

The one sirenian species present in the Northern GoM is the endangered West Indian Manatee (subspecies Florida manatee, *Trichechus manatus latirostris*). The species occurs mainly along the peninsular Florida coast and southeastern Georgia coasts in the winter and migrates to the North and East during summer. Migration routes and destinations are largely unknown (Pabody et al. 2009). The West Indian manatee is most common in warm, shallow waters of rivers, bays, estuaries, and coastal areas where their primary food source of aquatic plants is abundant (Gannon et al. 2007). A few individuals have been observed in deeper water and as far west as the Texas coast, but these sightings are considered extralimital (Fertl et al. 2005, Pabody et al. 2009). Because manatees are considered rare or absent from the survey areas, they are not included in this analysis.

There are currently no pinniped (sea lions, seals, and walruses) or fissiped (sea otters and polar bears) species known to inhabit the GoM. The Caribbean monk seal (*Monachus tropicalis*) has been extinct since the early 1950s; the last verified sighting in the GoM was made in 1932 (Wursig et al. 2000). There have been no reported sightings of the introduced California sea lion (*Zalophus californianus*) since 1972 (Jefferson et al. 1992, Wursig et al. 2000).

Marine mammal species resident in the GoM are shown in Table 5.

Table 5. Summary of marine mammal species considered in the acoustic exposure analysis.

Species of interest		Hearing group	Estimated auditory bandwidth[1]	Area population status[2]	GoM habitat distribution
Common name	Latin binomial				
Bryde's whales	*Balaenoptera brydei/edeni*	LFC	20–900 Hz	Uncommon	Non-migratory population resident in Northern GoM, especially De Soto Canyon (Schmidly 1981, Leatherwood and Reeves 1983)
Atlantic spotted dolphins	*Stenella frontalis*	MFC	0.1–160 kHz	Common	Occur in coastal and oceanic waters from 40° S to 40° N (Perrin and Hohn 1994, Perrin and Gilpatrick 1994).
Beaked whales[3]					
Blainville's	*Mesoplodon densirostris*	MFC	5–80 kHz	Rare	Occur in Northern GoM, particularly on shelf break (Hildebrand et al. 2015).
Cuvier's	*Ziphius cavirostris*	MFC		Rare	
Gervais'	*Mesoplodon europaeus*	MFC		Uncommon	
Bottlenose dolphins	*Tursiops truncatus*	MFC	150 Hz to 135 kHz	Common	Most widespread and common cetacean species in coastal waters of the GoM. Two genetically distinct geographic varieties (ecotypes) of bottlenose dolphins are known to occur in the GoM: a "coastal" ecotype and an "offshore" ecotype (Hersh and Duffield 1990, LeDuc and Curry 1998).
Clymene dolphins	*Stenella clymene*	MFC	0.1–160 kHz	Common	Occur in coastal and oceanic waters from 40° S to 40° N (Perrin and Hohn 1994, Perrin and Gilpatrick 1994).
False killer whales	*Pseudorca crassidens*	MFC	<1–115 kHz	Uncommon	Sightings of this species in the northern Gulf of Mexico are in oceanic waters, primarily in the eastern Gulf of Mexico (Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Fraser's dolphins	*Lagenodelphis hosei*	MFC	6.6–23.5 kHz	Rare	Sightings in the northern Gulf of Mexico recorded in all seasons in water depths > 200 m (656 ft) (Leatherwood et al. 1993, Hansen et al. 1996, Mullin and Hoggard 2000, Maze-Foley and Mullin 2006).
Killer whales	*Orcinus orca*	MFC	<500 Hz to 120 kHz	Uncommon	Sightings of killer whales in the northern Gulf of Mexico between 1921 and 1995 occurred primarily in oceanic waters ranging from 840 to 8,700 ft (256 to 2,652 m) (averaging 4,075 ft (1,242 m)), primarily in the North-central region (O'Sullivan and Mullin 1997). Very few killer whales in the Gulf of Mexico have been sighted on the continental shelf.
Melon-headed whales	*Peponocephala electra*	MFC	8–40 kHz	Common	Occur in water depths > 2,625 ft (800 m) and usually west of Mobile Bay, Alabama (Mullin et al. 1994, Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Pantropical spotted dolphins	*Stenella attenuatus*	MFC	0.1–160 kHz	Common	Found in coastal and oceanic waters from 40° S to 40° N (Perrin and Hohn 1994, Perrin and Gilpatrick 1994).

Species of interest		Hearing group	Estimated auditory bandwidth[1]	Area population status[2]	GoM habitat distribution
Common name	Latin binomial				
Pygmy killer whales	*Feresa attentuata*	MFC	70–85 kHz	Uncommon	Historic sightings of these animals in the northern GoM are in oceanic waters (Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Risso's dolphins	*Grampus griseus*	MFC	4–80 kHz	Common	Occur throughout oceanic waters of the northern GoM but are concentrated in areas near the continental slope (Baumgartner 1997, Maze-Foley and Mullin 2006).
Rough-toothed dolphins	*Steno bredanesis*	MFC	0.1–200 kHz	Common	Occur in oceanic, and to a lesser extent continental shelf, waters (Fulling et al. 2003, Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Short-finned pilot whales	*Globicephala macrorhyncus*	MFC	11–50 kHz	Common	Primarily on the continental slope, west of 89° W longitude (Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Sperm whales	*Physeter macrocephalus*	MFC	2.5–60 kHz	Common	Population surveys indicate that sperm whales are widely distributed during all seasons in continental slope and oceanic waters, particularly along and seaward of the 3,300 ft (1,000 m) isobath and within areas of steep depth gradients (NMFS Mullin et al. 1991, 1994, Hansen et al. 1996, Jefferson and Schiro 1997, Davis et al. 1998, Mullin and Hoggard 2000, Ortega Ortiz 2002, Fulling et al. 2003, Mullin and Fulling 2004, Mullin et al. 2004, Maze-Foley and Mullin 2006, Mullin 2007, Jefferson et al. 2008, 2009).
Spinner dolphins	*Stenella longirostris*	MFC	0.1–160 kHz	Common	Occur in coastal and oceanic waters from 40° S to 40° N (Perrin and Hohn 1994, Perrin and Gilpatrick 1994).
Striped dolphins	*Stenella coeruleoalba*	MFC	0.1–160 kHz	Common	Occur in coastal and oceanic waters from 40° S to 40° N (Perrin and Hohn 1994, Perrin and Gilpatrick 1994).
Kogia spp.[3]					
Dwarf sperm whales	*Kogia sima*	HFC	90–150 kHz	Uncommon	Sightings of these species in the northern GoM are primarily in oceanic waters (Mullin et al. 1991, Mullin and Fulling 2004, Maze-Foley and Mullin 2006).
Pygmy sperm whales	*Kogia breviceps*	HFC		Uncommon	

[1] Estimates of species auditory bandwidth are from many different sources included in the report bibliography

[2] Area population status in the GoM from Wursig et al. (2000). Categories: common–abundant wherever it occurs in the region; uncommon–may or may not be widely distributed but does not occur in large numbers; rare–present in such small numbers throughout the region that it is seldom seen

[3] Species are considered cryptic meaning they are seldom observed at the surface. These species are also difficult to classify from visual observation and are therefore often grouped when estimating population size.

2.5.1. Representative species

Because of the complexity associated with modeling thirty-two cetaceans, four survey types, seven zones, with and without aversion, representative species types were selected for modeling. Exposure results (number of animats exceeding thresholds) are expected to be similar for similarly behaving animals. As a practical measure, six representative species were chosen for full analysis: Bryde's whales, *Kogia spp,* bottlenose dolphins, short-finned pilot whales, sperm whales, and Cuvier's beaked whales. These species were chosen to represent different hearing groups, varying levels of behavioral sensitivity, and general diving patterns of marine mammals in the GOM. Bryde's whales and *Kogia spp* were chosen because they are, respectively, the only low-frequency and high-frequency marine mammals resident in the GOM. The remaining representatives are all mid-frequency species. Bottlenose dolphins in the estuarine stocks are a shallow-diving nearshore species. Short-finned pilot whales represent the relatively shallow diving small pelagic species. Sperm whales are large, deep-diving, and are the only endangered species in the GOM. Cuvier's beaked whales are deep diving and classified as behaviorally sensitive by Wood et al. (2012).

2.5.2. Animal densities

Simulations are run using a constant animat density that is typically much higher than the real-world animal density (see Appendix F). To get the number of real-world animals expected to exceed a threshold the number of animats exceeding the threshold must be scaled by the ratio of the simulation (animat) density and the real world (animal) density. Marine mammal densities used in modeling for the Draft and Final PEIS were from Duke MGEL's habitat-based model for the GoM (Roberts et al. 2016a). Densities for the representative species in each zone are listed in Appendix G. To test the effects of varying the real-world density input to exposure models IAGC/API provided alternate density values for comparison. The alternate density estimates for species in each zone and an explanation of their derivation are provided in Appendix H.

2.5.2.1. Evaluation time period

Animat exposure histories were processed to calculate the number of animats exposed to levels exceeding threshold (the number of exposures). For this analysis, seven-day simulations were run and the exposures estimated in 24 h windows within the seven days. The first 24 h window begins at the start of the simulation and each subsequent window is advanced by 4 h. In this sliding-windows approach, 42 exposure estimate samples are obtained for each seven-day simulation. The mean value is then used as the 24 h exposure estimate for that survey, as was done for the PEIS modeling.

3. Results

3.1. Estimated Sound Fields – 4130 in^3 airgun array

The 4130 in^3 airgun array is modeled (Appendix B) at the 30 sites described in Section 2.1 and Appendix B to determine the single-shot sound fields used in the model simulations. For assessment of potential injury the sound fields were weighted using the functions specified by the NMFS (2016) Technical Guidance, and for aversion and potential behavioral disruption the sound fields were weighted using Type 1 weighting (Southall et al. 2007) (see Appendix E for weighting functions).

3.1.1. Per-pulse peak SPL

To evaluate the risk of acoustic injury, the range to the unweighted, zero-to-peak SPL (dB re 1µPa) is used for the various hearing groups (LF: 219 dB re 1µPa, MF: 230 dB re 1µPa, and HF: 202 dB re 1µPa). The spherical spreading law:

$$L_{pk}(R) = L_{pkSL} - 20 \cdot \log(R) \quad ,$$

where L_{pkSL} is the peak SPL source level of the source and R is the range, was assumed as the propagation model for peak SPL. The ranges to the thresholds were calculated from the peak source level for the 4130 in^3 array and, for comparison, the 8000 in^3 array (Table 6) (see Section 6.3.1.1 of Appendix D in Volume II of the Draft PEIS (BOEM 2016) for details of the 8000 in^3 array).

Table 6. Ranges to hearing group peak SPL threshold.

Source	Source level (peak SPL; dB)	Range (m)		
		LF 219 dB peak SPL	MF 230 dB peak SPL	HF 202 dB peak SPL
4130 in^3 airgun array	247.9	28	8	197
8000 in^3 airgun array	255.2	65	18	457

3.1.2. Per-pulse SEL and SPL

The 3-D per-pulse acoustic fields used as inputs for acoustic exposure analysis were also processed to provide two other products:

- Maps of the acoustic field around the sources.
- Tables of ranges to various isopleths (radii tables) for each source.

The maps and radii tables are, respectively, 2-D and 1-D projections of the 3-D sound fields, which serve as quality assurance checkpoints to verify the acoustic modeling output and control the results of the exposure simulation. Maps were created from the 3-D grid of the acoustic pressure levels by taking the maximum-over-depth value at each horizontal sampling location. The maps therefore represent the maximum received acoustic level over all depths at each location.

The ranges to isopleths in the radii tables are provided as two statistical estimates:

- The maximum range (R_{max}, in meters)
- The 95% range ($R_{95\%}$, in meters)

Given a regularly gridded spatial distribution of sound levels, the $R_{95\%}$ for a given sound level is defined as the radius of the circle, centered on the source, encompassing 95% of the grid points with sound levels at or above the given value. This definition is meaningful in terms of potential effects on animals because, regardless of the shape of the contour for a given sound level, $R_{95\%}$ is the range from the source beyond which only 5% of a uniformly distributed population would be exposed to sounds at or above that level.

The R_{max} for a given sound level is the maximum distance at which the specified received level occurs (equivalent to $R_{100\%}$). It is more conservative than $R_{95\%}$, but could be relevant for defining exclusion zones to avoid any chance of exposures above the specified level. For cases where the volume ensonified to a specific level is discontinuous and small pockets of higher received levels occur beyond the main ensonified volume (e.g., due to convergence), the R_{max} can be much larger than $R_{95\%}$.

Example modeling results of the 4130 in^3 airgun array at site CM3, located in the Central-Slope zone at 750 m water depth, are presented below as maps of unweighted, per-pulse SEL, and SPL fields (Figure 7 to Figure 10). Site CM3 results are presented as example results because that site is centrally located within the Gulf. Maps appear similar as the maximum-over-depth metrics remove fine-scale variability, between the different metrics and seasons. To the south of the source, the maxium-over-depth isopleths of 139-130 dB (SEL) and 149-140 dB (SPL) extend to the modeled extent of 50 km. The corresponding radii tables for the site are shown in Tables 7 to 10 for Seasons 1 (January to March) and 3 (July to September) in SEL and SPL metrics with all applicable M-weighted filtering (see 4.6.Appendix E for auditory weighting functions). It is important to note that these tables show one example from the 30 sites that were modeled for this study, and that these ranges are not directly used in estimating animat exposure. Ranges at other sites could differ and it is the path through the sound field that determines the animat's exposure history. In the case of the SEL metric, even though no range for a single exposure exceeds the threshold, the integration of multiple lower-level exposure could still exceed threshold.

Table 7. 4130 in³ airgun array at Site CM3, Season 1 (February): Ranges to specific threshold levels (SEL).

SEL	Unweighted		Type III M-Weighting					
			LFC		MFC		HFC	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
210	< 10	< 10						
200	20	20	< 10	< 10				
190	70	60	20	20				
185	120	110	40	30				
183	150	130	60	50				
180	220	190	80	70				
170	740	650	270	220				
160	2700	2400	900	680				
155	7000	4400	2400	1200	< 10	< 10		
150	11000	9500	3900	3200	10	10	< 10	< 10
140	38000	30000	23000	13000	80	80	40	40
130	> 50000	48000	43000	28000	260	240	120	120
120		48000	> 50000	48000	820	780	410	390
110		48000		48000	4400	3000	1300	1200

Maximum (R_{max}, m) and 95% ($R_{95\%}$, m) horizontal distance from the source to modeled broadband maximum-over-depth sound level thresholds, with and without auditory frequency weighting applied for low-frequency cetaceans (LFC), mid-frequency cetaceans (MFC), and high-frequency cetaceans (HFC).
Units: rms SPL (dB re 1 µPa^2·s).

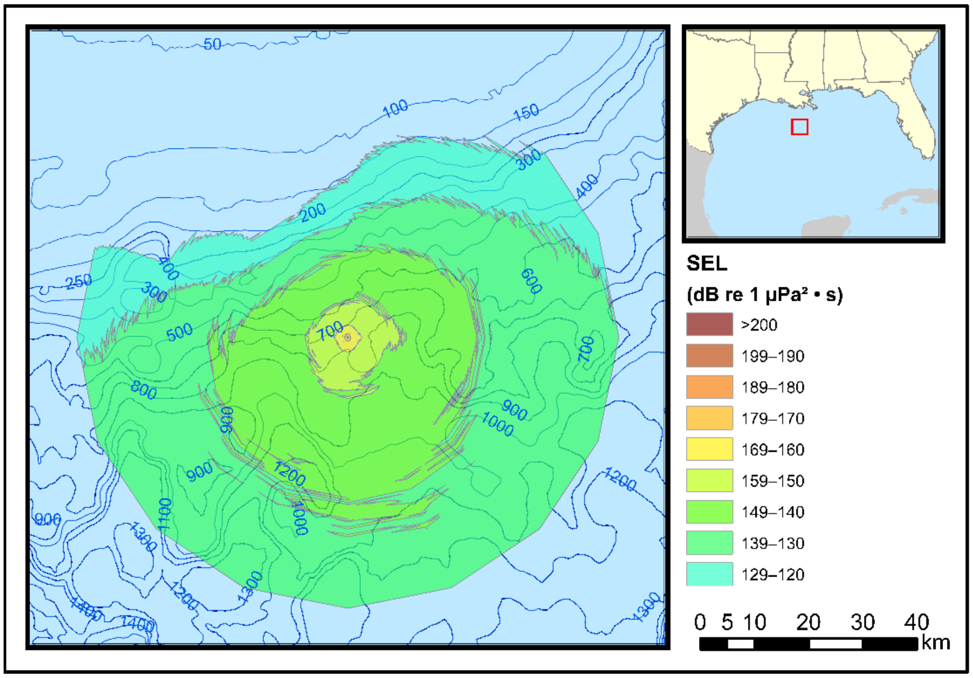

Figure 7. 4130 in³ airgun array at the Central-Slope region (Site CM3), Season 1 (February): Broadband (10–5,000 Hz) maximum-over-depth per-pulse SEL field. Blue contours indicate water depth in meters.

Table 8. 4130 in³ airgun array at Site CM3, Season 3 (September): Ranges to specific threshold levels (SEL).

SEL	Unweighted		Type III M-Weighting					
			LFC		MFC		HFC	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
210	< 10	< 10						
200	20	20	< 10	< 10				
190	70	60	20	20				
185	120	110	40	30				
183	150	130	60	50				
180	220	190	80	70				
170	730	650	260	210				
160	2700	2300	860	690				
155	6800	4200	2400	1300	< 10	< 10		
150	11000	9000	3700	3100	10	10	< 10	< 10
140	35000	29000	16000	13000	80	80	40	40
130	> 50000	47000	35000	26000	250	240	120	120
120		48000	> 50000	47000	860	820	390	360
110		48000		48000	8200	5800	1500	1300

Maximum (R_{max}, m) and 95% ($R_{95\%}$, m) horizontal distance from the source to modeled broadband maximum-over-depth sound level thresholds, with and without auditory frequency weighting applied for low-frequency cetaceans (LFC), mid-frequency cetaceans (MFC), and high-frequency cetaceans (HFC).
Units: rms SPL (dB re 1 $\mu Pa^2 \cdot s$).

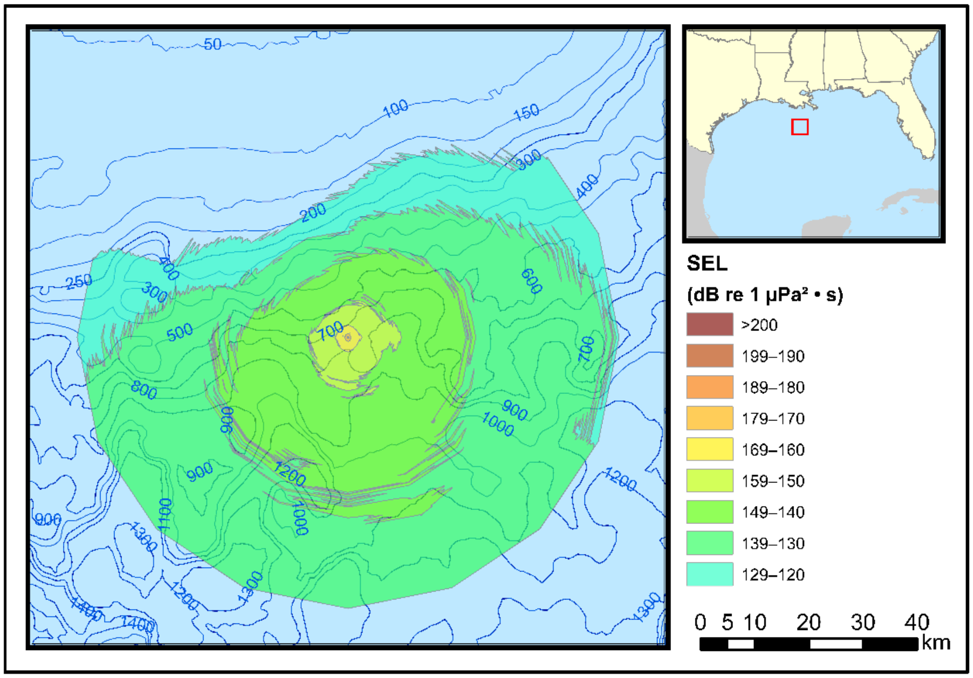

Figure 8. 4130 in³ airgun array at the Central-Slope region (Site CM3), Season 3 (September): Broadband (10–5,000 Hz) maximum-over-depth per-pulse SEL field. Blue contours indicate water depth in meters.

Table 9. 4130 in³ airgun array at Site CM3, Season 1 (February): Ranges to specific threshold levels (SPL).

rms SPL	Unweighted		Type I M-Weighting					
			LFC		MFC		HFC	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
210	20	20	20	20	< 10	< 10	< 10	< 10
200	80	70	70	60	20	20	10	10
190	240	220	230	210	70	60	60	50
180	830	620	720	570	260	210	190	150
170	2500	2200	2500	2000	770	610	600	470
160	11000	8400	11000	7800	3400	2900	2700	1100
150	34000	24000	31000	23000	14000	9100	11000	8500
140	> 50000	47000	> 50000	47000	27000	20000	26000	17000
130		48000		48000	> 50000	38000	48000	33000
120		48000		48000		48000	> 50000	48000
110		48000		48000		48000		48000

Maximum (R_{max}, m) and 95% ($R_{95\%}$, m) horizontal distance from the source to modeled broadband maximum-over-depth sound level thresholds, with and without auditory frequency weighting applied for low-frequency cetaceans (LFC), mid-frequency cetaceans (MFC), and high-frequency cetaceans (HFC). Units: rms SPL (dB re 1 µPa).

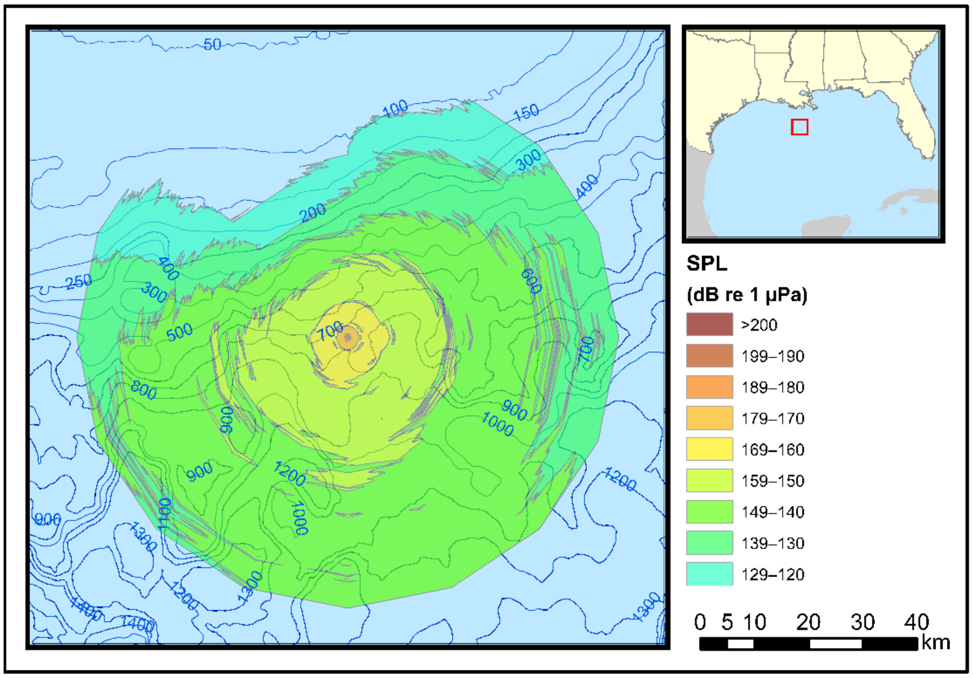

Figure 9. 4130 in³ airgun array at the Central-Slope region (Site CM3), Season 1 (February): Broadband (10–5,000 Hz) maximum-over-depth SPL field. Blue contours indicate water depth in meters.

Table 10. 4130 in³ airgun array at Site CM3, Season 3 (September): Ranges to specific threshold levels (SPL).

rms SPL	Unweighted		Type I M-Weighting					
			LFC		MFC		HFC	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
210	20	20	20	20	< 10	< 10	< 10	< 10
200	80	70	70	60	20	20	10	10
190	410	360	410	350	120	90	100	80
180	530	430	450	400	180	140	110	90
170	830	620	720	570	260	200	190	150
160	2500	2100	2500	2000	770	600	610	460
150	11000	7700	11000	7200	3300	2800	2800	1200
140	33000	23000	28000	21000	16000	9000	11000	8700
130	> 50000	46000	> 50000	46000	26000	19000	21000	16000
120		48000		48000	44000	36000	43000	31000
110		48000		48000	> 50000	48000	> 50000	48000

Maximum (R_{max}, m) and 95% ($R_{95\%}$, m) horizontal distance from the source to modeled broadband maximum-over-depth sound level thresholds, with and without auditory frequency weighting applied for low-frequency cetaceans (LFC), mid-frequency cetaceans (MFC), and high-frequency cetaceans (HFC). Units: rms SPL (dB re 1 µPa).

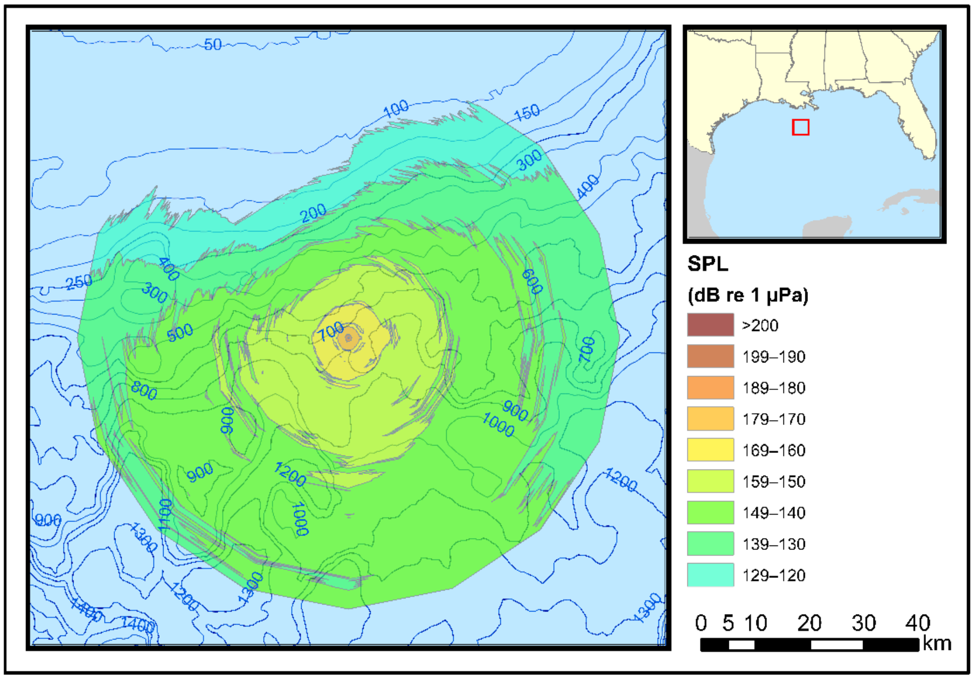

Figure 10. 4130 in³ airgun array at the Central-Slope region (Site CM3), Season 3 (September): Broadband (10–5,000 Hz) maximum-over-depth SPL field. Blue contours indicate water depth in meters.

3.2. 24-hour Exposure Estimates

Simulations were run with and without aversion. It is necessary to run separate simulations for aversion because the animats change their behavior as a function of received level in the model when aversion is included so have different trajectories (and exposure histories) than model runs where no reaction to a received level is included. Both with and without aversion, the number of animats exposed to levels exceeding the specified thresholds were determined in 24-h windows within the seven-day simulations. In a sliding-window approach, the first 24-h window begins at the start of the simulation and each subsequent window is advanced by 4 h, resulting in 42 samples for each survey. The number of individuals exposed to levels exceeding the injury and behavioral thresholds were calculated within each of the 24-h samples. SEL was determined by summing acoustic energy received from the source integrated over 24 h. Slant range was used to determine the zero-to-peak SPL for each animat relative to the source following the spherical spreading law (Section 3.1.1). The number of animats within the range (Table 6) where the received level could exceed threshold were found. The step function proposed by Wood et al. (2012) was used as a metric to evaluate potential behavioral response. The mean value from the 42 24-h estimates was used as the 24-hr exposure estimates for that survey.

Animals are only considered ‘taken’ once during a 24-hr period, and animats are not removed or replaced based on exceeding a threshold. The 24-hr reset was stipulated by BOEM and serves as a recovery mechanism and as a time basis on which survey effort could be based. When scaling up from 24 hours to longer surveys, e.g. 30 days, there is some repeated counting compared to analysis of longer-duration simulations. Overestimate by scaling occurs for single-exposure, SPL-based metrics, and is likely for SEL-based metrics as well. For SEL, the 24 hour duration limits the accumulation of energy but allows for multiple counting of an individual that exceeds threshold on multiple separate days. A fuller evaluation of this issue can be found in the DPEIS (Test Case 1 - Appendix D Section 6.5.1).

To get the real-world individual exposure estimates, the 24-h mean animat exposure estimates were scaled using the mean real-world density estimate in each zone. Two density estimates were used for scaling each representative species: (1) the Duke MGEL model used in the PEIS (Roberts et al. 2016a) (Section 2.5.1, and Tables 1–7) and (2) alternate density estimates supplied by IAGC/API for this study (Appendix H).

3.3. Annual Decade Individual Exposure Estimates

For comparison with exposure estimates from the Draft and Final PEIS, the output of this analysis are estimates of the number of exposures for each species for each year for the entire Gulf using the same methods as the PEIS with selected alternate modeling parameters (seismic array volume, behavioral aversion, alternate densities, and mitigation). Projections of survey level of effort for the different survey types for the Gulf Planning Areas (Eastern, Central, and Western; divided into shallow and deep zones) were the same as those used in the PEIS modeling and were provided by BOEM (Appendix I). Our modeling zones and survey locations were chosen, in part, to coincide with BOEM’s Planning Areas so that the survey projections could be easily used for scaling. The shallow portion of the east, central, and western Planning Areas were the same as our modeling zones 1–3. A portion of each of the deep parts of Planning Areas maps directly to our modeling zones 4–6. The remainder of the deep parts of the Planning Areas were combined as modeling zone 7. The 24-h exposure estimates were scaled by the projected number of survey days to get the annual aggregate exposure estimates. The annual individual estimates using the alternate modeling parameters for each survey type (summed for all zones) are shown in Appendix J with estimates for the two density estimates (PEIS and Alternate), both with and without behavioral aversion. Similarly, the annual individual aggregate estimates (summed for all survey types and zones) are shown in Appendix K with estimates for the two density estimates (PEIS and Alternate), with and without behavioral aversion. The decade aggregate estimates are shown in Tables 11–14.

Table 11. Individual exposure estimates over a decade for all surveys (using 4130 in^3 array volume) and zones using the PEIS densities without aversion.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	1	0	621579
Bottlenose dolphins	436	0	4647116
Bryde's whales	9	62	4103
Kogia spp.	13956	0	60986
Short-finned pilot whales	0	0	72297
Sperm whales	8	0	125607

Table 12. Individual exposure estimates over a decade for all surveys (using 4130 in^3 array volume) and zones using the PEIS densities with aversion.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	574580
Bottlenose dolphins	73	0	4542106
Bryde's whales	7	57	4061
Kogia spp.	8221	8	64238
Short-finned pilot whales	1	0	76184
Sperm whales	7	0	120018

Table 13. Individual exposure estimates over a decade for all surveys (using 4130 in^3 array volume) and zones using alternate densities without aversion.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	310261
Bottlenose dolphins	432	0	4605021
Bryde's whales	2	11	715
Kogia spp.	6963	0	30427
Short-finned pilot whales	0	0	65186
Sperm whales	4	0	62556

Table 14. Individual exposure estimates over a decade for all surveys (using 4130 in^3 array volume) and zones using alternate densities and with aversion.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	286795
Bottlenose dolphins	73	0	4500962
Bryde's whales	1	10	708
Kogia spp.	4102	4	32050
Short-finned pilot whales	1	0	68328
Sperm whales	3	0	59772

4. Discussion

Exposure estimates for the Draft PEIS were generated by JASCO using SPL criteria with thresholds of 180 dB for potential injury and 160 dB potential behavioral disruption. These thresholds applied to all marine mammals and do not take into account the different hearing ranges of the animals. NOAA released technical guidance (NMFS 2016) for evaluating potential injury due to acoustic exposure after the Draft PEIS was completed. The exposure estimates for potential injury were then updated for NOAA by JASCO using the Technical Guidance for the Final PEIS. Exposure estimates from both the Draft PEIS and Final PEIS are shown here as baseline values (columns 1 and 2 in Tables 15-17) to evaluate the effects of alternate parameter choices on exposure estimates. The parameters investigated (including the use of the NOAA Technical Guidance) were airgun array volume, behavioral aversion, and marine mammal density estimates. Summarized comparisons of the effect alternate parameter choices have on exposure estimates are shown in this section in Tables 15-17.

Table 15. Number individual animals estimated to exceed peak SPL threshold over a decade for all surveys and zones (rounded to nearest integer). The Draft PEIS used 180 dB rms SPL as the threshold for injury, the Final PEIS uses NOAA’s Technical Guidance (NMFS 2016).

Species	PEIS		4130 in^3 array, NMFS 2016			
	8000 in^3, no aversion, PEIS densities		PEIS densities		Alternate densities	
	180 dB SPL	NMFS 2016	No aversion	Aversion	No aversion	Aversion
Cuvier’s beaked whales	51655	425	1	0	0	0
Bottlenose dolphins	2743723	22841	436	73	432	73
Bryde’s whales	589	32	9	7	2	1
Kogia spp.	30620	29171	13956	8221	6963	4102
Short-finned pilot whales	25182	506	0	1	0	1
Sperm whales	81239	350	8	7	4	3

Table 16. Number individual animals estimated to exceed SEL threshold over a decade for all surveys and zones (rounded to nearest integer). The Draft PEIS used 180 dB rms SPL as the threshold for injury, the Final PEIS uses NOAA’s Technical Guidance (NMFS 2016).

Species	PEIS		4130 in^3 array, NMFS 2016			
	8000 in^3, no aversion, PEIS densities		PEIS densities		Alternate densities	
	180 dB SPL	NMFS 2016	No aversion	Aversion	No aversion	Aversion
Cuvier’s beaked whales	51655	1	0	0	0	0
Bottlenose dolphins	2743723	95	0	0	0	0
Bryde’s whales	589	152	62	57	11	10
Kogia spp.	30620	108	0	8	0	4
Short-finned pilot whales	25182	0	0	0	0	0
Sperm whales	81239	0	0	0	0	0

Table 17. Number individual animals estimated to exceed behavioral threshold over a decade for all surveys and zones using (rounded to nearest integer). The Draft and Final PEIS both use 160 dB rms SPL as the threshold for behavioral disruption.

Species	PEIS		4130 in^3 array, Step function (Wood et al. 2012)			
	8000 in^3, no aversion, PEIS densities		PEIS densities		Alternate densities	
	160 dB SPL	Step function*	No aversion	Aversion	No aversion	Aversion
Cuvier's beaked whales	440986	1809109	621579	574580	310261	286795
Bottlenose dolphins	10433991	7860889	4647116	4542106	4605021	4500962
Bryde's whales	6487	5493	4103	4061	715	708
Kogia spp.	275816	127150	60986	64238	30427	32050
Short-finned pilot whales	282759	141502	72297	76184	65186	68328
Sperm whales	680502	322020	125607	120018	62556	59772

* The Draft and Final PEIS did not use the Wood et al. (2012) step function to evaluate potential behavioral disruption but the values were calculated during the modeling and are shown here to aid in comparison.

4.1. NOAA Technical Guidance for injury

For most species, adoption of NOAA's Technical Guidance (NMFS 2016) for evaluating potential injury from acoustic exposure results in a substantial reduction of injurious exposure estimates relative to the Draft PEIS (column one of Table 15 and Table 16). The Technical Guidance uses different metrics (peak SPL and SEL) than the previous criteria (rms SPL) and divides the animals into hearing groups with different threshold levels. With the peak SPL metric, mid-frequency species (beaked whales, bottlenose dolphins, short-finned pilot whales, and sperm whales) have the highest thresholds (230 dB peak SPL re 1 µPa) and the greatest reduction in estimated injurious exposure relative to the previous criteria (column two versus column one in Table 15). The threshold level for low-frequency species (Bryde's whale, 219 dB peak SPL re 1 µPa) is less than the mid-frequency species and the resulting reduction in estimated injurious exposures is less than the mid-frequency species. High-frequency species (*Kogia spp*.) have the lowest thresholds (202 dB peak SPL re 1 µPa) and little reduction in estimated injurious exposure numbers (Table 15) relative to the Draft PEIS. For the SEL metric, the sound fields are weighted for the different hearing groups and each group also has a different threshold level. Most of the acoustic energy emitted by airguns is < 500 Hz, so the auditory (frequency) weighting functions, especially for the mid- and high-frequency species, discount much of the energy. Again, the mid-frequency animals have the highest thresholds and the greatest decrease in exposure estimates (column two versus column one in Table 16). High-frequency species have the lowest thresholds and least reduction, and low-frequency species are in between (Table 16).

4.2. Seismic Sound Source Array Volume

The maximum broadband, far-field, peak source level for the 4130 in^3 array is about 7 dB less than the 8000 in^3 array, and the ranges to the injury threshold for peak SPL are about ½ of those for the 8000 in^3 array (Table 6). The expected reduction in estimated injury due to exceeding peak SPL threshold is ~8 times because the ensonified volume above threshold is reduced in proportion to the cube of the range ($2^3 = 8$). The reductions found are more than a factor of 8 for mid-frequency species but less for low- and mid-frequency species (column 2 divided by column 3 in Table 15). There are a few factors that could explain differences in the expected reduction rates and the observed reduction rates:

1. Exceedance is rare and the summaries across the zones and surveys for a decade can amplify small differences and uncertainty. Simulations where only 0, 1, or 2 animats exceed threshold have less statistical power and more uncertainty than when hundreds or thousands of animats exceed threshold

providing a better mean estimate of exceedance probability -- for example, the difference in behavioral threshold exceedance is more consistently ~1/2 when comparing the use of the 4130 in^3 array to the 8000 in^3 array (column 3 divided by column 2 in Table 17).

2. The sound field modeling resolution is in increments of 5 and 10 meters near the source, which is similar to the range to threshold for mid-frequency animals. This granularity contributes to the noise with few samples.
3. Other factors such as counting only the maximum exposure for each animat and the movement of sources and animats could also contribute to differences between expected and observed outcomes.

For the SEL metric it is difficult to estimate an a priori reduction rate because the acoustic energy is integrated. With the exception of low-frequency Bryde's whales, there are essentially no exceedances of the SEL threshold when using the smaller array (Table 16), and few or none when the larger array is used. Limited examples and granularity remain contributing factors when comparing the effects of array size, but because SEL is so rare and is less than peak SPL, SEL is proving not to be the primary consideration when evaluating the potential injurious impacts of these surveys for most species.

As mentioned above, the number of exposures above behavioral threshold is reduced to ~1/2 for the 4130 in^3 array versus the 8000 in^3 array. The ensonified volume above behavioral threshold is much larger than for injury and there are many samples above threshold. While the factor of ½ is relatively consistent, it should not necessarily be generalized. The number of animats above threshold depends on many factors from sound propagation to animal movement. Very roughly, sound levels decrease logarithmically with distance so all other factors being equal, increasing the source level by 6 dB more than doubles the volume of the ensonified area when no boundaries are present. Depth limitations (boundaries) can limit the increase in the ensonified volume (e.g., depth may be 2 km but the range to a threshold level may be > 40 km), and similarly, animals tend to sample from a limited depth range (e.g., shallow divers may only sample a relatively small portion of the water column).

4.3. Aversion

Animals may avoid loud sounds (F.1.4), and this aversion does appear to decrease the estimated number of injurious exposures (columns 4 and 6 versus columns 3 and 5 in Tables 15 and 16). Because the predicted number of animals exceeding injury thresholds (peak SPL and SEL) are already low, it is difficult to generalize about the effects of aversion on exposure rates. The same factors regarding limited number of samples and granularity (Section 4.2) apply but are compounded by our lack of knowledge in modeling aversive behaviors. For example, injury due to peak SPL exposure in *Kogia spp*. is decreased but the SEL exposure increases. It is noted that the number of peak SPL exceedances is much greater than the number of SEL exceedances, and that the increase in SEL exposures could represent a rare event with a small number of samples. It also suggests a lack of understanding in implementing aversion and highlights the potential for non-intuitive results. In this case animals may turn away from the source and receive a lower maximum exposure level but remain near the source and accumulate greater SEL. Aversive behavior, as implemented, could increase exposure because animats are programmed to ignore the received level for a short period of time and move away from the source. Because animats and sources are moving, ignoring the received level may allow the animats to remain near a source longer than if they had maintained their normal behavior. We do not know if this would occur in the real animals or not, but it is not entirely unrealistic given the natural variability in animal behaviors.

We used the step function proposed by Wood et al. (2012) to implement aversion. The step function was also used to gauge behavioral disruption, so aversion in this case is by definition a behavioral disruption, but as seen in Table 17 the number of behavioral disruptions decrease somewhat with aversion. This result occurs because the step function probability of disruption is graded. 10% of the animats receiving 140-160 dB SPL (all species except beaked whales) are counted as disruption, while 50% for 160-180 dB SPL, and 90% above 180 dB SPL are counted. An animat that receives 140-160 dB SPL and averts to avoid a higher level exposure contributes less to the overall behavioral disruption estimation.

4.4. Alternate Densities

Determining the effects of using different real-world animal density estimates on exposure calculations is straightforward compared to evaluating the effects of other variables. Real-world densities are used to scale the simulation results to obtain the number of real-world individual animals expected to exceed the thresholds. Scaling is done after the simulation and is linear — doubling the density estimate doubles the number of individuals estimated to exceed threshold. The density estimates from the PEIS and the alternate densities provided by IAGC are similar for bottlenose dolphins; IAGC used density estimates from CETMAP for Bryde's whales (~5.8 times lower than the PEIS density estimates). The densities of the rest of the representative species were halved in the IAGC parametrization relative to the PEIS density estimates. A reduction in exposure estimates by these ratios is evident in Tables 15–17 (by comparing column 3 to column 5, and column 4 to column 6).

4.5. Mitigation

In the modeling for the Draft PEIS, a study was undertaken to better understand how mitigation by shutting down the sound source when a protected species enters an exclusion zone of 500 m radius around the source, affects the number of predicted animals exceeding threshold (Section 6.5.3 of Appendix D in Volume II of the Draft PEIS (BOEM 2016). It was shown that detection probability is a primary factor in predicting mitigation effectiveness because shutdowns only occur when the animals are detected. However, detection probability depends on many factors. It is species and weather dependent, and also depends on the skill and equipment of the observer or observing system. Weather is unknown during planning phases and the detection probability varies greatly among species – sperm whales are relatively easy to detect while smaller while cryptic species such as beaked whales are much more difficult to detect. In the modeling study for the Draft PEIS, JASCO evaluated a range of detection probabilities for the same representative species. While a number of factors may contribute to effectiveness, a rough but reasonable summary is that mitigation effectiveness is approximated by the detection probability. That is, if 50% of the animals entering the exclusion zone are detected, then the number of animals exceeding injury threshold is reduced by up to one half. Mitigation effectiveness is roughly predicted by detection probability because exceeding injury threshold in these surveys is usually the result of receiving a small number of pulses close to the source rather than accumulation of energy over longer time period and area. This observation, however, depends on the source, survey design, size of exclusion zone, and is also influenced by the hearing group. Detection probability ranges explored in the Draft PEIS were: beaked whales and *Kogia spp*. 5 – 45%, and bottlenose, short-finned pilot whales, and sperm whales 50-90%, so a reduction in potential injury by up to these detection probabilities could be expected. Tables 18 and 19 respectively shows the peak SPL and SEL decade-long injury that might be expected when shut down is used as a mitigation procedure when an animal is detected within an exclusion zone of 500 m.

Table 18. Number individual animals estimated to exceed peak SPL threshold over a decade for all surveys and zones (rounded to nearest integer), with and without mitigation procedures.

Species	Probability detection range (%)	4130 in^3 array, NMFS 2016, Alternate densities, Aversion			
		Mitigation			
		No Mitigation	low	mid	high
Cuvier's beaked whales	5-45	0	0	0	0
Bottlenose dolphins	50-90	73	33	22	11
Bryde's whales	50-90	1	0	0	0
Kogia spp.	5-45	4102	3692	3077	2461
Short-finned pilot whales	50-90	1	0	0	0
Sperm whales	50-90	3	1	1	0

Table 19. Number individual animals estimated to exceed SEL threshold over a decade for all surveys and zones (rounded to nearest integer), with and without mitigation procedures.

Species	Probability detection range (%)	4130 in^3 array, NMFS 2016, Alternate densities, Aversion			
		Mitigation			
		No Mitigation	Low	Mid	High
Cuvier's beaked whales	5-45	0	0	0	0
Bottlenose dolphins	50-90	0	0	0	0
Bryde's whales	50-90	10	5	3	1
Kogia spp.	5-45	4	4	3	2
Short-finned pilot whales	50-90	0	0	0	0
Sperm whales	50-90	0	0	0	0

4.6. Conclusions

For most species, the greatest reduction in injurious exposure estimates relative to the Draft PEIS - but not the Final PEIS - arise from the implementation of NOAA's Technical Guidance that was released in 2016 (NMFS 2016). Exceptions to this conclusion are high-frequency species whose predicted injury rates remain about the same. The Technical Guidance uses different acoustic metrics (peak SPL and SEL), divides the species into hearing groups with different thresholds, and weights the sound field in accordance with the hearing group for the SEL metric. The Technical Guidance was not released at the time the Draft PEIS was completed (2015), but injurious exposure estimates have since been recalculated for NOAA using the Technical Guidance and will be included in the Final PEIS. While baseline values included here are from both the Draft PEIS using the previous criteria and from the final PEIS using the Technical Guidance, it is important to note that this is for completeness in comparison only. The Final PEIS with significantly decreased estimates of injurious exposure is the best baseline to use in determining the relative influence of model parameters, the stated objective of this study.

New official guidance is not available for estimating potential behavioral disruption, but a step function proposed by Wood et al. (2012) is frequently used in project-specific exposure modeling completed for Environmental Assessments. The step function is a graded probability of response and uses frequency-weighted sound fields to account for hearing ranges of different species. While neither the Draft or Final PEIS use the step function, behavioral disruption for the modeled data from the Draft and Final PEIS was evaluated using the step function for comparison purposes. With the exception of behaviorally sensitive species, such as beaked whales, a reduction in the predicted number of behavioral disruptions was found but not to the same degree as the reduction in injurious exposures when the Technical Guidance is used. For the behaviorally-sensitive beaked whales, behavioral disruption exposures estimates increase using the Wood et al. (2012) step function relative to the unweighted 160 dB rms threshold (HESS 1999).

The parameter changes studied, namely reduction in array volume, inclusion of aversion, and use of alternate densities, reduced injurious and behavioral exposure estimates for all species to varying extents. Combining all parameters results in a cumulative reduction in exposure numbers. Use of a smaller airgun array volume with lower source level creates a smaller ensonified area resulting in fewer numbers of animals expected to exceed a given threshold. Having animals avoid loud sounds (aversion) appears to reduce the number of injurious exposures, though the magnitude of the effect was variable. This variability is likely because, when using the Technical Guidance to assess potential injury, there are few samples of injurious exposure exceedance so the statistical variability of re-running simulations is evident.

Mitigation effectiveness was assessed in the modeling for the Draft PEIS. In this study, the probability of detection rates included in the Draft PEIS were used to assess the influence of this parameter on estimates of injurious exposures. The large range in detection probability reflects the uncertainty associated with this parameter, as not only weather conditions, but also observer experience and height of observation platform can affect detections. Mitigation measures are expected to reduce the potential for injury roughly in proportion to the detection rate. This is observed in the calculations for species that are more easily detected, such as bottlenose dolphins. For cryptic species such as *Kogia spp*. and beaked whales, mitigation parameters have less influence on estimates of injurious exposures relative to other parameters such as frequency weighting and densities.

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Appendix A. Sound Metrics Used in Modeling

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_o = 1 µPa. Because the loudness of impulsive (pulsed) sounds, e.g., shots from seismic source arrays, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate the loudness of impulsive sound and its effects on marine life.

The zero-to-peak sound pressure level (SPL), or peak SPL (L_{pk}, dB re 1 µPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an impulse, $p(t)$:

$$L_{\mathrm{pk}} = 10\log_{10}\left[\frac{\max\left(\left|p^2(t)\right|\right)}{p_{\mathrm{o}}^2}\right] \tag{A-1}$$

The peak-to-peak SPL ($L_{pk\text{-}pk}$, dB re 1 µPa) is the difference between the maximum and minimum instantaneous sound pressure level in a stated frequency band attained by an impulse, $p(t)$:

$$L_{\mathrm{pk-pk}} = 10\log_{10}\left\{\frac{\left[\max\left(p(t)\right) - \min\left(p(t)\right)\right]^2}{p_{\mathrm{o}}^2}\right\} \tag{A-2}$$

The root-mean square (rms) SPL (L_p, dB re 1 µPa) is the rms pressure level in a stated frequency band over a time window (T, s) containing the pulse:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \bigg/ p_{\mathrm{o}}^2\right) \tag{A-3}$$

The rms SPL can be thought of as a measure of the average pressure or as the “effective” pressure over the duration of an acoustic event, such as the emission of one acoustic pulse. Because the window length, T, is a divisor, pulses more spread out in time have a lower rms SPL for the same total acoustic energy.

By convention, when computing airgun safety radii, T is defined as the “90% energy pulse duration”, containing the central 90% (from 5% to 95% of the total) of the cumulative square pressure (or energy) of the pulse, rather than over a fixed time window (Malme et al. 1983, Greene 1997, McCauley et al. 1998a, McCauley et al. 1998b). The 90% rms SPL (L_{p90}, dB re 1 µPa) in a stated frequency band is calculated over this 90% energy time window, T_{90}:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)dt \bigg/ p_{\mathrm{o}}^2\right) \tag{A-4}$$

The sound exposure level (SEL) (L_E, dB re 1 µPa^2·s) is the time integral of the squared pressure in a stated frequency band over a stated time interval or event. The per-pulse SEL is calculated over the time window containing the entire pulse (i.e., 100% of the acoustic energy), T_{100}:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)dt \bigg/ T_{\mathrm{o}}\, p_{\mathrm{o}}^2\right) \tag{A-5}$$

where T_o is a reference time interval of 1 s. The per-pulse SEL, with units of dB re 1 µPa·√s, or equivalently dB re 1 µPa^2·s, represents the total acoustic energy delivered over the duration of the acoustic event at a receiver location. It is a measure of sound energy (or exposure) rather than sound pressure although it is not measured in energy units.

SEL is a cumulative metric that is calculated over a specified time period that may contain multiple pulses. SEL can be computed by summing (in linear units) the SELs of the *N* individual pulses (L_{Ei}).

$$L_{E\mathrm{c}} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}}\right) \tag{A-6}$$

The cumulative SEL, with units of dB re 1 µPa·√s, or equivalently dB re 1 µPa²·s, represents the total acoustic energy delivered over the duration of the set period of time, i.e., 24 h. It is a representation of the accumulated sound energy (or exposure) delivered by multiple acoustic events.

Because the rms SPL and SEL are both computed from the integral of square pressure, these metrics are related by a simple expression, which depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{p90} + 10\log_{10}\left(T_{90}\right) + 0.458 \tag{A-7}$$

where the 0.458 dB factor accounts for the rms SPL containing 90% of the total energy from the per-pulse SEL.

Appendix B. Source and Propagation Modeling

B.1. Acoustic Source Model

B.1.1. 4130 in^3 seismic source array

The source levels and directivity of the 4130 in^3 seismic source array were predicted with JASCO's Airgun Array Source Model (AASM, MacGillivray 2006). This model is based on the physics of oscillation and radiation of airgun bubbles described by Ziolkowski (1970). The model solves the set of parallel differential equations governing bubble oscillations. AASM also accounts for nonlinear pressure interactions among array elements, port throttling, bubble damping, and generator-injector (GI) gun behavior that are discussed by Dragoset (1984), Laws et al. (1990), and Landro (1992). AASM includes four empirical parameters that are tuned so model output matches observed airgun behavior. The model parameters fit to a large library of empirical airgun data using a "simulated annealing" global optimization algorithm. AASM produces a set of "notional" signatures for each array element based on:

- Array layout;
- Volume, tow depth, and firing pressure of each element; and
- Interactions between different elements in the array.

These notional signatures are the pressure waveforms of the individual elements at a standard reference distance of 1 m, and they account for the interactions with the other elements in the array. The signatures are summed with the appropriate phase delays to obtain the far-field source signature of the entire array in all directions. This far-field array signature is filtered into 1/3-octave passbands to compute the source levels (SLs) of the array as a function of frequency band and azimuthal angle in the horizontal plane (at the source depth). It can then be treated as a directional point source in the far field.

A seismic array consists of many sources and the point-source assumption is not valid in the near field where the array elements add incoherently. The maximum extent of the near field of an array (R_{nf}) is:

$$R_{nf} < \frac{l^2}{4\lambda} , \tag{B-1}$$

where λ is the sound wavelength and l is the longest dimension of the array (Lurton 2002, §5.2.4). For example, using equation C-1, an array length of l = 16 m yields a near-field range of 85 m at 2 kHz and 17 m at 100 Hz. Beyond this R_{nf} range, the array is assumed to radiate like a directional point source and is treated as such for propagation modeling.

The interactions between individual elements of the array create directionality in the overall acoustic emission. Generally, this directionality is prominent mainly at frequencies in the mid-range of several tens to several hundred hertz; at lower frequencies, with acoustic wavelengths much larger than the inter-array separation distances, directivity is small. At higher frequencies, the pattern of lobes is too finely spaced to be resolved and the effective directivity is less.

AASM was used to compute the pressure signatures of the individual source array elements and the composite 1/3-octave-band source levels of the array, as functions of azimuthal angle (in the horizontal plane). While effects of source depth on bubble interactions are accounted for in the AASM source model, the surface-reflected signal (i.e., surface ghost) is not included in the far-field source signatures. The surface reflections, a property of the medium rather than the source, are accounted for by the acoustic propagation models. In this study, the source levels for a 4130 in^3 element array acted as the acoustic source for the MONM sound propagation models.

The horizontal overpressure signatures and corresponding power spectrum levels for the 4130 in^3 element array, at a depth of 8 m (to the vertical center of the element clusters), are shown in Figure B-1 and Table B-1 for the broadside (perpendicular to the tow direction) and endfire (parallel to the tow direction) directions. The signatures consist of a strong primary peak related to the initial firing of the source, followed by a series of pulses associated with bubble oscillations. Most energy is produced at frequencies below 250 Hz (Figure B-2). The spectrum contains peaks and nulls resulting from interference among array elements, where the frequencies at which they occur depend on the volumes of each element and their locations within the array. The maximum (horizontal) 1/3-octave-band sound levels over all directions are plotted in Figure B-2. The horizontal 1/3-octave-band directivities are shown in Figure B-3.

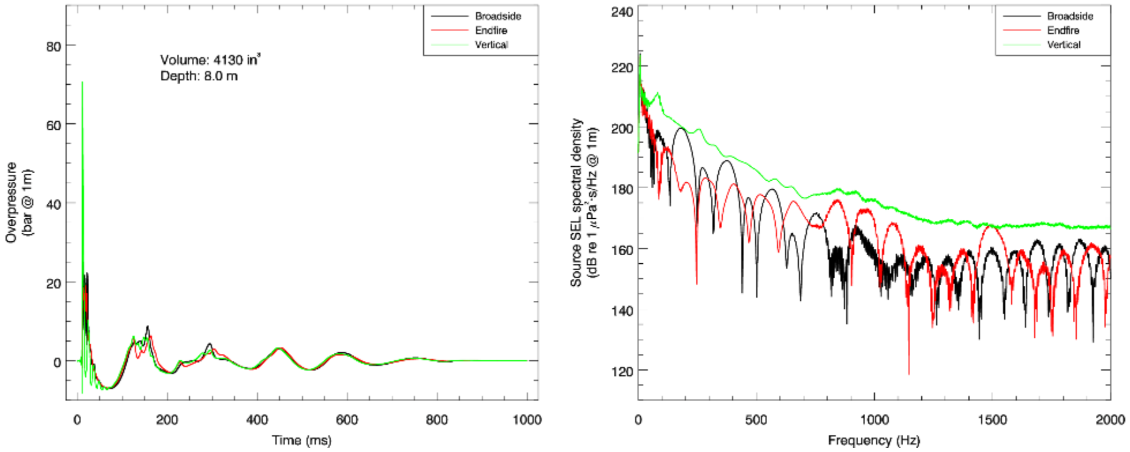

Figure B-1. The 4130 in^3 array: Predicted (a) overpressure signature and (b) power spectrum in the broadside, endfire, and vertical directions. Surface ghosts (effects of the pulse reflection at the water surface) are not included in these signatures as they are accounted for by the MONM propagation model.

Table B-1. Horizontal source level specifications (10–5000 Hz) for the 4130 in^3 seismic airgun array at 8 m depth, computed with AASM in the broadside and endfire directions. Surface ghost effects are not included as they are accounted for by the MONM propagation model.

Direction	Zero-to-peak SPL (dB re 1 µPa @ 1 m)	SEL (0.01–5 kHz) (dB re 1 µPa^2 @ 1 m)
Broadside	247.9	228.9
Endfire	245.6	228.2

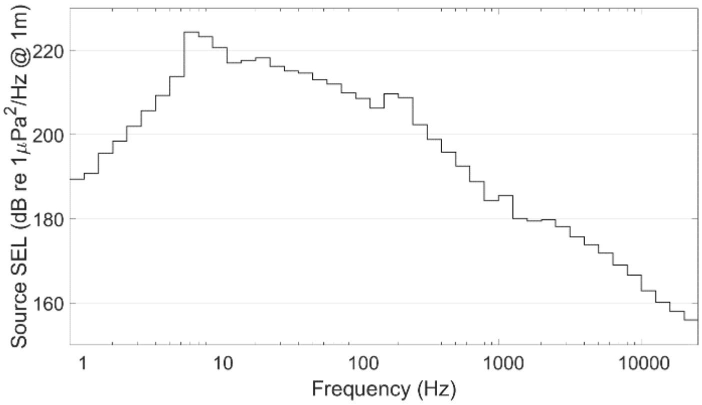

Figure B-2. Maximum directional source level (SL) in the horizontal plane, in each 1/3-octave-band, for the 4130 in^3 airgun array (1–25,000 Hz).

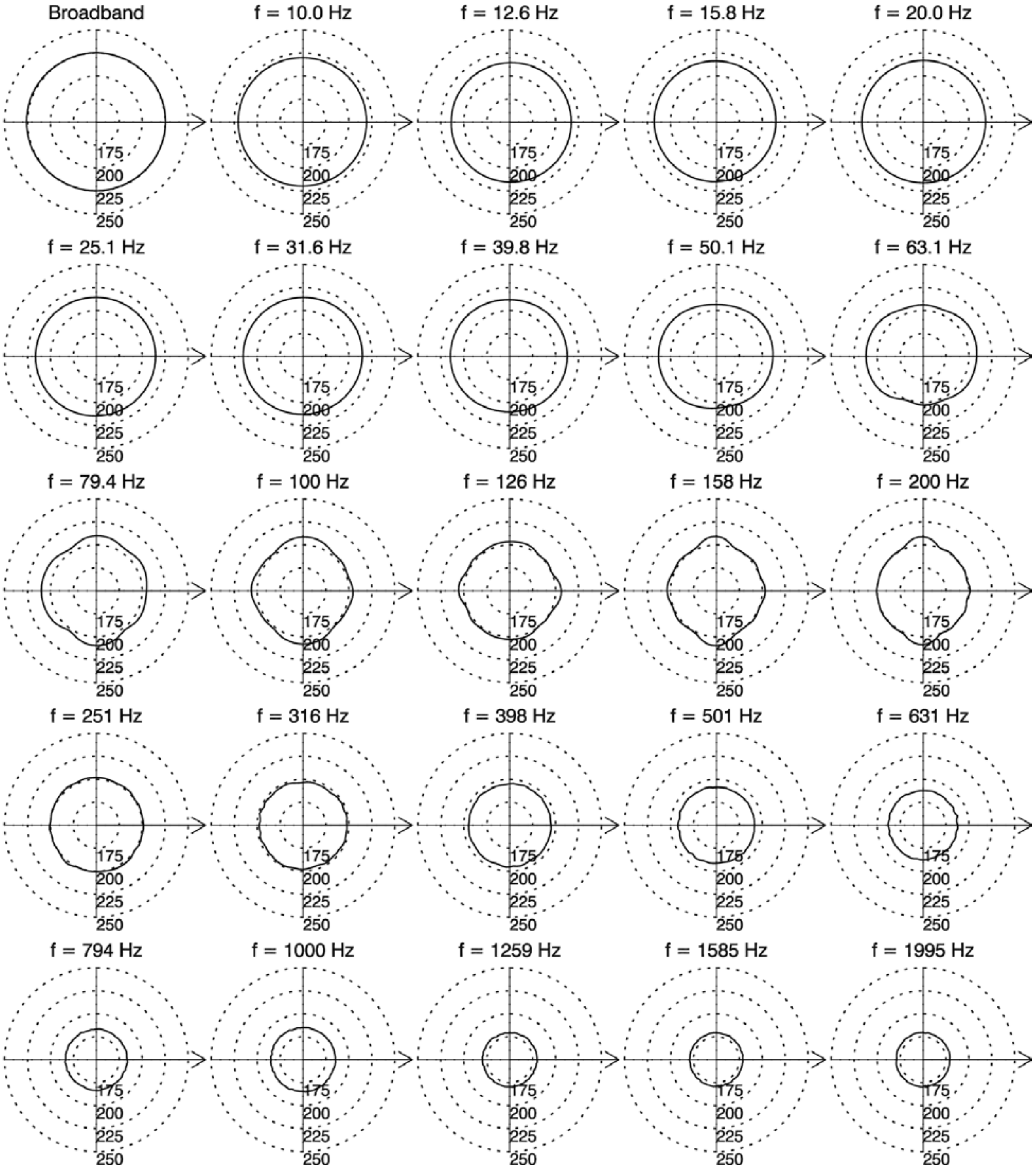
Broadband
f = 10.0 Hz
f = 12.6 Hz
f = 15.8 Hz
f = 20.0 Hz
f = 25.1 Hz
f = 31.6 Hz
f = 39.8 Hz
f = 50.1 Hz
f = 63.1 Hz
f = 79.4 Hz
f = 100 Hz
f = 126 Hz
f = 158 Hz
f = 200 Hz
f = 251 Hz
f = 316 Hz
f = 398 Hz
f = 501 Hz
f = 631 Hz
f = 794 Hz
f = 1000 Hz
f = 1259 Hz
f = 1585 Hz
f = 1995 Hz

Figure B-3. Horizontal directivity of the 4130 in^3 array. Source levels (SLs, dB re 1 µPa^2·s) in 1/3-octave-bands. The 1/3-octave-band center frequencies are indicated above each plot.

Appendix C. Acoustic Propagation Modeling

C.1. Marine Operations Noise Model (MONM)

Underwater sound propagation (i.e., transmission loss) at frequencies below 4 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). This model computes received sound levels at specified depths. MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a modeled area bathymetric grid, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

The accuracy of MONM's predictions have been validated against experimental data from numerous sound source verification programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010). An inherent variability in measured sound levels is caused by temporal variability in the environment and the variability in the signature of repeated acoustic impulses (sample sound source verification results are presented in Figure C-1.

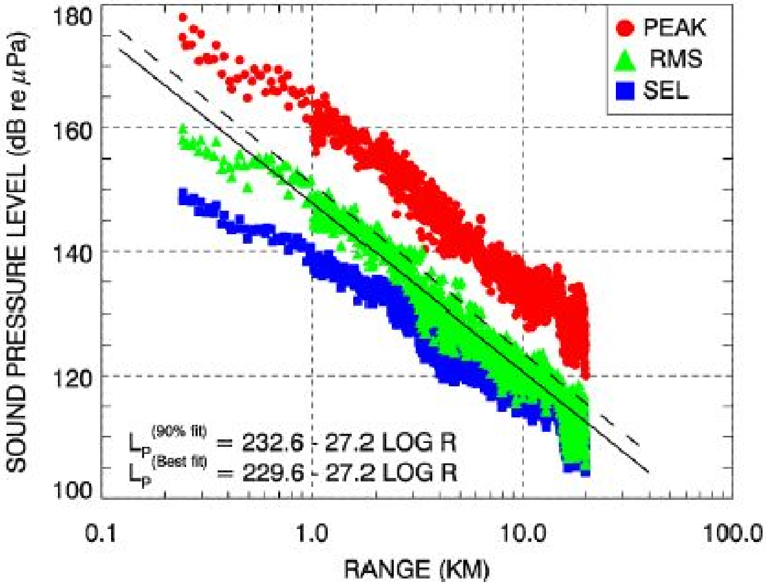

Figure C-1. Field measurements of peak and root-mean-square (rms) sound pressure level (SPL) and sound exposure level (SEL) versus range from a 20 in^3 airgun array. Solid line is the least squares best fit to rms SPL (Ireland et al. 2009).

A model validation assessment was performed between the original modeling study and the SIT measurements. The comparison revealed that the short-range model results exceeded measurements, but at longer distances (> 10 km), the measurements were between 2 and 5 dB above the model. Therefore, a uniform 3 dB was applied to the model to match the longer-range measurements and to be conservative (Figure C-2) (Hannay 2015, MacDonnell et al. 2015).

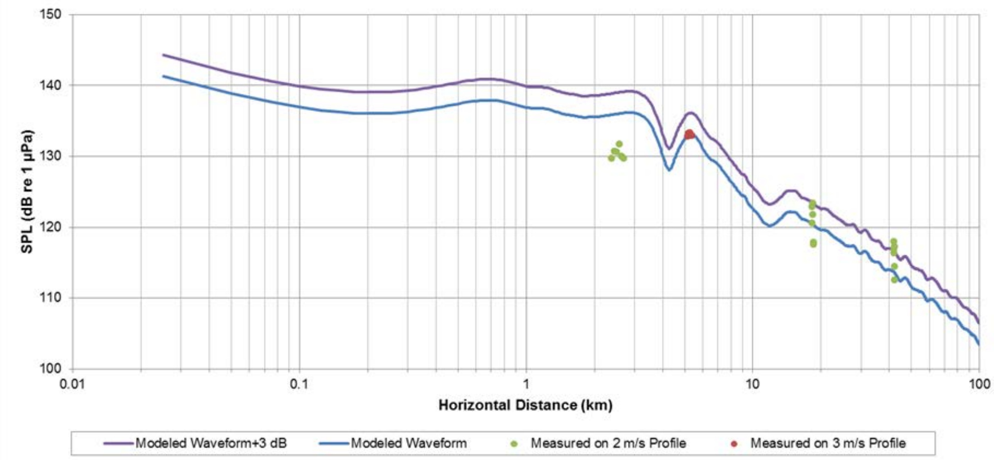

Figure C-2. Modeled results (lines) and measurements (symbols) of SPL for the 2–8 Hz frequency sweep received at a seabed depth of 2490 m (no frequency weighting, maximum 1 second value over the period of the sweep) at several measurement ranges. Two transducer settings are shown (2 m/s with green symbols and 3 m/s with red). The ground-truthed model (mauve line) is derived from the base model (blue line) with a 3 dB positive shift (Hannay 2015).

For frequencies above 4 kHz, MONM model computes sound propagation from high-frequency acoustic sources via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994). This version of MONM accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water in addition to acoustic attenuation due to reflection at the medium boundaries and internal layers (Fisher and Simmons 1977). The former type of sound attenuation is significant for frequencies higher than 5 kHz and cannot be neglected without noticeably affecting the model results. MONM computes acoustic fields in three dimensions by modeling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as *N*×2-D. These vertical radial planes are separated by an angular step size of 22.5°, yielding 16 planes (Figure C-3).

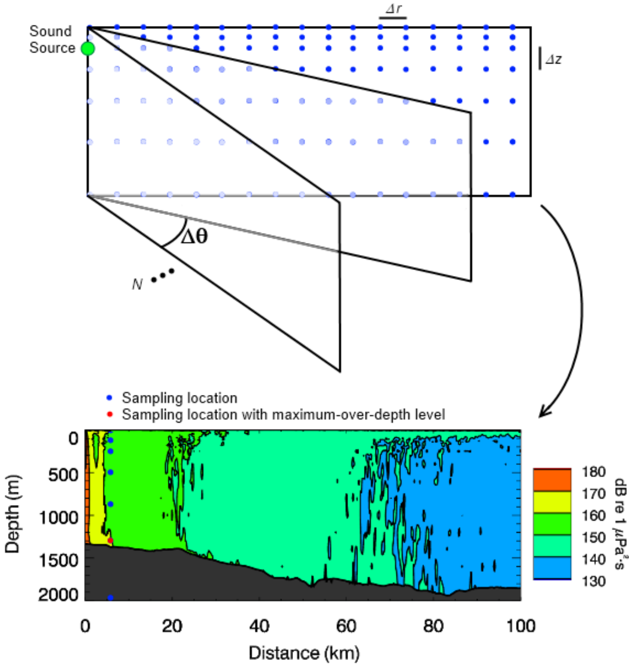

Figure C-3. The *N*×2-D and maximum-over-depth modeling approach.

C.2. Per-pulse Acoustic Field for Input to JASMINE

The transmission loss for exposure simulation is modeled along 16 radial profiles (angular step 22.5°) to a range of at least 100 km from the source location (i.e., to the edge of the larger modeling area). The horizontal step size along the radials is 30 m. At each radial sampling location, the sound field is sampled at up-to 87 depths, from 0.5 m down to the maximum water depth along the profile. The vertical step size in receiver depth is smaller near the surface, gradually increasing to as much as 100 m for the greatest depths. A total of 48 source frequencies (at the center of 1/3-octave-bands), from 1 Hz to 50 kHz were considered for the source array in the calculations of the broadband received levels. The broadband acoustic field passed as input to JASCO's Animal Simulation Model Including Noise Exposure (JASMINE) model is both in SPL and SEL metrics, and it was both range- and depth-dependent (Figure C-4).

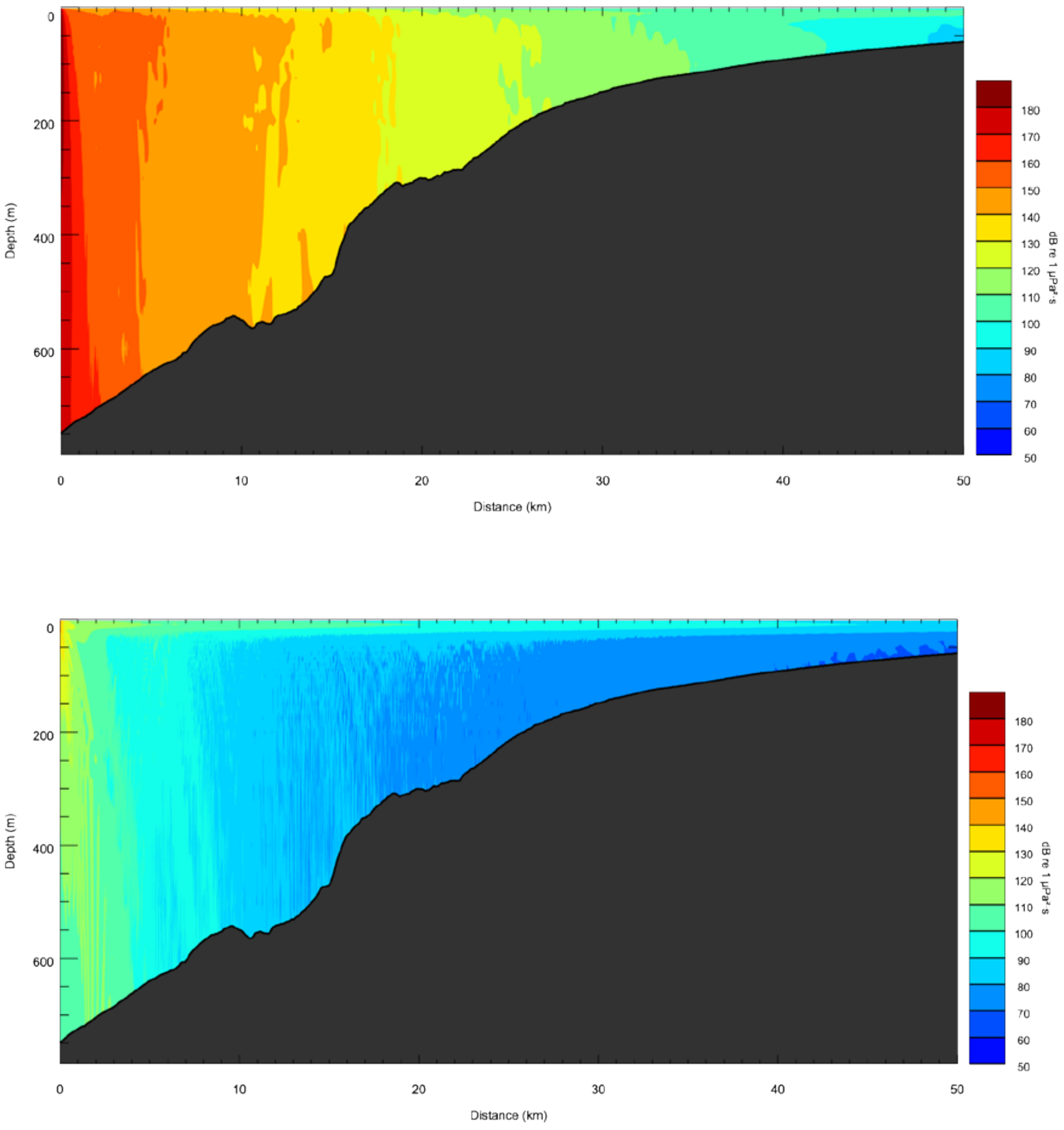

Figure C-4. An example of a per-pulse received sound exposure level (SEL) field along one radial, without frequency weighting (top) and with Type-III weighting for mid-frequency cetaceans (bottom) for the 4130 in^3 source array.

C.3. Frequency Dependence: Summing over 1/3-Octave-Bands

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave-bands. Many 1/3-octave-bands, starting at 10 Hz, are modeled to include most acoustic energy emitted by the source. At each center frequency, the transmission loss is modeled within each of the *N* vertical planes as a function of depth and range from the source. The 1/3-octave-band received per-pulse SELs are computed by subtracting the band transmission loss values from the SL in that frequency band.

Composite broadband received SELs are computed by combining the transmission loss (TL) values obtained from propagation modeling with MONM and SLs obtained from source modeling in each 1/3-octave-band and summing the band levels:

$$\mathrm{RL} = 10 \cdot \log_{10} \sum_{i=1}^{n} 10^{(\mathrm{SL}_i - \mathrm{TL}_i)/10} \tag{C-1}$$

where *n* is the number of modeled 1/3-octave-bands, SL_i and TL_i are the source level and transmission loss in the respective 1/3-octave-band.

The frequency weighted received levels ($\mathrm{RL}_{\mathrm{MW}}$) were obtained by adding the relative levels (MW) to the equation:

$$\mathrm{RL}_{\mathrm{MW}} = 10 \cdot \log_{10} \sum_{i=1}^{N} 10^{(\mathrm{SL}_i - \mathrm{TL}_i + \mathrm{MW}_i)/10} \tag{C-2}$$

Increasing frequency requires an increasingly finer computational grid, and, therefore, increased computational time. The transmission loss calculation for a single 2 kHz band can take as long as the time required for all other lower frequency bands combined. Transmission loss was modeled in 1/3-octave-bands from 1 Hz up to 50 kHz.

C.4. Converting SEL to rms SPL

The output from the modeling of the source is the sound field value in sound exposure level (SEL) units. A conversion factor is applied to estimate the rms (root-mean-square) sound pressure level (SPL). The rms SPL is conventionally based on an integration interval corresponding to the pulse length of the received signal, generally defined as the shortest time window containing 90% of the pulse energy (90% rms). Computation of rms levels from SEL requires knowledge of this pulse length, which in shallow water can be quite variable and dependent on several factors such as seabed composition, water sound speed profile, and distance from the source. A nominal conversion offset of +10 dB from SEL to rms SPL, corresponding to a pulse arrival duration of ~ 100 ms is commonly used. This value for the conversion offset is expected to be accurate for short-range distances (up to 2 km), based on field measurements. More accurate estimates of the conversion from SEL to rms SPL as a function of distance can be evaluated through full-waveform modeling.

Seismic airgun pulses typically lengthen in duration as they propagate away from their source, due to seabed and surface reflections, as well as other waveguide dispersion effects. The changes in pulse length affect SPL, therefore a full wave model must be used to reproduce the time domain signal and account for the changes in the pulse length. For the current study, JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM) was used to model synthetic airgun pulses along the modeled radials. The synthetic pulses were analyzed to determine pulse length versus depth, distance, and azimuth from the source. The pulse lengths were averaged in 1 km bins along the radials, and the results were used to derive a conversion function between single-pulse SEL and SPL(T90) (Figure 7). The range- and depth-dependent conversion function was applied to predicted SEL per-pulse results from MONM to model SPL values in a 360° field.

Appendix D. Environmental Parameters

Parameters used for this study are the same as were used in modeling for the PEIS, including modeling locations, geoacoustic parameters, and the use of mean sound speed profiles.

D.1. Bathymetry

Water depths throughout the modeled area were obtained from the National Geophysical Data Center's U.S. Coastal Relief Model I (NDGC 2014) that extends up to about 200 km from the U.S. coast. These bathymetry data have a resolution of 3 arc-seconds (~ 80 × 90 m at the studied latitude). Bathymetry data for an area were extracted and re-gridded, using the minimum curvature method, onto a Universal Transverse Mercator (UTM) Zone 15 coordinate projection with a horizontal resolution of 50 × 50 m.

Two bathymetry grids were used for modeling. The first covered the West region (Boxes 1 and 2 in Figure 1); the second covered Central and East regions (Boxes 3–7 in Figure 1).

D.1.1. Multi-layer geoacoustic profile

The top sections of the sediment cover in the Gulf of Mexico are represented by layers of unconsolidated sediments at least several hundred meters thick. The grain size of the surficial sediments follows the general trend for the sedimentary basins: the grain size of the deposited sediments decreases with the distance from the shore. For the Shelf zone, the general surficial bottom type was assumed to be sand, for the Slope zone silt, and for the Deep zone clay. In constructing a geoacoustic model for input to MONM , a median value of φ was selected for each sediment type with the exception of the geoacoustic profile for the East-Shelf area. Because the grain size of the surficial sediment offshore Florida is consistently larger than in other shelf areas, we assumed φ equal to 1 for the sand in this zone.

Four sets of geoacoustic parameters were used in the acoustic propagation modeling:

- Center-West Shelf (Table D-1)
- East Shelf (Table D-2)
- Slope (Table D-3)
- Deep (Table D-4)

Table D-1. Shelf zone Center and West: Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor, for fine sand. Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation **(dB/λ)**	S-wave speed (m/s)	S-wave attenuation **(dB/λ)**
0–20	Sand φ=2	1.61	1610	0.62	200	0.76
20–50		1.7	1900	1.44		
50–200		1.78	2090	1.77		
200–600		1.87	2500	2.31		
> 600		2.04	2500	2.67		

Table D-2. Shelf zone East: Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor (mbsf), for medium-sand. Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation **(dB/λ)**	S-wave speed (m/s)	S-wave attenuation **(dB/λ)**
0–20	Sand *φ=1*	1.7	1660	0.76	200	1.13
20–50		1.78	2040	1.68		
50–200		1.87	2290	2.03		
200–600		1.96	2500	2.56		
> 600		2.04	2500	2.91		

Table D-3. Slope zone: Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor (mbsf), for medium silt. Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation **(dB/λ)**	S-wave speed (m/s)	S-wave attenuation **(dB/λ)**
0–20	Silt *φ=6*	1.44	1515	0.33	150	0.22
20–50		1.7	1670	0.82		
50–200		1.7	1750	1.07		
200–600		1.87	1970	1.48		
> 600		2.04	2260	1.82		

Table D-4. Deep zone: Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor (mbsf), for medium clay. Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation **(dB/λ)**	S-wave speed (m/s)	S-wave attenuation **(dB/λ)**
0–20	Clay *φ=9*	1.52	1472	0.17	100	0.06
20–50		1.7	1560	0.43		
50–200		1.78	1610	0.56		
200–600		1.87	1720	0.83		
> 600		2.04	1890	1.05		

D.1.2. Sound speed profiles

The sound speed profiles for the modeled sites were derived using the same source and method as described in Section 2.

We investigated variation in the sound speed profile throughout the year and produced a set of 12 sound speed profiles, each representing one month, in the Shelf, Slope, and Deep zones (Figure D-1). The set was divided into four seasons:

- Season 1: January, February, and March
- Season 2: April, May, and June
- Season 3: July, August, and September
- Season 4: October, November, and December

For each zone, a month was selected to represent the propagation conditions in the water column in each season (Table D-5).

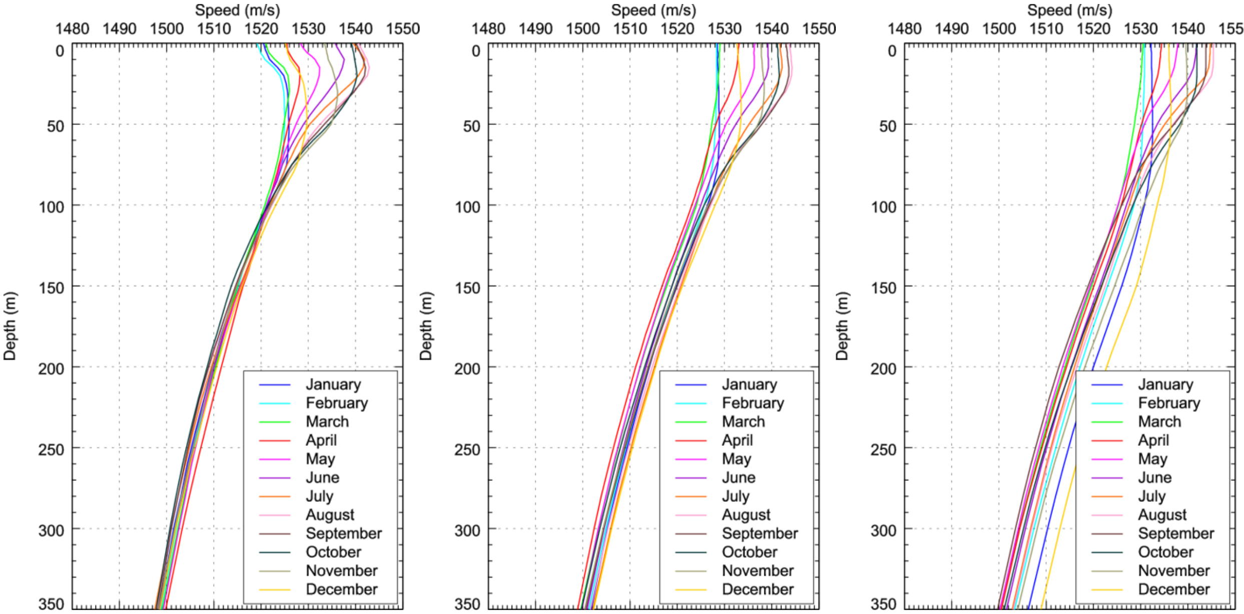

Figure D-1. Sound speed profiles at the (left) Shelf, (center) Slope, and (right) Deep zones, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

Table D-5. Representative months for each season and modeling zone.

Zone	SSP GDEM location	Season 1 (Jan to Mar)	Season 2 (Apr to Jun)	Season 3 (Jul to Sep)	Season 4 (Oct to Dec)
Shelf	25.5° N 90° W	Feb	May	Aug	Oct
Slope	27.25° N 90° W			Sep	Nov
Deep	28.5° N 90° W			Aug	Dec

ssp = sound speed profile

Acoustic fields were modeled using sound speed profiles for Season 1 and Season 3, and all three regions—East, Central, and West—used the same month. Profiles for Season 1 (February) provided the most conservative propagation environment because a surface duct, caused by upward refraction in the top 50–75 m, was present. Although a surface duct of this depth will not be able to prevent leakage of frequencies below 500–250 Hz (respectively), the ducting of frequencies above this cut off is important because these are the frequencies to which most marine mammals are most sensitive and the horizontal far-field acoustic projection from the airgun array seismic sources do have significant energy in this part of the spectrum. The modeling results obtained when the duct was present, therefore, represent the most precautionary propagation environment. Profiles for Season 3 (August or September) provided the least conservative results because they have weak to no sound channels at the surface and are strongly downward refracting in the top 200 m. Only the top 100 m of the water column are affected by the seasonal variation in the sound speed.

The possibility of separately modeling the spring and fall seasons was investigated; however, the results for spring and fall are almost identical to the results for summer, which were used as a proxy for the spring and fall results.

D.1.2.1. Sound speed profiles for box centers

Sound speed profiles were gathered from the center of each modeling box for Seasons 1 and 3. Table D-6 presents the months modeled for each of these seasons. Figure D-2 to Figure D-3 show the sound speed profiles for Seasons 1 and 3, respectively.

Table D-6. Modeling seasons for each box.

Box	Region	Zone	Season 1	Season 3
1	West	Shelf	Feb	Aug
2		Slope		Sep
3	Central	Shelf		Aug
4		Slope		Sep
5		Deep		Aug
6	East	Slope		Sep
7		Shelf		Aug

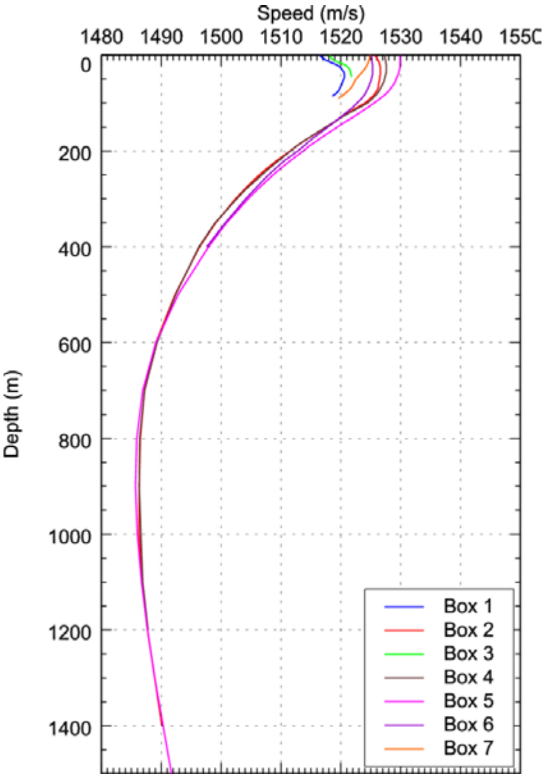

Figure D-2. Sound speed profiles at modeling boxes, Season 1, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

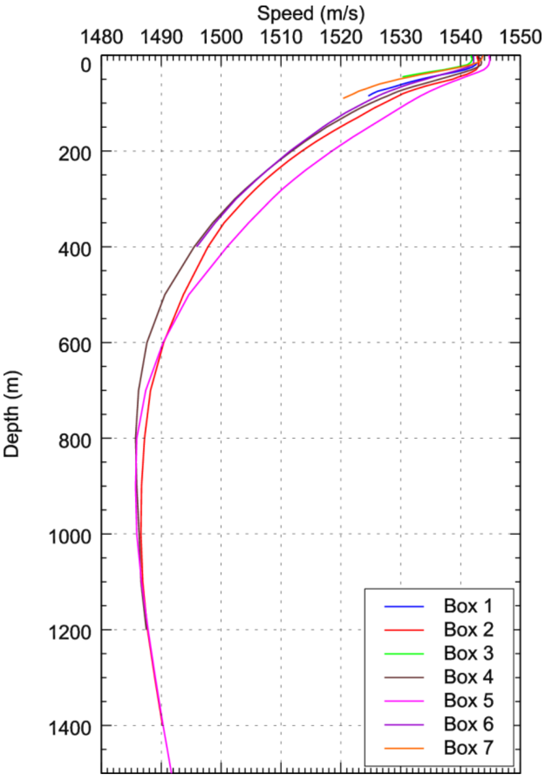

Figure D-3. Sound speed profiles at modeling boxes, Season 3, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

D.1.2.2. Sound speed profiles for acoustic modeling sites along transects

Sound speed profiles were obtained at three locations along each transect. Profiles were selected for Season 1 and Season 3. The months modeled for each season are presented in Table D-7. Figure D-4 to Figure D-6 show the sound speed profiles for transects in the West, Central, and East regions respectively.

Table D-7. Modeling seasons for the sites along transects.

Region	Zone	Season 1	Season 3
West	Shelf	Feb	Aug
	Slope		Sep
	Shelf		Aug
Central	Shelf		Aug
	Slope		Sep
	Shelf		Aug
East	Shelf		Aug
	Slope		Sep
	Deep		Aug

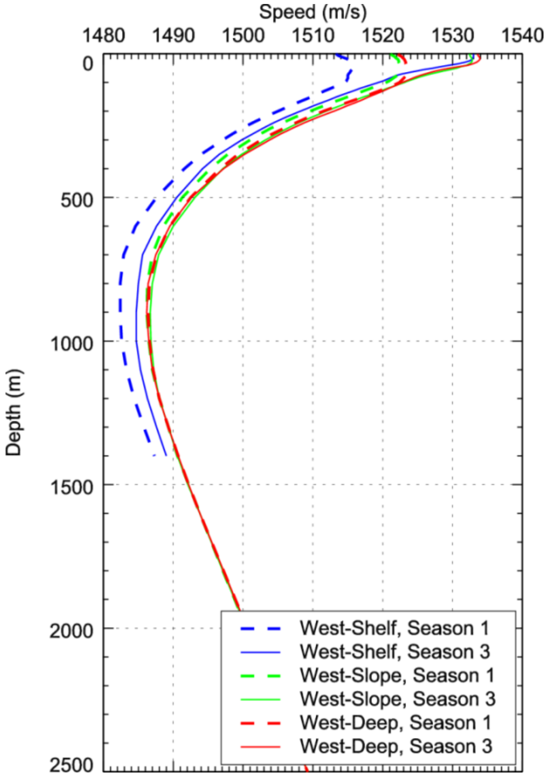

Figure D-4. Sound speed profiles along the West transect, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

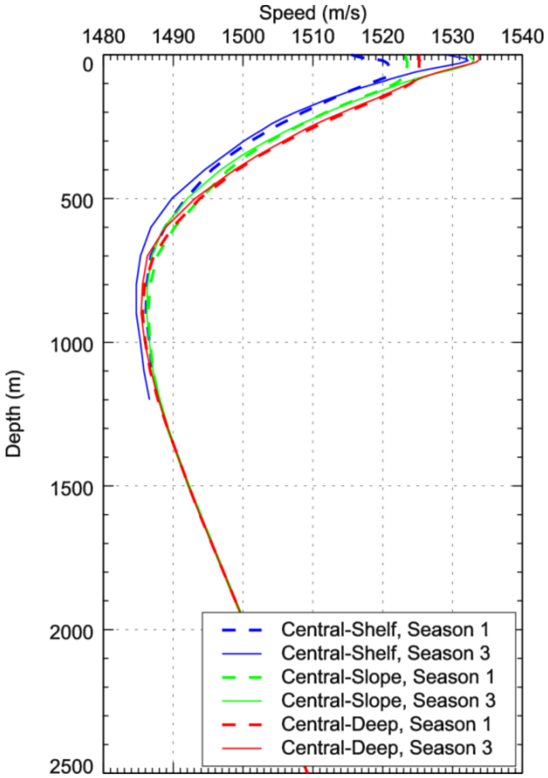

Figure D-5. Sound speed profiles along Central transect, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

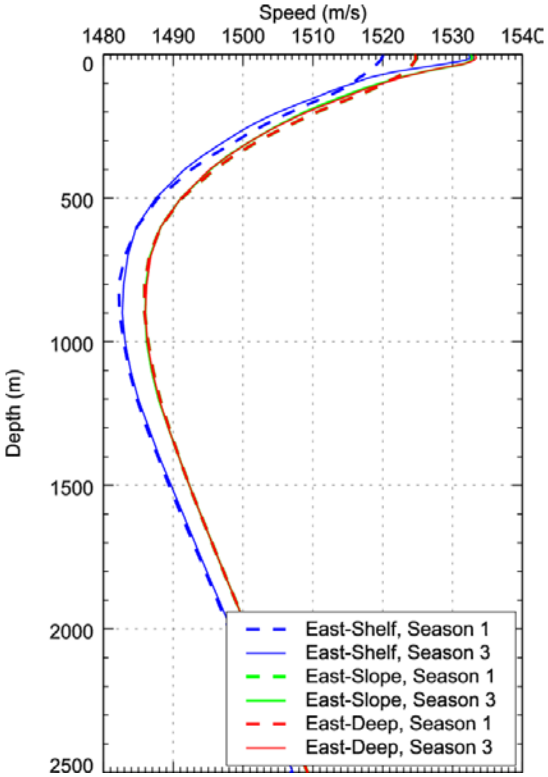

Figure D-6. Sound speed profiles along East transect, derived from data obtained from GDEM V 3.0 (Teague et al. 1990, Carnes 2009).

Appendix E. Auditory (Frequency) Weighting Functions

Described in Section 2.4.2, weighting functions are applied to the sound spectra under consideration to weight the importance of received sound levels at particular frequencies in a manner reflective of an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007). In this study, multiple weighting functions were used. Type I, also referred to as M-weighting (Southall et. 2007), was used to obtain rms SPL sound fields for gauging potential behavioral disruption and likelihood of aversion (Section E.1.1). Type III weighting (NMFS 2016) was used to assess potential injurious exposure from the sources.

E.1.1. Type I marine mammal frequency weighting functions

Auditory weighting functions for marine mammals—called *M-weighting* functions—were proposed by Southall et al. (2007). Functions were defined for five hearing groups of marine mammals:

- Low-frequency cetaceans (LFCs)—mysticetes (baleen whales)
- Mid-frequency cetaceans (MFCs)—some odontocetes (toothed whales)
- High-frequency cetaceans (HFCs)—odontocetes specialized for using high-frequencies
- Pinnipeds in water—seals, sea lions, and walrus
- Pinnipeds in air (not addressed here)

The M-weighting functions have unity gain (0 dB) through the passband and their high and low frequency roll-offs are approximately –12 dB per octave. The amplitude response in the frequency domain of each M-weighting function is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{a^2}{f^2}\right)\left(1+\frac{f^2}{b^2}\right)\right] \tag{E-1}$$

where *G*(f) is the weighting function amplitude (in dB) at the frequency *f* (in Hz), and *a* and *b* are the estimated lower and upper hearing limits, respectively, which control the roll-off and passband of the weighting function. The parameters *a* and *b* are defined uniquely for each hearing group (Table E-1). The auditory weighting functions recommended by Southall et al. (2007) are shown in Figure E-1.

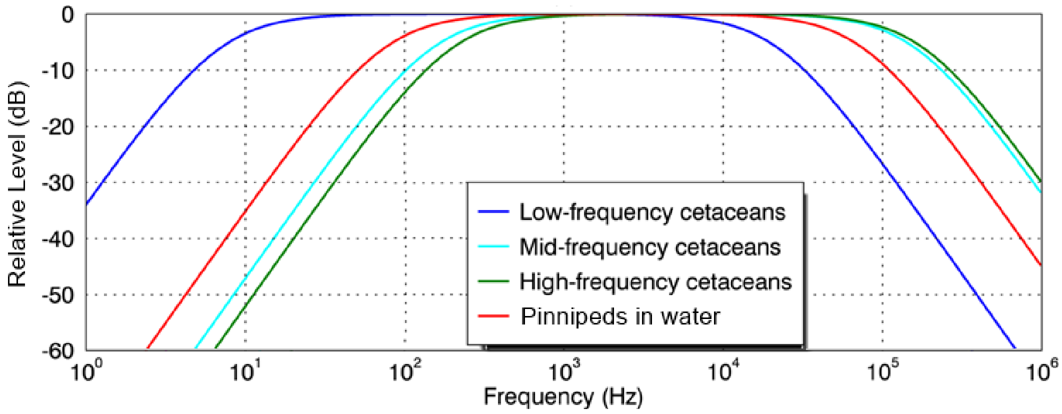

Figure E-1. Auditory weighting functions for functional marine mammal hearing groups as recommended by Southall et al. (2007).

Table E-1. Parameters for the auditory weighting functions recommended by Southall et al. (2007).

Hearing group	Southall et al. (2007)	
	a (Hz)	*b* (Hz)
Low-frequency cetaceans (LFC)	7	22,000
Mid-frequency cetaceans (MFC)	150	160,000
High-frequency cetaceans (HFC)	200	180,000
Pinnipeds in water (Pw)	75	75,000

E.1.2. Type III marine mammal frequency weighting functions

In 2015, a U.S. Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^2\right]^a\left[1+(f/f_{hi})^2\right]^b}\right)\right] \tag{E-2}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016). Table E-2 lists the frequency-weighting parameters for each hearing group; Figure E-2 shows the resulting frequency-weighting curves.

Table E-2. Parameters for the auditory weighting functions recommended by NMFS (2016).

Hearing group	*a*	*b*	f_{lo} (Hz)	f_{hi} (kHz)	*K* (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

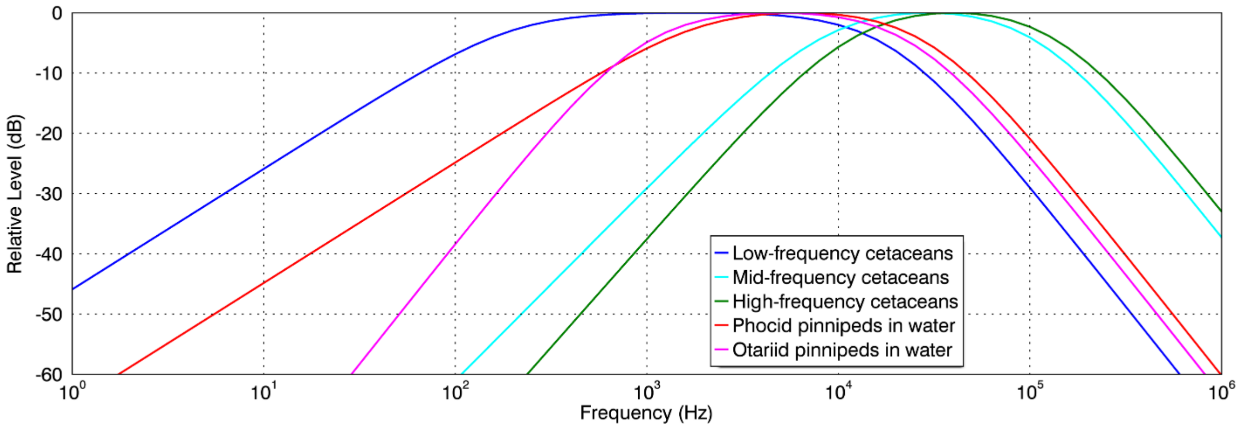

Figure E-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2016).

Appendix F. Animal Simulation and Acoustic Exposure Model

To assess the risk of impacts from exposure, an estimate of received sound levels for the animals in the area during operations is required. Sound sources move and so do animals. The sound fields may be complex and the sound received by an animal is a function of where the animal is at any given time. To a reasonable approximation, the location of the sound source(s) is known and acoustic modeling can be used to predict the 3-D sound field (Appendix B). The location and movement of animals within the sound field, however, is unknown. Realistic animal movement within the sound field can be simulated, and repeated random sampling (Monte Carlo)—achieved by simulating many animals within the operations area—used to estimate the sound exposure history of animals during the operation. Monte Carlo methods provide a heuristic approach for determining the probability distribution function (PDF) of complex situations, such as animals moving in a sound field. The probability of an event's occurrence is determined by the frequency with which it occurs in the simulation. The greater the number of random samples, in this case the more simulated animals (animats), the better the approximation of the PDF. Animats are randomly placed, or seeded, within the simulation boundary at a specified density (animats/km^2). The animat density is much higher than the real-world density to ensure good representation of the PDF. The resulting PDF is scaled using the real-world density.

Several models for marine mammal movement have been developed (Ellison et al. 1987, Frankel et al. 2002, Houser 2006). These models use an underlying Markov chain to transition from one state to another based on probabilities determined from measured swimming behavior. The parameters may represent simple states, such as the speed or heading of the animal, or complex states, such as likelihood of participating in foraging, play, rest, or travel. Attractions and aversions to variables like anthropogenic sounds and different depth ranges can be included in the models.

Analysis in this report uses the JASCO Animal Simulation Model Including Noise Exposure (JASMINE) 2017. JASMINE uses the same animal movement algorithms as the Marine Mammal Movement and Behavior (3MB) model (Houser 2006), but has been extended for use with JASCO-formatted acoustic fields, inclusion of source tracks, and for animats to change behavioral states based on modeled variables such as received level. JASMINE also includes aversion in response to realistic received levels.

F.1. Animal Movement Parameters

JASMINE uses previously measured behavior to forecast behavior in new situations and locations. The parameters used for forecasting realistic behavior are determined (and interpreted) from marine species studies (e.g., tagging studies). Each parameter in the model is described as a probability distribution. When limited or no information is available for a species parameter, a Gaussian or uniform distribution may be chosen for that parameter. For the Gaussian distribution, the user determines the mean and standard deviation of the distribution from which parameter values are drawn. For the uniform distribution, the user determines the maximum and minimum distribution from which parameter values are drawn. When detailed information about the movement and behavior of a species are available, a user-created distribution vector, including cumulative transition probabilities, may be used (referred to here as a vector model; Houser 2006). Different sets of parameters can be defined for different behavior states. The probability of an animat starting out in or transitioning into a given behavior state can in turn be defined in terms of the animat's current behavioral state, depth, and the time of day. In addition, each travel parameter and behavioral state has a termination function that governs how long the parameter value or overall behavioral state persists in simulation.

The parameters used in JASMINE describe animal movement in both the vertical and horizontal planes. The parameters relating to travel in these two planes are briefly described below.

F.1.1. Travel sub-models

Direction–determines the animat's choice of direction in the horizontal plane. Sub-models are available for determining the bearing of animats, allowing for movement to range from strongly biased to undirected. A random walk model can be used for behaviors with no directional preference, such as feeding and playing. In a random walk, all bearings are equally likely at each parameter transition time step. A correlated random walk can be used to smooth the changes in bearing by using the current bearing as the mean of the distribution from which to draw the next heading. An additional variant of the correlated random walk is available that includes a directional bias for use in situations where animals have a preferred absolute direction, such as migration. A user-defined vector of directional probabilities can also be defined to control animat bearing. For more detailed discussion of these parameters, see Houser (2006) and Houser and Cross (1999).

Travel rate–defines the rate of travel of an animat in the horizontal plane. When combined with vertical speed and dive depth, the dive profile of the animat is produced.

F.1.2. Dive sub-models

Ascent Rate–defines the rate of travel of an animat in the vertical plane during the ascent portion of a dive.

Descent Rate–defines the rate of travel of an animat in the vertical plane during the descent portion of a dive.

Depth–defines the maximum depth to which an animat will dive.

Bottom Following–determines whether an animat returns to the surface once reaching the ocean floor, or whether it follows the contours of the bathymetry.

Reversals–determines whether multiple vertical excursions occur once reaching the maximum dive depth. This behavior is used to emulate the foraging behavior of some marine mammal species at depth. Reversal-specific ascent and descent rates may be specified.

Surface Interval–determines the amount of time spent at the surface prior to performing another dive.

F.1.3. Boundaries

Ideally, the simulation area would be large enough to include ranges in which every animal that could approach the survey area during the operation would be included. Similarly, any animat that was exposed could not subsequently reach the boundary of the simulation during the operation. There are limits to the simulation area and computational overhead increases with area. For practical reasons, the simulation area for potential behavioral responses was limited to a maximum range of approximately 55 km from the modeled source tracks. In the simulation, every animat that reaches a border is replaced by another animat entering at the opposing border—e.g., an animat crossing the northern border of the simulation is replaced by one entering the southern border at the same longitude. Where this places the animat in an inappropriate water depth, the animat is randomly placed on the map at a depth suited to its species definition. The exposure history of all animats (including those leaving the simulation and those entering) are kept for exposure analysis. This approach maintains a consistent animat density and allows for longer integration periods with smaller simulation areas. It differs from simulating a larger area in that animats that cross the border are not allowed to re-enter the simulation (they are replaced by new animats) so the possibility of an animat leaving the area after exposure and then re-entering later to be re-exposed is excluded.

F.1.4. Aversion

Animals may avoid loud sounds by moving away from the source. A group of experts was convened to create a framework for assessing acoustic impacts to marine mammals in the GOM (Southall 2016). In this Risk Assessment Framework (RAF), it is suggested that aversion be included in simulations and the results be compared to simulations without aversion. While there are few data on which aversive behavior can be based, the RAF includes some aversion parameters, based on the Wood et al. (2012) behavioral step function. We follow the RAF aversion parameters (Table F-1). Animats avert by changing their headings by a fixed amount away from the source, with higher received levels associated with a greater deflection, and animats remain in the aversive state for a specified amount of time, depending on the level of exposure that triggered aversion (Table F-1). During this time, travel parameters are recalculated periodically as with normal behaviors. At the end of the aversion interval, the animat once again applies the parameters in Table F-1 and, depending on the current level of exposure, either begins another aversion interval or transitions to a non-aversive behavior; while aversion begins immediately, transition to a regular behavior occurs at the end of the next surfacing interval, consistent with regular behavior transitions.

Table F-1. Aversion parameters for the animal movement simulation based on Wood et al. (2012) behavioral response criteria

Probability of aversion	Received sound level (SPL, dB re 1 µPa)			Change in course (°)	Duration of aversion(s)
	Beaked whales	All other marine mammals	Sea turtles		
10%	100	140	146	10	300
50%	120	160	166	20	60
90%	140	180	186	30	30

F.2. Marine Mammal Species-Specific Details

Most marine mammals likely to be near the operations site are mid-frequency odontocetes. Bryde's whales (mysticete) is the only low-frequency animal and the *Kogia* species are the only high-frequency animals. Sperm whale is the only endangered species, although all of the marine mammals are protected. Details for the representative species are listed below.

F.2.1. Bryde's whales (*Balaenoptera edeni*)

Bryde's whales occur in tropical and warm temperate oceans around the world (Atlantic, Indian, and Pacific) from about 40° S to 40° N (Reeves et al. 2002, Jefferson et al. 2008). Southeast Atlantic and northwest Pacific populations migrate seasonally, moving toward higher latitudes during the summer and toward the equator during the winter. Migration patterns of the other populations are poorly known (Reilly et al. 2008). Bryde's whales are usually sighted individually or in pairs, but there are reports of loose aggregations of up to twenty animals associated with feeding areas. They feed on plankton, crustaceans, and schooling fish. Bryde's whales use different methods to feed, including skimming the surface, lunging, and creating bubble nets. They regularly dive for about 5–15 min (maximum of 20 min) and are capable of reaching depths up to 300 m during dives (Reeves et al. 2002, Jefferson et al. 2008).

Few Bryde's whale sightings have been recorded in the Gulf of Mexico. During aerial surveys conducted from summer 1992 through spring 1994, only one Bryde's whale was recorded at ~ 200 m water depth (Mullin et al. 2004). During ship-based spring surveys from 1991–2001 a total of 17 (on- and off-transect) sightings of Bryde's whales with an average group size of 2 animals was recorded, all concentrated along the shelf-edge in water depths ranging from ~200 to ~300 m. About 95% were sighted in the De Soto Canyon area, northeast Gulf of Mexico (Maze-Foley and Mullin 2006). One sighting of two animals was observed in the De Soto Canyon area from similar ship-based surveys in 2003–2004 (Mullin 2007) and three sightings in 2009 (Waring et al. 2013). Three groups of Bryde's whales were observed during the Atlantic Marine Assessment Program for Protected Species (AMAPPS) survey in the Gulf of Mexico, all on 31 July and in the De Soto Canyon (Širović et al. 2014). Because the few sightings of Bryde's whales in the Gulf of Mexico occurred in the De Soto Canyon area, over 300 km from the survey site, Bryde's whales are not expected to receive acoustic energy because of the project.

F.2.1.1. Behavioral parameters for animat modeling

Table F-2. Bryde's whales: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Deep	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Random 0.81–1.53	Murase et al. (2015)
	Ascent rate (m/s)	Gaussian 0.95 (0.55)	Alves et al. (2010)
	Descent rate (m/s)	Gaussian 1.25 (0.4)	Alves et al. (2010)
	Average depth (m)	Gaussian 314 (61.5)	Alves et al. (2010)
	Bottom following	No	Approximated
	Reversals	Gaussian 1.5 (1.5)	Alves et al. (2010)
	Probability of reversal	0.7	Approximated
	Reversal ascent dive rate (m/s)	1.0 (0.2)	Approximated
	Reversal descent dive rate (m/s)	1.0 (0.2)	Approximated
	Time in reversal (s)	Gaussian 50.1 (45.3)	Alves et al. (2010)
	Surface interval (s)	Random, 120 - 300	Alves et al. (2010)
	Bout duration (s)	Gaussian 600 (120) Night Gaussian 3600 (420) Day	Approximated
Shallow	Travel direction	Correlated random walk	Ward (1999)
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Random 0.81–1.53	Murase et al. (2015)
	Ascent rate (m/s)	Gaussian 0.95 (0.55)	Alves et al. (2010)
	Descent rate (m/s)	Gaussian 1.25 (0.4)	Alves et al. (2010)
	Average depth (m)	Random, maximum = 40	Alves et al. (2010)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Random, 141 - 236	Di Sciara (1983)
	Bout duration (s)	Gaussian 3600 (420) Day Gaussian 0 (0) Night	Approximated
General	Shore following (m)	20	Gonçalves et al. (2016)
	Depth limit on seeding (m)	20 (minimum), 3000 (maximum)	Gonçalves et al. (2016)

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results, for example.

F.2.2. Sperm whales (*Physeter macrocephalus*)

The sperm whale is listed as endangered under the Endangered Species Act and depleted under the Marine Mammal Protection Act (MMPA) throughout its entire range. Due to commercial whaling at a large scale from the early 18th to 20th century, sperm whale numbers declined globally. In the Gulf of Mexico, sperm whales were commercially hunted by American whalers until the early 1900s (Townsend 1935). Sperm whale population sizes have increased since commercial whaling ceased, however, they have not reached projected historical numbers (Whitehead 2002).

Sperm whales of all ages and both sexes occur year-round in the Gulf of Mexico, where they are the most common large whale species (Mullin et al. 2004, Waring et al. 2010). Systematic aerial and ship surveys indicate that they inhabit continental slope and oceanic waters and they generally occur in waters deeper than 1000 m (Mullin and Fulling 2004, Mullin et al. 2004, Maze-Foley and Mullin 2006, Mullin 2007). Movements from satellite tagged sperm whales showed that most whales frequented waters of 700–1000 m deep, but that animals were also sighted in waters of 3000 m (Mate and Ortega-Ortiz 2004).

The northern Gulf of Mexico stock is considered by some to be distinct from the U.S. Atlantic stock (Waring et al. 2010). Findings from the Sperm Whale Seismic Study on movement patterns, genetic structure, size, photo-identification data, and vocalizations support the concept of two separate stocks (Jochens et al. 2008). The site fidelity of the Gulf of Mexico sperm whales appears to be high. Although genetic evidence shows that male sperm whales move in and out the Gulf (Engelhaupt et al. 2009), tracks from 39 satellite-tagged northern Gulf sperm whales monitored for up to 607 days displayed no seasonal migrations and tracked only one animal (a male) that left the Gulf of Mexico (Mate and Ortega-Ortiz 2004). During ship-based surveys in continental slope and oceanic waters, 164 groups with an average of 2–3 animals were observed in 1991–2001, and 85 groups with an average of 4 animals were observed in 2003–2004 (Maze-Foley and Mullin 2006, Mullin 2007). In both surveys, sperm whales were frequently observed in the proposed operations area.

Sperm whales feed primarily on squid and occasionally on fish (Wynne and Schwartz 1999). They make deep and long dives reaching depths of ~ 3000 m (Jefferson et al. 2008), but with average diving depths of about 700 m (Watwood et al. 2006). Although dive durations can be as long as 2 h, most recorded dives lasted about 30–45 min (Thode et al. 2002, Watwood et al. 2006, Palka and Johnson 2007). Sperm whales are mid-frequency cetaceans with functional hearing sensitivity estimated to range from 150 Hz to 160 kHz (Southall et al. 2007).

The most prevalent vocalization pattern of sperm whales is the ‘usual' click, which is produced by foraging whales as echolocation to target prey at depth (Watwood et al. 2006). Socializing whales sometimes produce short stereotyped sequences of clicks, termed ‘codas’, which have also been recorded at the beginning of foraging dives and just prior to surfacing. Sperm whale social units have different repertoires or dialects as they show different usage patterns of specific codas (Whitehead and Rendell 2004, Schulz et al. 2011). Most clicks and codas produced by sperm whales are in the 8–25 kHz frequency range (Madsen et al. 2002).

F.2.2.1. Behavioral parameters for animat modeling

Table F-3. Sperm whales: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Deep Foraging Dive	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.88 (0.27)	Miller et al. (2004)
	Ascent rate (m/s)	Gaussian 1.3 (0.2)	Watwood et al. (2006)
	Descent rate (m/s)	Gaussian 1.1 (0.2)	Watwood et al. (2006)
	Average depth (m)	Gaussian 546.9 (130)	Watwood et al. (2006)

Behavior	Variable	Value	Reference
	Bottom following	No	Approximated
	Reversals	Gaussian 8.2 (4.2)	Aoki et al. (2007)
	Probability of reversal	1	Approximated
	Reversal ascent dive rate (m/s)	1.8 (0.5)	Aoki et al. (2007)
	Reversal descent dive rate (m/s)	1.8 (0.5)	Aoki et al. (2007)
	Time in reversal (s)	Gaussian 141 (82.7)	Aoki et al. (2007) Amano and Yoshioka (2003)
	Surface interval (s)	Gaussian 486 (156)	Watwood et al. (2006)
	Bout duration (s)	Gaussian 42012 (20820)	Approximated
V Dive	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.88 (0.27)	Miller et al. (2004)
	Ascent rate (m/s)	Gaussian 0.67 (0.43)	Amano and Yoshioka (2003)
	Descent rate (m/s)	Gaussian 0.85 (0.05)	Amano and Yoshioka (2003)
	Average depth (m)	Gaussian 282.7 (69.9)	Amano and Yoshioka (2003)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 408 (114)	Amano and Yoshioka (2003)
	Bout duration (s)	Gaussian 2286 (384)	Approximated
Inactive Bottom Time	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.88 (0.27)	Miller et al. (2004)
	Ascent rate (m/s)	Gaussian 1.13 (0.07)	Amano and Yoshioka (2003)
	Descent rate (m/s)	Gaussian 1.4 (0.13)	Amano and Yoshioka (2003)
	Average depth (m)	Gaussian 490 (74.6)	Amano and Yoshioka (2003)
	Bottom following	No	Approximated
	Reversals	Gaussian 1 (0)	Approximated
	Probability of reversal	1	Approximated
	Reversal ascent dive rate (m/s)	0.1 (0.1)	Approximated
	Reversal descent dive rate (m/s)	0.1 (0.1)	Approximated
	Time in reversal (s)	Gaussian 1188 (174.6)	Amano and Yoshioka (2003)
	Surface interval (s)	Gaussian 486 (156)	Watwood et al. (2006)
	Bout duration (s)	Gaussian 6192 (4518)	Approximated
Surface active	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.88 (0.27)	Miller et al. (2004)
	Ascent rate (m/s)	Gaussian 0.67 (0.43)	Amano and Yoshioka (2003)
	Descent rate (m/s)	Gaussian 0.85 (0.05)	Amano and Yoshioka (2003)
	Average depth (m)	Gaussian 25 (25)	Amano and Yoshioka (2003)

Behavior	Variable	Value	Reference
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 408 (114)	Amano and Yoshioka (2003)
	Bout duration (s)	Gaussian 3744 (2370)	Approximated
Surface Inactive–Head Up	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0 (0)	Approximated
	Ascent rate (m/s)	Gaussian 0.1 (0.1)	Miller et al. (2008)
	Descent rate (m/s)	Gaussian 0.1 (0.1)	Miller et al. (2008)
	Average depth (m)	Gaussian 8.6 (4.8)	Miller et al. (2008)
	Bottom following	No	Approximated
	Reversals	Gaussian 1 (0)	Approximated
	Probability of reversal	1	Approximated
	Reversal ascent dive rate (m/s)	0 (0)	Miller et al. (2008)
	Reversal descent dive rate (m/s)	0 (0)	Miller et al. (2008)
	Time in reversal (s)	Gaussian 708 (522)	Miller et al. (2008)
	Surface interval (s)	Gaussian 462 (360)	Miller et al. (2008)
	Bout duration	T50 = 486 (s), k=0.9	Approximated
Surface Inactive–Head Down	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0 (0)	Approximated
	Ascent rate (m/s)	Gaussian 0.1 (0.1)	Miller et al. (2008)
	Descent rate (m/s)	Gaussian 0.1 (0.1)	Miller et al. (2008)
	Average depth (m)	Gaussian 16.5 (4.9)	Miller et al. (2008)
	Bottom following	No	Approximated
	Reversals	Gaussian 1 (0)	Approximated
	Probability of reversal	1	Approximated
	Reversal ascent dive rate (m/s)	0 (0)	Miller et al. (2008)
	Reversal descent dive rate (m/s)	0 (0)	Miller et al. (2008)
	Time in reversal (s)	Gaussian 804 (522)	Miller et al. (2008)
	Surface interval (s)	Gaussian 462 (360)	Miller et al. (2008)
	Bout duration	T50 = 486 (s), k=0.9	Approximated
General	Depth limit on seeding (m)	500	Herzing and Elliser (2016)

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results for example.

F.2.3. Beaked whales

Four species of beaked whales could be encountered in the Gulf of Mexico. The Cuvier's beaked whale (*Ziphius cavirostris*), and three of the *Mesoplodon* genus: Blainville's beaked whale (*Mesoplodon densirostris*), Gervais' beaked whale (*Mesoplodon europaeus*), and Sowerby's beaked whale (*Mesoplodon bidens*). Sowerby's beaked whale (*Mesoplodon bidens*), however, is a rare visitor to the area. The only recorded occurrence of the Sowerby's beaked whale in the Gulf of Mexico was a stranded one in Gulf County, Florida (Wursig et al. 2000). Sowerby's beaked whales are not considered further analyzed. Beaked whales are found in temperate, tropical, and subtropical waters. They occur year-round in the Gulf of Mexico where they frequent deep pelagic waters (Wynne and Schwartz 1999). The depth range at which most beaked whale sightings were recorded was 500–3500 m, with an average depth of >1000 m (Maze-Foley and Mullin 2006). Beaked whales make the longest and deepest dives of any whale species, often diving to depths >300 m (Hooker and Baird 1999, Baird et al. 2006a, Baird et al. 2006b, Tyack et al. 2006, Baird et al. 2008). They are dive feeders, usually feeding on squid, but also on fish and crustaceans (Wynne and Schwartz 1999). During eight aerial line-transect surveys conducted from summer 1992 to spring 1994, covering 85,815 km^2 in the north-central and north-western Gulf of Mexico, 11 beaked whales were sighted. One was a Cuvier's beaked whale, four were Mesoplodon spp., and eight were of unidentified beaked whales (Mullin et al. 2004). Ship-based line-transect surveys in 1991–2001 recorded 15 Cuvier's beaked whale sightings, 29 Mesoplodon spp. sightings, and 19 unidentified beaked whale sightings, all with an average groups size of 2 animals (Maze-Foley and Mullin 2006). Observations from similar 2003–2004 ship-based survey data recorded 2 Cuvier's beaked whale sightings and 2 *Mesoplodon spp* sightings, with an average group size of 3 animals, and 15 unidentified beaked whale sightings with an average group size of 2 animals (Mullin 2007).

Information on hearing sensitivity of beaked whales is somewhat limited. Most data are available from stranded whales, using audio evoked potential. The Gervais' beaked whale was found to be most sensitive to high frequency signals between 40 and 80 kHz, but produced smaller evoked potentials to 5 kHz, the lowest frequency tested (Cook et al. 2006, Finneran et al. 2009). Blainville's beaked whale sounds included one frequency-modulated whistle and three frequency- and amplitude-modulated pulsed sounds, with energy between 6 and 16 kHz (Rankin and Barlow 2007). Beaked whale hearing sensitivity measured through audio evoked potential was like those measured in other echolocating odontocetes.

F.2.3.1. Behavioral parameters for animat modeling

Table F-4. Cuvier's beaked whales: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Deep Foraging Dive	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 1.5 (0.5)	Approximated
	Ascent rate (m/s)	Gaussian 0.69 (0.19)	Tyack et al. (2006) Baird et al. (2006b)
	Descent rate (m/s)	Gaussian 1.47 (0.13)	Tyack et al. (2006) Baird et al. (2006)
	Average depth (m)	Gaussian 1070 (317)	Tyack et al. (2006)
	Bottom following	No	Approximated
	Reversals	Gaussian 20 (2)	Tyack et al. (2006)
	Probability of reversal	0.95	Approximated
	Reversal ascent dive rate (m/s)	0.8 (0.2)	Madsen et al. (2005)
	Reversal descent dive rate (m/s)	0.8 (0.2)	Madsen et al. (2005)

	Time in reversal (s)	Gaussian 40 (20)	Tyack et al. (2006)
	Surface interval (s)	Gaussian 474 (996)	Tyack et al. (2006)
	Bout duration	T_{50} = 1200 (s), k=10	Approximated
Shallow Dive	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 1.5 (0.5)	Approximated
	Ascent rate (m/s)	Gaussian 0.61 (0.2)	Baird et al. (2006b), Tyack et al. (2006)_ENREF_15
	Descent rate (m/s)	Gaussian 0.53 (0.24)	Baird et al. (2006b), Tyack et al. (2006)_ENREF_15
	Average depth (m)	Gaussian 221 (100)	Tyack et al. (2006)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 474 (996)	Tyack et al. (2006)
	Bout duration (s)	Gaussian 3780 (1860)	Tyack et al. (2006)
General	Depth limit on seeding (m)	1381	Baird et al. (2006b)

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results for example.

Table F-5. *Mesoplodon* beaked whales: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Deep Foraging Dive	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 1.5 (0.5)	Approximated
	Ascent rate (m/s)	Gaussian 0.79 (0.13)	Tyack et al. (2006) Baird et al. (2006b)
	Descent rate (m/s)	Gaussian 1.45 (0.2)	Tyack et al. (2006) Baird et al. (2006b)
	Average depth (m)	Gaussian 835 (143)	Tyack et al. (2006)
	Bottom following	No	Approximated
	Reversals	Gaussian 20 (2)	Tyack et al. (2006)
	Probability of reversal	0.95	Approximated
	Reversal ascent dive rate (m/s)	0.8 (0.2)	Madsen et al. (2005)
	Reversal descent dive rate (m/s)	0.8 (0.2)	Madsen et al. (2005)
	Time in reversal (s)	Gaussian 40 (20)	Tyack et al. (2006)
	Surface interval (s)	Gaussian 228 (276)	Tyack et al. (2006)
	Bout duration	T_{50} = 1200 (s), k=10	Approximated
	Travel direction	Correlated random walk	Approximated

Behavior	Variable	Value	Reference
Shallow Dive	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 1.5 (0.5)	Approximated
	Ascent rate (m/s)	Gaussian 0.35 (0.2)	Baird et al. (2006b), Tyack et al. (2006)_ENREF_15
	Descent rate (m/s)	Gaussian 0.34 (0.24)	Tyack et al. (2006) Baird et al. (2006)
	Average depth (m)	Gaussian 71 52)	Tyack et al. (2006)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 228 (276)	Tyack et al. (2006)
	Bout duration (s)	Gaussian 3700 (1860)	Tyack et al. (2006)
General	Depth limit on seeding (m)	633	Baird et al. (2006) Waring et al. (2001)

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results for example.

F.2.4. Bottlenose dolphins (*Tursiops truncatus*)

Bottlenose dolphins occur globally in temperate and tropical waters where they inhabit various habitats, such as estuaries, bays, coastal areas, and oceanic environments. Many different stocks have been identified in the Gulf of Mexico, with exact stock definitions still in flux as more information becomes available (Waring et al. 2010). The coastal stock's diet consists of invertebrates and fish, while the oceanic stock feeds mainly on squid and fish (Wynne and Schwartz 1999).

The bottlenose stock most relevant for this survey is the oceanic stock that occurs from the 200 m isobath to the seaward extent of the U.S. Exclusive Economic Zone (Waring et al. 2010). Abundance estimates based on 1996–2001 and 2003–2004 ship-based survey data were very similar (i.e., 2239 and 3708, respectively). During the spring 1991–2001 ship-based surveys with transect lines in waters of >200 m depth, a total of 151 dolphin groups were sighted with average group sizes of about 20 animals (Maze-Foley and Mullin 2006). During the 2003–2004 ship-based surveys in the same general area, 26 groups were observed with an average group size of 25 (Mullin 2007). All these sightings were concentrated in water depths between 200 m and 1000 m.

Bottlenose dolphins produce a variety of sounds, such as whistles, moans, trills, grunts, squeaks, and other. These sounds vary in volume, wavelength, frequency, and pattern. The frequency of the sounds produced by a bottlenose dolphin ranges from 200 Hz to 150 kHz. The lower frequency vocalizations (up to 50 kHz) are likely used in social communication. Social signals have most of their energy at frequencies less than 40 kHz. Higher frequency clicks (40–150 kHz) are primarily used for echolocation (Kastelein et al. 1995).

F.2.4.1. Behavioral parameters for animat modeling

Table F-6. Bottlenose dolphins: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Foraging	Travel direction	Vector model	Ward (1999)
	Travel rate (m/s)	Vector model	Ward (1999)
	Ascent rate (m/s)	Gaussian 2.1 (0.3)	Houser et al. (2010)
	Descent rate (m/s)	Gaussian 1.6 (0.2)	Houser et al. (2010)
	Average depth (m)	Gaussian 25 (5)	Hastie et al. (2006)
	Bottom following	Yes	Approximated
	Reversals	Gaussian 18 (1.1)	Approximated
	Probability of reversal	0.09	Approximated
	Reversal ascent dive rate (m/s)	1.0 (0.2)	Approximated
	Reversal descent dive rate (m/s)	1.0 (0.2)	Approximated
	Time in reversal (s)	Gaussian 1 (0.1)	Approximated
	Surface interval (s)	Gaussian 46.4 (2.5)	Lopez (2009)
	Bout duration (s)	Gaussian 252 (210)	Ward (1999)
Playing	Travel direction	Vector model	Ward (1999)
	Travel rate (m/s)	Vector model	Ward (1999)
	Ascent rate (m/s)	Gaussian 2.1 (0.3)	Houser et al. (2010)
	Descent rate (m/s)	Gaussian 1.6 (0.2)	Houser et al. (2010)
	Average depth (m)	Gaussian 7 (3)	Würsig and Würsig (1979), Hastie et al. (2006)

	Bottom following	Yes	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 3 (2)	Approximated
	Bout duration (s)	Gaussian 138 (54)	Ward (1999)
Resting	Travel direction	Vector model	Ward (1999)
	Travel rate (m/s)	Vector model	Ward (1999)
	Ascent rate (m/s)	Gaussian 0.5 (0.1)	Approximated
	Descent rate (m/s)	Gaussian 0.5 (0.1)	Approximated
	Average depth (m)	Random, max = 2	Approximated
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 3 (2)	Approximated
	Bout duration (s)	Gaussian 174 (96)	Ward (1999)
Socializing	Travel direction	Vector model	Ward (1999)
	Travel rate (m/s)	Vector model	Ward (1999)
	Ascent rate (m/s)	Gaussian 2.1 (0.3)	Houser et al. (2010)
	Descent rate (m/s)	Gaussian 1.6 (0.2)	Houser et al. (2010)
	Average depth (m)	Random, max = 10	Hastie et al. (2006) Würsig and Würsig (1979)
	Bottom following	Yes	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 3 (2)	Approximated
	Bout duration (s)	Gaussian 204 (174)	Ward (1999)
Travel	Travel direction	Vector model	Ward (1999)
	Travel rate (m/s)	Vector model	Ward (1999)
	Ascent rate (m/s)	Gaussian 2.1 (0.3)	Houser et al. (2010)
	Descent rate (m/s)	Gaussian 1.6 (0.2)	Houser et al. (2010)
	Average depth (m)	Gaussian 7 (3)	Hastie et al. (2006) Würsig and Würsig (1979)
	Bottom following	Yes	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 3 (2)	Approximated
	Bout duration	Gaussian 306 (276)	Ward (1999)
General	Shore following (m)	2	Würsig and Würsig (1979)
	Depth limit on seeding (m)	2 (minimum), 40 (maximum)	Würsig and Würsig (1979)

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results for example.

F.2.5. Short-finned pilot whales (*Globicephala macrorhynchus*)

Short-finned pilot whale is known to occur year-round in the Gulf of Mexico in coastal to pelagic waters along the continental shelf and over submarine canyons (Wynne and Schwartz 1999, Wursig et al. 2000). They feed primarily on squid (but also fish and octopus), and congregations are often associated with high densities of squid. Maze-Foley and Mullin (2006) reported 18 sightings of short-finned pilot whales over the period 1991–2001, with several sightings within or near the proposed survey. Vocalizations from short-finned pilot whales recorded in the Canary Islands consisted of calls, clicks, and grunts with most energy within frequencies between 280 Hz and 23 kHz (Scheer 2013).

F.2.5.1. Behavioral parameters for animat modeling

Table F-7. Short-finned pilot whales: Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
State 1	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Wells et al. (2013)
	Ascent rate (m/s)	Gaussian 2.2 (0.2)	Aguilar Soto et al. (2009)
	Descent rate (m/s)	Gaussian 2 (0.2)	Aguilar Soto et al. (2009)
	Average depth (m)	Gaussian 43 (15)	Quick et al. (2017)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 165 (69)	Sakai et al. (2011)
	Bout duration (s)	T_{50} = 300 (s), k=7	Approximated
State 2	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Wells et al. (2013)
	Ascent rate (m/s)	Gaussian 3.2 (0.4)	Aguilar Soto et al. (2009)
	Descent rate (m/s)	Gaussian 3 (0.4)	Aguilar Soto et al. (2009)
	Average depth (m)	Gaussian 550 (200)	Quick et al. (2017)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 165 (69)	Sakai et al. (2011)
	Bout duration (s)	T_{50} = 6000 (s), k=7	Approximated
State 3	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Wells et al. (2013)
	Ascent rate (m/s)	Gaussian 2.2 (0.2)	Aguilar Soto et al. (2009)
	Descent rate (m/s)	Gaussian 2 (0.2)	Aguilar Soto et al. (2009)

Behavior	Variable	Value	Reference
	Average depth (m)	Gaussian 150 (100)	Quick et al. (2017)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 165 (69)	Sakai et al. (2011)
	Bout duration (s)	T_{50} = 3600 (s), k=7	Approximated
State 4	Travel direction	Correlated random walk	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Wells et al. (2013)
	Ascent rate (m/s)	Gaussian 3.2 (0.4)	Aguilar Soto et al. (2009)
	Descent rate (m/s)	Gaussian 3 (0.4)	Aguilar Soto et al. (2009)
	Average depth (m)	Gaussian 850 (100)	Quick et al. (2017)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 165 (69)	Sakai et al. (2011)
	Bout duration (s)	T_{50} = 3600 (s), k=7	Approximated
Surface	Travel direction	Vector model	Approximated
	Perturbation value	10	Approximated
	Termination coefficient	0.2	Approximated
	Travel rate (m/s)	Gaussian 0 (0)	Approximated
	Ascent rate (m/s)	Gaussian 0.1 (0.1)	Approximated
	Descent rate (m/s)	Gaussian 0.1 (0.1)	Approximated
	Average depth (m)	Gaussian 12 (5)	Quick et al. (2017)
	Bottom following	No	Approximated
	Reversals	No	Approximated
	Surface interval (s)	Gaussian 165 (69)	Sakai et al. (2011)
	Bout duration	T_{50} = 3600 (s), k=7	Approximated
General	Shore following (m)	200	Approximated
	Depth limit on seeding (m)	200	Approximated

Approximated: value based on the best fit for diving profile. Those values were not available from literature but were estimated producing a diving profile similar to D-tag results for example.

F.2.6. *Kogia* species

The dwarf and pygmy sperm whales (*Kogia breviceps* and *Kogia sima*) are the only species in the Gulf of Mexico that are characterized as high-frequency cetaceans (Southall et al. 2007). Dwarf and pygmy sperm whales were difficult to distinguish during the ship-based surveys and were often reported under the combined name dwarf/pygmy sperm whales or *Kogia* spp. They were most commonly observed in waters of >2000 m depth (Maze-Foley and Mullin 2006, Mullin 2007). During the 1991–2001 ship-based surveys a total of 133 groups with an average size of 2 animals were observed (Maze-Foley and Mullin 2006). Similar surveys conducted in 2003–2004 reported 27 groups with an average of 1.5 animals per group (Mullin 2007).

Sound recordings of stranded *Kogia breviceps* revealed that echolocation clicks for this species ranged from 60 to 200 kHz, with a dominant frequency of 120 to 130 kHz (Caldwell and Caldwell 1991). Almost all energy of low-frequency vocalizations was below 2 kHz (Caldwell et al. 1966). An auditory brainstem response study supports a hearing range of 90–150 kHz (Ridgway and Carder 2001).

F.2.6.1. Behavioral parameters for animat modeling

Table F-8. *Kogia spp*, including Dwarf Sperm Whales and Pygmy Sperm Whales (*Kogia sima* and *K. breviceps*) based on short-finned pilot whale data. Data values and references for inputs in JASMINE software to create diving behavior (number values represent Means (SD) unless otherwise indicated).

Behavior	Variable	Value	Reference
Day dive	Travel direction	Random walk	Approximate
	Termination coefficient	0.2	Approximate
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Short-finned pilot whales
	Ascent rate (m/s)	Gaussian 2.2 (0.2)	Short-finned pilot whales
	Descent rate (m/s)	Gaussian 2 (0.2)	Short-finned pilot whales
	Average depth (m)	Gaussian 30 (20)	Short-finned pilot whales
	Bottom following	No	Approximate
	Reversals	No	Approximate
	Surface interval (s)	Gaussian 165 (69)	Short-finned pilot whales
Night dive	Travel direction	Random walk	Approximate
	Termination coefficient	0.2	Approximate
	Travel rate (m/s)	Gaussian 0.875 (0.572)	Short-finned pilot whales
	Ascent rate (m/s)	Gaussian 3.2 (0.4)	Short-finned pilot whales
	Descent rate (m/s)	Gaussian 3 (0.4)	Short-finned pilot whales
	Average depth (m)	Gaussian 300 (100)	Short-finned pilot whales
	Bottom following	No	Approximate
	Reversals	No	Approximate
	Surface interval (s)	Gaussian 165 (69)	Short-finned pilot whales

Appendix G. Habitat-Density Model by Species

Cetacean density estimates (animals/km^2) were obtained using the Duke University's Marine Geospatial Ecology Laboratory (MGEL) model (Roberts et al. 2016a), preliminary results, which are hereafter referenced as PEIS densities. These estimates were produced with distance sampling methodology (Buckland et al. 2001) from 195,000 linear kilometers of shipboard and aerial surveys conducted by NOAA's Southeast Fisheries Science Center (SEFSC) in the Gulf of Mexico from 1992–2009. For each species, the count of animals per 10 km survey segment was modeled using a Horvitz-Thompson-like estimator (Marques and Buckland 2004, Miller et al. 2013). Species-specific detection functions were fitted using observation-level covariates such as Beaufort sea state, sun glare, and group size. When possible, availability and perception bias were estimated on a per-species basis using results from the scientific literature. After the sightings were corrected for detectability, availability, and perception bias, statistical regressions were used to model counts of animals per segment.

The density of frequently-sighted species were modeled with generalized additive models based on a collection of physiographic, physical oceanographic, and biological productivity predictor variables that plausibly relate to cetacean habitat. Both contemporaneous and climatological predictors were tested. Models were fitted to survey data and insignificant predictors were dropped from the models (Wood 2006). Final models were predicted across a time series of grids at 10 km resolution and averaged to produce a single surface representing mean density at each 10 km × 10 km grid square or cell.

There was insufficient data for infrequently seen species to model density from habitat variables. Instead, the geographic area of probable habitat was delineated from the scientific literature; patterns in the available sightings and density were estimated from the survey segments that occurred there using a statistical model that had no covariates. This model ran over the entire extent of the habitat area, yielding a uniform density estimate for each area.

Marine mammal density estimates for each species in the modeling zones are shown in Table G-1 to Table G-7.

Table G-1. Zone 1 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	0.004306	0.000107	0.000402
Bottlenose dolphins	10.718610	143.330322	37.130025	20.297288
Bryde's whales	0.000000	0.167721	0.012267	0.035798
Kogia spp	0.000000	0.381413	0.016379	0.046385
Short-finned pilot whales	0.078137	0.017168	0.000262	0.001151
Sperm whales	0.000000	0.004952	0.000150	0.000473

Table G-2. Zone 2 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	0.000281	0.000003	0.000018
Bottlenose dolphins	8.439063	113.845413	53.082960	22.977138
Bryde's whales	0.000000	0.028985	0.000164	0.001293
Kogia spp	0.000000	0.043914	0.000937	0.004897
Short-finned pilot whales	0.000000	0.002055	0.000010	0.000086
Sperm whales	0.000000	0.000350	0.000007	0.000035

Table G-3. Zone 3 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	0.000140	0.000001	0.000012
Bottlenose dolphins	8.936208	79.201904	39.405915	14.535437
Bryde's whales	0.000000	0.007863	0.000041	0.000375
Kogia spp	0.000000	0.024987	0.000187	0.001645
Short-finned pilot whales	0.000000	0.001161	0.000005	0.000054
Sperm whales	0.000000	0.000212	0.000002	0.000018

Table G-4. Zone 4 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	4.682173	0.725775	1.107739
Bottlenose dolphins	0.003873	66.720116	11.553444	12.482596
Bryde's whales	0.000000	0.167727	0.035179	0.055666
Kogia spp	0.000000	2.564462	0.958299	0.613179
Short-finned pilot whales	0.000000	5.891473	0.685525	0.842500
Sperm whales	0.000000	2.049208	0.482223	0.480525

Table G-5. Zone 5 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	3.432981	1.080930	0.851019
Bottlenose dolphins	0.025899	46.434166	5.728691	8.809752
Bryde’s whales	0.000000	0.167701	0.014526	0.039290
Kogia spp	0.000000	1.972867	0.726706	0.450570
Short-finned pilot whales	0.000000	3.430244	0.639206	0.665957
Sperm whales	0.000000	2.049208	0.725159	0.527590

Table G-6. Zone 6 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.000000	2.336602	0.832344	0.536911
Bottlenose dolphins	0.030806	24.043407	3.342733	5.111497
Bryde’s whales	0.000000	0.167480	0.013691	0.037372
Kogia spp	0.000000	1.100742	0.411093	0.228572
Short-finned pilot whales	0.000000	5.996468	1.249850	1.434598
Sperm whales	0.000000	1.356392	0.486587	0.286136

Table G-7. Zone 7 Marine mammal density estimates.

Species	Density estimate			
	Min	Max	Mean	STD
Beaked whales	0.222212	3.113844	0.519543	0.286857
Bottlenose dolphins	0.001245	1.554906	0.027482	0.067843
Bryde’s whales	0.000000	0.000004	0.000000	0.000000
Kogia spp	0.151227	0.825459	0.342218	0.062230
Short-finned pilot whales	0.003767	0.771689	0.121555	0.104179
Sperm whales	0.354441	1.140214	0.467025	0.131315

G.1. Marine Mammal Distribution Maps

This section contains distribution maps for representative marine mammal species likely to be affected by geological and geophysical exploration surveys (the remaining species distribution maps can be found in Appendix D of the Draft PEIS). The distributions were obtained from the Duke Marine Geospatial Ecology Laboratory model (Roberts et al. 2016a) as GIS-compatible rasters of density estimates in 100 km^2 areas. These animal distributions guided our selection of modeling zones, which were also patterned on BOEM's planning areas, and to maintain acoustic uniformity throughout zones. The zone boundaries are shown as overlays in the figures.

G.2. Beaked Whales

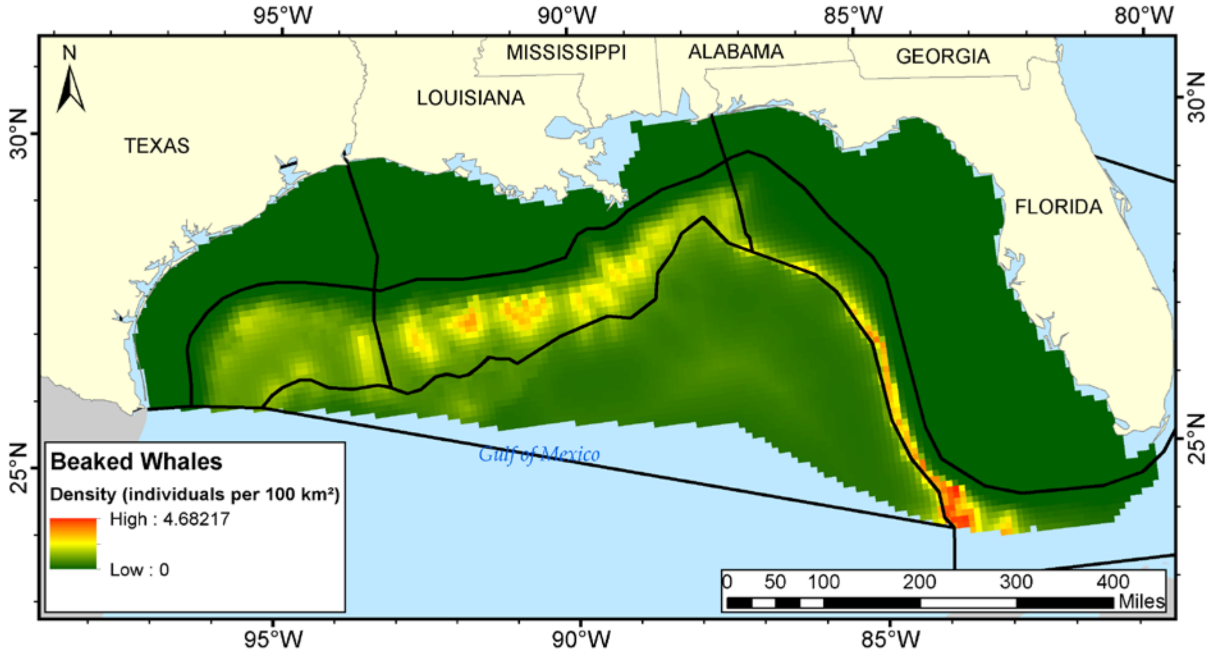

Figure G-1. Beaked whale distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

G.3. Common Bottlenose Dolphins

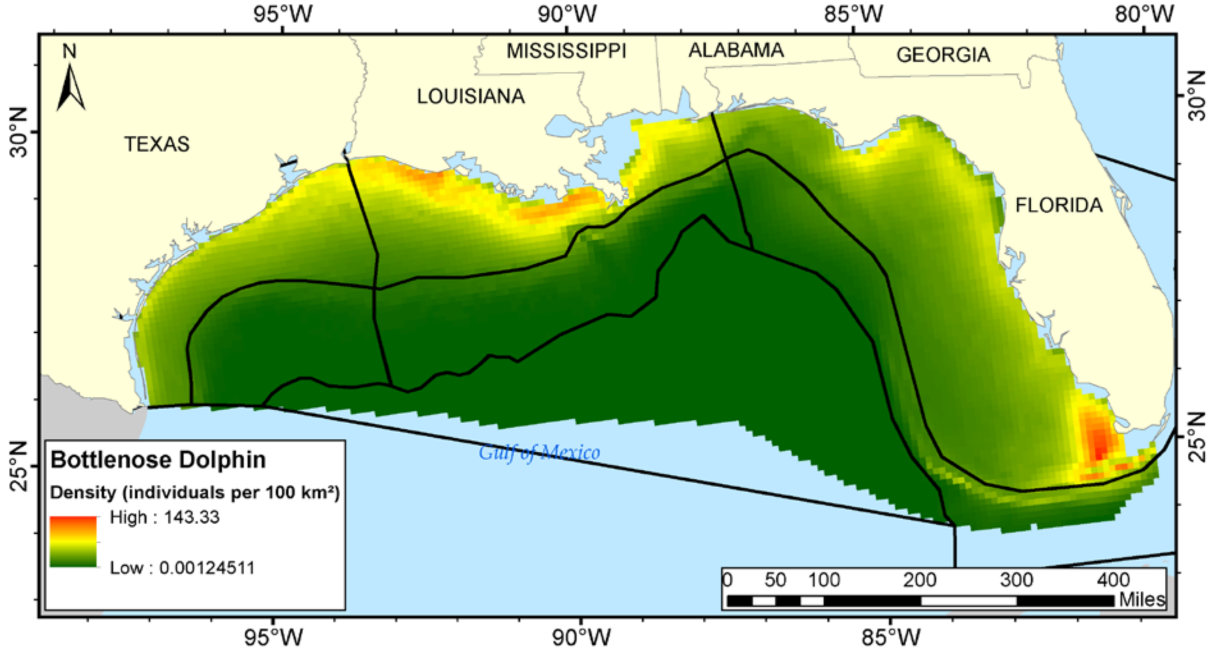

Figure G-2. Common bottlenose dolphin distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

G.4. Bryde's Whales

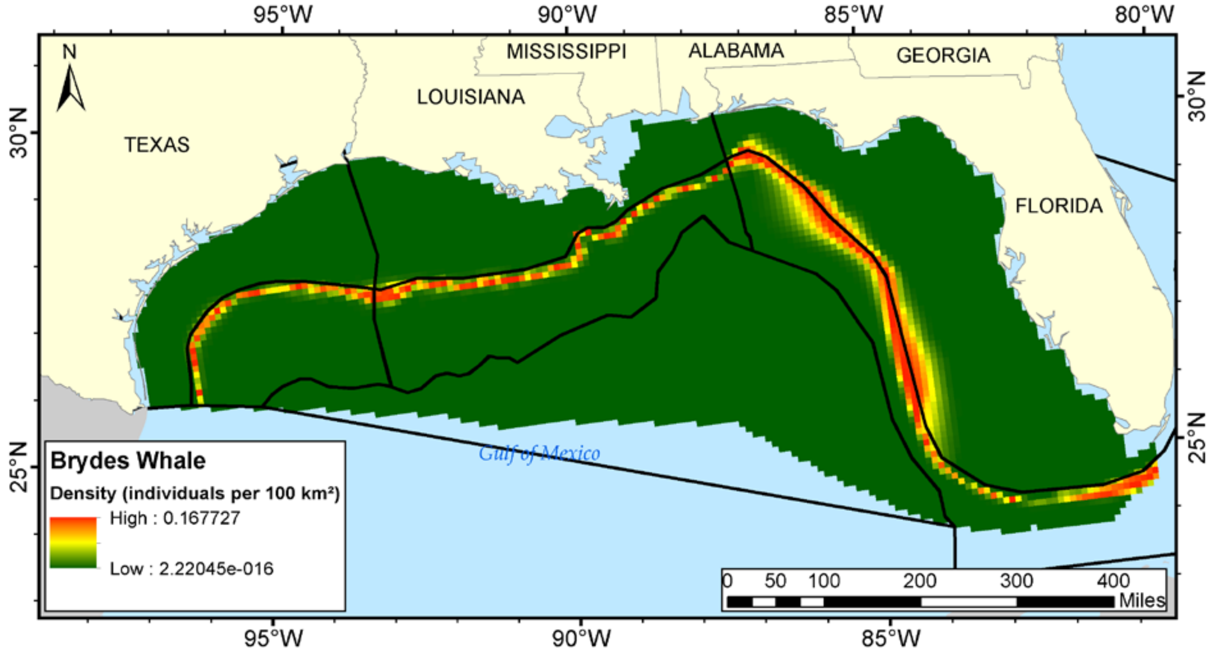

Figure G-3. Bryde's whale distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

G.5. Kogia Species

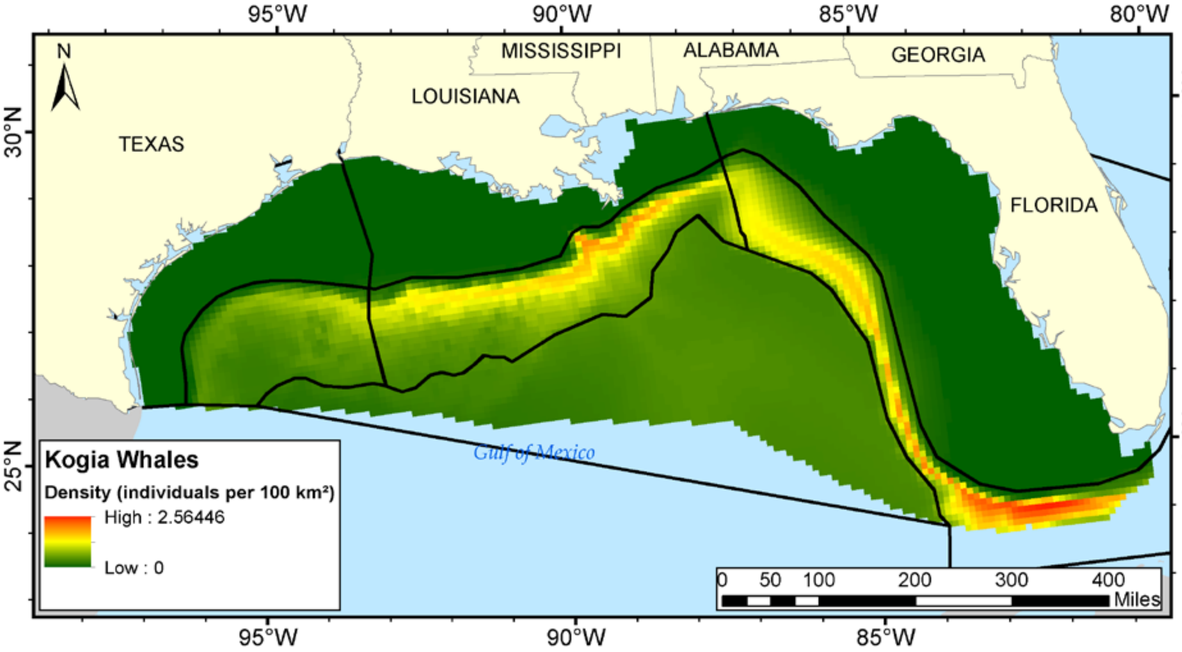

Figure G-4. *Kogia* distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

G.6. Short-finned Pilot Whales

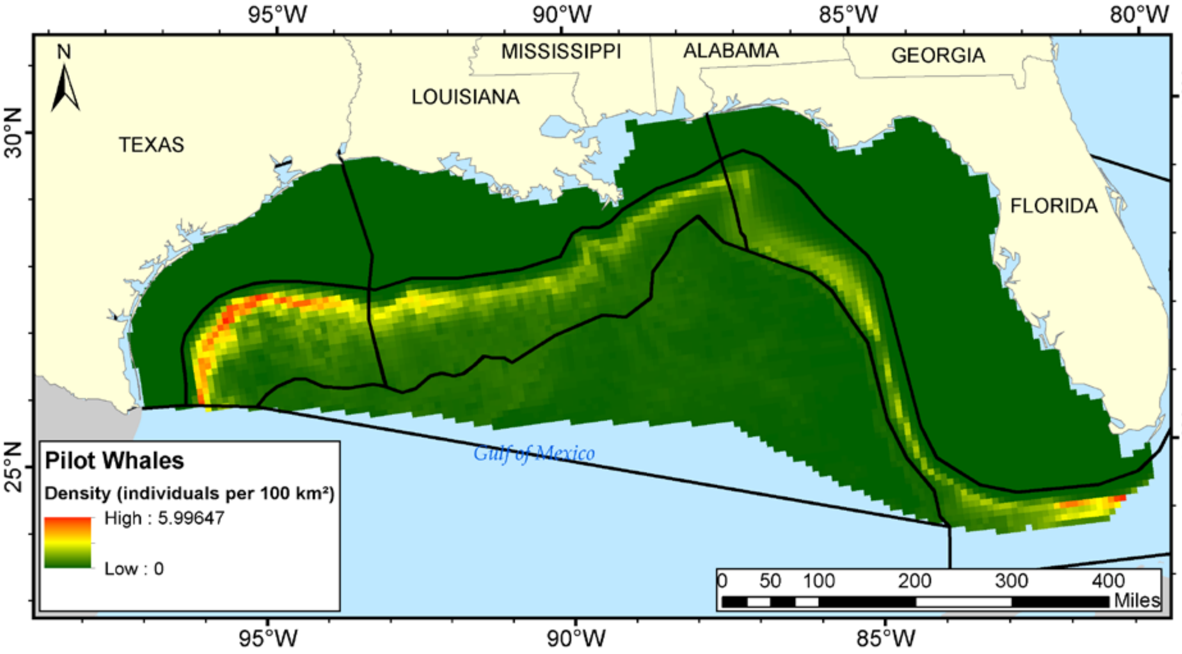

Figure G-5. Short-finned pilot whale distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

G.7. Sperm Whales

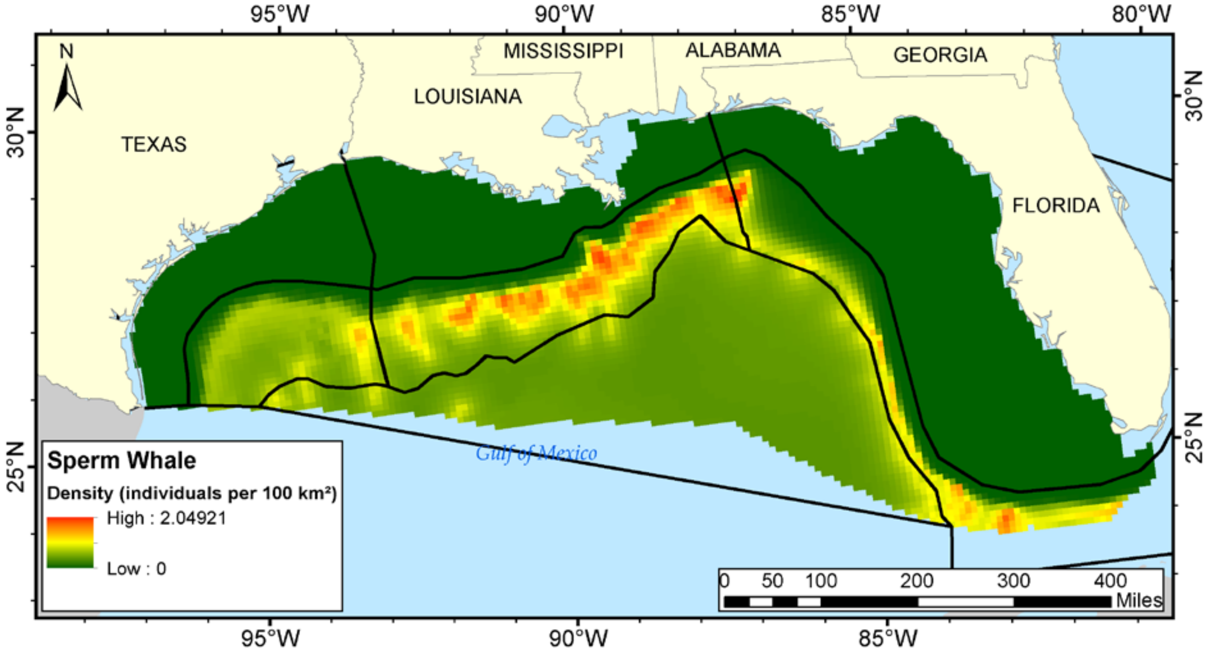

Figure G-6. Sperm whale distribution in the Gulf of Mexico project area. Density estimates were obtained from the Marine Geospatial Ecology Laboratory (Duke University) model (Roberts et al. 2016a), black lines depict the boundaries of the modeling zones.

Appendix H. Alternate Density Estimates

*** From IAGC ***

EXPLANATION OF ALTERNATE DENSITY VALUES

There is general agreement that the NMFS official Stock Assessment Report (SAR) minimum population estimates are probably not the best metric of actual GOM marine mammal population numbers and distribution, based on infrequent data sampling, and conservative assumptions in the Distance modeling (e.g. G_0=1.0). We therefore did not derive our density estimates from SAR data, although the surprisingly unexpected disparity between SAR values and the Duke model in many cases led us to adjust (halve) average regional densities derived from CETMAP/Duke information, at least until the Duke model can be tested and verified, or adjusted with new data. For two species for which there has been no SAR estimate since 2009 (Atlantic spotted dolphins and Frasers dolphins) we used historical NOAA SAR estimates from the 1996-2004 time period.

It may turn out, after additional future survey effort and further model iterations, that the values forecast by the Duke model are closer to the actual numbers of animals than the SARs, but dramatic leaps of as much as 10 to 85 times the previous SAR values for some species (notably Clymene dolphins, and Kogia spp.) led us to halve density values that were more than 3 times historical SAR estimates. We are not taking the position that the CETMAP and Duke estimates are incorrect, but we did note that these dramatic and unprecedented differences would contribute to dramatically increased MMPA take estimates and that the Duke model is not at this time sufficiently verified and validated to employ without some reservations.

Since the purpose of this exercise was to illustrate how the use of alternate numbers would affect model outcome, and was not come up with a "better estimate than any other", we chose a somewhat arbitrary "middle ground" for the sole purpose of illustrating model sensitivity. We did not choose those numbers to make a statement about what might or might not be a better alternative than the Duke model values. Building confidence in the Duke values or adopting an alternate set of values would require more data collection as well as model refinement.

We concur with JASCO that using the direct Duke model predictions for 100 km^2 density values is vulnerable to sampling errors during the modeling process. Geophysical surveys will not be distributed evenly but their specific locations cannot be predicted, and animal distributions are similarly variable and hard to predict for a given date and location. Use of a smoothed average across a manageable number of oceanographic, acoustic and ecological provinces is therefore the best choice for modeling the likely outcome for any given year's activities and animal distribution.

Gulf population estimates on the NOAA CETMAP website generally produced population estimates for each species in GOM that are very similar to the JASCO values used in the BOEM DPEIS. Both are derived from the same Duke model geospatial distribution data, though our estimates were derived in a different way than JASCO handled the Duke density values. Specifically, we divided the CETMAP total population estimate in proportion to the relative size of each region and the average density value for each region so that the summed population estimates within each region would add up to the CETMAP total population estimate. In two notable cases, for Brydes whales and for short-finned pilot whales, JASCO's method of averaging density values within a region without regard to the CETMAP total population estimate yielded total GOM population estimates that greatly differed from CETMAP estimates. For example, CETMAP offers a Bryde's whale population total for the Gulf of 44 individuals, not far from historical SAR values of 33 individuals. But the JASCO model predicts a population of 256 or almost six times the NOAA CETMAP population estimate. In those unusual cases we relied on the CETMAP-derived regional density estimates, and those will differ significantly from the values previously used in the BOEM DPEIS.

The specific rationales for choosing the density values we offered for each species are presented in the accompanying Excel spreadsheet, along with the regional average density values themselves. The total GOM population estimates for each species from recent Stock Assessment Reports (SAR), CETMAP and the JASCO Appendix D of the BOEM Gulf of Mexico DPEIS are also provided to indicate those species for which SARs, CETMAP and JASCO provide similar numbers, and those species for which the three sources disagree considerably, prompting an adjustment on our part to previously used regional density values.

When differences between SARs, CETMAP, and JASCO population estimates were less than 300% (no value was three times greater than any other) we used the CETMAP-based values, which were very similar to the JASCO values (with the two exceptions noted earlier). But where differences between population estimates were three, four or as much as ten, twelve or even 85 times historical SAR values, we halved the CETMAP-based value. We consider this a conservative compromise until we have a better understanding of whether the new models like the Duke model may have made some seriously incorrect assumptions about the habitat use and ecology of some species, requiring further model refinement and testing. These differences not only have a dramatic effect on the estimated sound exposure risk from geophysical surveys but also imply dramatic consequences for our understanding of the Gulf ecosystem, it’s productivity, trophic dynamics, and vulnerability to anthropogenic or natural perturbations like fishery bycatch and Loop Current dynamics.

It is important to repeat that our choice of regional density values was guided to some degree by the aim of offering numbers sufficiently different from the original JASCO values to produce a discernable difference in model outcome. But our choices were not completely arbitrary, and are based on a consistent rationale, as described above.

Table H-1.

Species	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	SAR	CetMap	JASCO	Comments
Atlantic spotted dolphins	19.336809	7.370539	8.097456	2.749779	2.007792	1.25886	0.000004	37611	47488	48040	No SAR estimate, so 2000-2004 values were applied. CETMAP-based density values were used
Beaked whales (3)	0.0000535	0.0000015	0.0000005	0.362261	0.5395315	0.4154535	0.259323	223	2910	2915	CetMap estimates are more than 10 times SAR, CETMAP-based density values were halved
Bottlenose dolphins (mult stocks)	36.793692	52.602121	39.048966	11.44879	5.676799	3.312454	0.027233	96732	138602	139869	not surprisingly, SARs, CETMAP and JASCO agree relatively closely on these generally well-characterized stocks (especially estuarine and coastal). CETMAP values were used
Bryde's whales	0.02109	0.000028	0.000007	0.006048	0.002497	0.002354	0	33	44	256	JASCO's use of the Duke density data led to much larger population estimates than either CETMAP or SAR, so CETMAP was used
Clymene dolphins	0.000394	0.000001	0	0.459086	1.71583	2.1406395	1.319643	129	11000	10952	CETMAP and JASCO model were 85 times greater than SAR, CETMAP-based densities were halved
False killer whales	0.0615285	0.0142795	0.0065685	0.361636	0.3611945	0.365652	0.37178	777	3204	3224	CETMAP and JASCO model were four times greater than SAR, CETMAP-based densities were halved
Fraser's dolphins	0.063948	0.014841	0.006827	0.375853	0.375394	0.380026	0.386406	726	1665	1675	CETMAP and JASCO numbers were a little over double the SARs, CETMAP-based densities were used
Killer whales	0.000195	0.000082	0.000085	0.0066	0.010028	0.009839	0.038745	28	185	186	CETMAP and JASCO numbers were five times the SARs, CETMAP-based densities were halved
kogia (2)	0.008172	0.0004675	0.0000935	0.478119	0.3625715	0.2051045	0.170741	186	2234	2239	CETMAP and JASCO numbers were 12 times higher than SAR, CETMAP-based densities were halved
Melon-headed whales	0.001345	0.0000905	0.000031	0.5908705	1.104694	0.9449345	0.766659	2235	6733	6734	CETMAP and JASCO numbers were 3 times higher than SAR, CETMAP-based densities were halved
Pantropical spotted dolphins	0.110796	0.002309	0.000595	21.688002	15.447613	9.828148	25.992595	50880	84014	84322	CETMAP and JASCO numbers were less than double the SAR, CETMAP-based densities were used
Pygmy killer whale	0.000141	0.0000055	0.0000025	0.368834	0.343913	0.672459	0.0654055	152	2126	1976	CETMAP and JASCO numbers were about 13 times higher than SAR, CETMAP-based densities were halved
Risso's dolphins	0.001848	0.000115	0.000043	0.437355	0.673816	0.702498	0.975053	2442	3137	2127	CETMAP and JASCO numbers were less than double the SAR, CETMAP-based densities were used
Rough-toothed dolphins	0.0137505	0.000643	0.0002285	1.093325	0.7489755	0.6119455	0.3233085	624	4853	3151	CETMAP and JASCO numbers were 5 to 7 times higher than SAR, CETMAP-based densities were halved
Short-finned pilot whales	0.164829	0.160061	0.160709	0.390128	0.425843	0.404707	0.323965	2417	1981	4885	JASCO's use of the Duke density data led to much larger population estimates than either CETMAP or SAR, so CETMAP was used
Sperm whales	0.0000795	0.0000035	0.000001	0.240159	0.361147	0.2423325	0.23259	763	2128	2136	CETMAP and JASCO numbers were about 3 times higher than the SAR and the SAR data are stronger for sperm whales than most other GOM species. CETMAP-based densities were halved
Spinner dolphins	0.018356	0	0	11.676661	4.124051	0.234841	0.607681	11441	13485	13584	CETMAP and JASCO numbers were close and near SAR, CETMAP-based densities were used.
Striped dolphins	0.002593	0.000025	0.00003	0.796473	1.329813	1.087864	1.360301	1849	4914	4931	CETMAP and JASCO numbers were about 2.7 times higher than SAR, CETMAP-based densities were used.

Appendix I. Survey Level of Effort

Survey effort in miles by year and zone, supplied by BOEM (same as used in PEIS).

I.1. 2 D Seismic Survey

Year	Eastern Shallow	Central Shallow	Western Shallow	Eastern Deep	Central Deep	Western Deep
2016	0	0	0	0	12,000	0
2017	0	0	0	6,000	0	0
2018	0	0	0	0	0	0
2019	0	0	0	12,000	6,000	0
2020	0	0	0	0	0	0
2021	0	0	0	0	0	0
2022	0	0	0	6,000	6,000	0
2023	0	0	0	2,000	2,000	0
2024	0	0	0	0	0	0
2025	0	0	0	1,000	0	0
Total	0	0	0	27,000	26,000	0

I.2. 3-D Narrow Azimuth Seismic Survey

Year	Eastern Shallow	Central Shallow	Western Shallow	Eastern Deep	Central Deep	Western Deep
2016	0	23,292	2,911	0	84,070	20,583
2017	0	34,938	0	0	84,070	11,000
2018	0	23,292	0	0	73,856	20,588
2019	0	34,938	2,911	11,200	53,428	11,000
2020	0	23,292	0	16,800	63,642	11,000
2021	0	34,938	0	16,800	53,428	20,588
2022	0	23,292	2,911	11,200	53,428	11,000
2023	0	34,938	0	11,200	53,428	11,000
2024	0	23,292	0	11,200	43,214	11,000
2025	0	34,938	2,911	11,200	43,214	11,000
Total	0	291,150	11,644	89,600	605,778	138,759

I.3. 3-D Wide Azimuth Seismic Survey

Year	Eastern Shallow	Central Shallow	Western Shallow	Eastern Deep	Central Deep	Western Deep
2016	0	0	0	0	41,551	5,397
2017	0	4,155	0	0	41,551	0
2018	0	0	0	0	34,626	5,397
2019	0	4,155	0	3,920	20,775	0
2020	0	0	0	0	41,551	0
2021	0	4,155	0	0	34,626	5,397
2022	0	0	0	3,920	34,626	0
2023	0	4,155	0	0	27,700	0
2024	0	0	0	0	41,551	0
2025	0	4,155	0	0	34,626	0
Total	0	20,773	0	7,840	353,180	16,191

I.4. Coil Seismic Survey

Year	Eastern Shallow	Central Shallow	Western Shallow	Eastern Deep	Central Deep	Western Deep
2016	0	0	0	0	17,807	2,313
2017	0	1,781	0	0	17,807	0
2018	0	0	0	0	14,840	2,313
2019	0	1,781	0	1,680	8,904	0
2020	0	0	0	0	17,807	0
2021	0	1,781	0	0	14,840	2,313
2022	0	0	0	1,680	14,840	0
2023	0	1,781	0	0	11,872	0
2024	0	0	0	0	17,807	0
2025	0	1,781	0	0	14,840	0
Total	0	8,903	0	3,360	151,363	6,939

Appendix J. Annual Exposure Estimates

J.1. No Aversion, PEIS Marine Mammal Density Estimates

J.1.1. 2016

Table J-1. 2016 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	5232
Bottlenose dolphins	0	0	3732
Bryde's whales	0	0	27
Kogia spp.	50	0	447
Short-finned pilot whales	0	0	441
Sperm whales	0	0	955

Table J-2. 2016 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	51384
Bottlenose dolphins	34	0	365055
Bryde's whales	1	5	300
Kogia spp.	712	0	4490
Short-finned pilot whales	0	0	6290
Sperm whales	1	0	10383

Table J-3. 2016 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	22258
Bottlenose dolphins	4	0	18884
Bryde's whales	0	0	135
Kogia spp.	715	0	2341
Short-finned pilot whales	0	0	2733
Sperm whales	0	0	4809

Table J-4. 2016 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	5633.6
Bottlenose dolphins	2	0	4395.9
Bryde's whales	0	2	31.0
Kogia spp.	228	0	602.9
Short-finned pilot whales	0	0	710.3
Sperm whales	0	0	1313.6

J.1.2. 2017

Table J-5. 2017 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1680
Bottlenose dolphins	0	0	2903
Bryde's whales	0	0	32
Kogia spp.	34	0	235
Short-finned pilot whales	0	0	195
Sperm whales	0	0	183

Table J-6. 2017 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	46867
Bottlenose dolphins	39	0	491101
Bryde's whales	1	4	262
Kogia spp.	662	0	4174
Short-finned pilot whales	0	0	5079
Sperm whales	1	0	9367

Table J-7. 2017 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	19775
Bottlenose dolphins	4	0	74562
Bryde's whales	0	0	112
Kogia spp.	651	0	2136
Short-finned pilot whales	0	0	1976
Sperm whales	0	0	4246

Table J-8. 2017 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4991
Bottlenose dolphins	6	0	15734
Bryde's whales	0	2	26
Kogia spp.	208	0	550
Short-finned pilot whales	0	0	521
Sperm whales	0	0	1151

J.1.3. 2018

Table J-9. 2018 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-10. 2018 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	46322
Bottlenose dolphins	27	0	337980
Bryde’s whales	1	4	274
Kogia spp.	638	0	4027
Short-finned pilot whales	0	0	5843
Sperm whales	1	0	9387

Table J-11. 2018 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	18962
Bottlenose dolphins	4	0	16089
Bryde’s whales	0	0	117
Kogia spp.	607	0	1985
Short-finned pilot whales	0	0	2404
Sperm whales	0	0	4101

Table J-12. 2018 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	4802
Bottlenose dolphins	2	0	3751
Bryde’s whales	0	2	27
Kogia spp.	193	0	511
Short-finned pilot whales	0	0	623
Sperm whales	0	0	1122

J.1.4. 2019

Table J-13. 2019 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	5976
Bottlenose dolphins	0	0	7672
Bryde's whales	0	0	78
Kogia spp.	93	0	693
Short-finned pilot whales	0	0	612
Sperm whales	0	0	844

Table J-14. 2019 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	35223
Bottlenose dolphins	47	0	510215
Bryde's whales	1	4	248
Kogia spp.	548	0	3312
Short-finned pilot whales	0	0	4170
Sperm whales	1	0	6797

Table J-15. 2019 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	11129
Bottlenose dolphins	2	0	68848
Bryde's whales	0	0	81
Kogia spp.	405	0	1285
Short-finned pilot whales	0	0	1161
Sperm whales	0	0	2293

Table J-16. 2019 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	2793
Bottlenose dolphins	6	0	14342
Bryde’s whales	0	1	17
Kogia spp.	131	0	336
Short-finned pilot whales	0	0	306
Sperm whales	0	0	609

J.1.5. 2020

Table J-17. 2020 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde’s whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-18. 2020 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	42062
Bottlenose dolphins	26	0	340812
Bryde’s whales	1	5	307
Kogia spp.	674	0	4034
Short-finned pilot whales	0	0	4835
Sperm whales	1	0	8003

Table J-19. 2020 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	19775
Bottlenose dolphins	4	0	16772
Bryde's whales	0	0	112
Kogia spp.	651	0	2135
Short-finned pilot whales	0	0	1976
Sperm whales	0	0	4246

Table J-20. 2020 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4991
Bottlenose dolphins	2	0	3870
Bryde's whales	0	2	26
Kogia spp.	208	0	550
Short-finned pilot whales	0	0	521
Sperm whales	0	0	1151

J.1.6. 2021

Table J-21. 2021 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-22. 2021 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	41517
Bottlenose dolphins	40	0	493039
Bryde's whales	1	5	319
Kogia spp.	650	0	3892
Short-finned pilot whales	0	0	5599
Sperm whales	1	0	8024

Table J-23. 2021 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	18962
Bottlenose dolphins	4	0	73879
Bryde's whales	0	0	117
Kogia spp.	607	0	1986
Short-finned pilot whales	0	0	2404
Sperm whales	0	0	4101

Table J-24. 2021 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4802
Bottlenose dolphins	6	0	15615
Bryde's whales	0	2	27
Kogia spp.	193	0	511
Short-finned pilot whales	0	0	623
Sperm whales	0	0	1122

J.1.7. 2022

Table J-25. 2022 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4296
Bottlenose dolphins	0	0	4769
Bryde's whales	0	0	46
Kogia spp.	59	0	458
Short-finned pilot whales	0	0	416
Sperm whales	0	0	661

Table J-26. 2022 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	35223
Bottlenose dolphins	34	0	357541
Bryde's whales	1	4	248
Kogia spp.	547	0	3310
Short-finned pilot whales	0	0	4169
Sperm whales	1	0	6797

Table J-27. 2022 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	17720
Bottlenose dolphins	4	0	16649
Bryde's whales	0	0	118
Kogia spp.	622	0	1996
Short-finned pilot whales	0	0	1820
Sperm whales	0	0	3708

Table J-28. 2022 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4456
Bottlenose dolphins	3	0	3768
Bryde's whales	0	2	26
Kogia spp.	201	0	519
Short-finned pilot whales	0	0	479
Sperm whales	0	0	993

J.1.8. 2023

Table J-29. 2023 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1432
Bottlenose dolphins	0	0	1590
Bryde's whales	0	0	15
Kogia spp.	20	0	153
Short-finned pilot whales	0	0	139
Sperm whales	0	0	220

Table J-30. 2023 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	35223
Bottlenose dolphins	39	0	486721
Bryde's whales	1	4	248
Kogia spp.	548	0	3312
Short-finned pilot whales	0	0	4170
Sperm whales	1	0	6797

Table J-31. 2023 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	13183
Bottlenose dolphins	3	0	68971
Bryde's whales	0	0	75
Kogia spp.	434	0	1424
Short-finned pilot whales	0	0	1318
Sperm whales	0	0	2831

Table J-32. 2023 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	3328
Bottlenose dolphins	5	0	14444
Bryde's whales	0	1	17
Kogia spp.	139	0	367
Short-finned pilot whales	0	0	348
Sperm whales	0	0	767

J.1.9. 2024

Table J-33. 2024 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-34. 2024 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	22230
Bottlenose dolphins	26	0	204336
Bryde's whales	1	4	180
Kogia spp.	474	0	2093
Short-finned pilot whales	0	0	2733
Sperm whales	1	0	4297

Table J-35. 2024 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	14598
Bottlenose dolphins	4	0	12301
Bryde's whales	0	0	95
Kogia spp.	651	0	1584
Short-finned pilot whales	0	0	1460
Sperm whales	0	0	3152

Table J-36. 2024 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	3675
Bottlenose dolphins	2	0	2804
Bryde's whales	0	2	23
Kogia spp.	208	0	407
Short-finned pilot whales	0	0	385
Sperm whales	0	0	850

J.1.10. 2025

Table J-37. 2025 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	280
Bottlenose dolphins	0	0	484
Bryde’s whales	0	0	5
Kogia spp.	6	0	39
Short-finned pilot whales	0	0	33
Sperm whales	0	0	31

Table J-38. 2025 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	30159
Bottlenose dolphins	47	0	506633
Bryde’s whales	1	4	221
Kogia spp.	474	0	2850
Short-finned pilot whales	0	0	3721
Sperm whales	1	0	5801

Table J-39. 2025 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	16479
Bottlenose dolphins	4	0	71766
Bryde’s whales	0	0	93
Kogia spp.	542	0	1780
Short-finned pilot whales	0	0	1647
Sperm whales	0	0	3538

Table J-40. 2025 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4159
Bottlenose dolphins	6	0	15089
Bryde's whales	0	1	21
Kogia spp.	174	0	459
Short-finned pilot whales	0	0	435
Sperm whales	0	0	959

J.2. Aversion, PEIS Marine Mammal Density Estimates

Table J-41. 2016 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4982
Bottlenose dolphins	1	0	3724
Bryde's whales	0	0	27
Kogia spp.	27	0	459
Short-finned pilot whales	0	0	470
Sperm whales	0	0	936

Table J-42. 2016 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	47811
Bottlenose dolphins	6	0	357577
Bryde's whales	1	4	297
Kogia spp.	436	1	4790
Short-finned pilot whales	0	0	6694
Sperm whales	1	0	9929

Table J-43. 2016 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	21475
Bottlenose dolphins	1	0	18561
Bryde’s whales	0	0	134
Kogia spp.	406	0	2444
Short-finned pilot whales	0	0	2862
Sperm whales	0	0	4665

Table J-44. 2016 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	4797
Bottlenose dolphins	1	0	4256
Bryde’s whales	0	2	30
Kogia spp.	119	0	575
Short-finned pilot whales	0	0	654
Sperm whales	0	0	1156

J.2.1. 2017

Table J-45. 2017 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	1392
Bottlenose dolphins	0	0	2901
Bryde’s whales	0	0	32
Kogia spp.	23	0	254
Short-finned pilot whales	0	0	213
Sperm whales	0	0	181

Table J-46. 2017 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	43389
Bottlenose dolphins	6	0	480531
Bryde's whales	0	4	259
Kogia spp.	405	1	4451
Short-finned pilot whales	0	0	5406
Sperm whales	0	0	8953

Table J-47. 2017 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	19012
Bottlenose dolphins	1	0	72451
Bryde's whales	0	0	112
Kogia spp.	369	0	2226
Short-finned pilot whales	0	0	2078
Sperm whales	0	0	4117

Table J-48. 2017 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4199
Bottlenose dolphins	0	0	14831
Bryde's whales	0	2	25
Kogia spp.	108	0	525
Short-finned pilot whales	0	0	481
Sperm whales	0	0	1018

J.2.2. 2018

Table J-49. 2018 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-50. 2018 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	43158
Bottlenose dolphins	6	0	330971
Bryde's whales	1	4	271
Kogia spp.	391	1	4298
Short-finned pilot whales	0	0	6218
Sperm whales	1	0	8978

Table J-51. 2018 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	18306
Bottlenose dolphins	0	0	15817
Bryde's whales	0	0	116
Kogia spp.	344	0	2073
Short-finned pilot whales	0	0	2516
Sperm whales	0	0	3979

Table J-52. 2018 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	4097
Bottlenose dolphins	1	0	3631
Bryde's whales	0	2	26
Kogia spp.	101	0	487
Short-finned pilot whales	0	0	573
Sperm whales	0	0	986

J.2.3. 2019

Table J-53. 2019 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	5274
Bottlenose dolphins	0	0	7664
Bryde's whales	0	0	78
Kogia spp.	60	0	738
Short-finned pilot whales	0	0	661
Sperm whales	0	0	831

Table J-54. 2019 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	32147
Bottlenose dolphins	6	0	499159
Bryde's whales	1	4	245
Kogia spp.	346	1	3551
Short-finned pilot whales	0	0	4457
Sperm whales	0	0	6506

Table J-55. 2019 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	10545
Bottlenose dolphins	0	0	66778
Bryde's whales	0	0	80
Kogia spp.	240	0	1353
Short-finned pilot whales	0	0	1230
Sperm whales	0	0	2225

Table J-56. 2019 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2251
Bottlenose dolphins	0	0	13485
Bryde's whales	0	1	17
Kogia spp.	70	0	320
Short-finned pilot whales	0	0	282
Sperm whales	0	0	543

J.2.4. 2020

Table J-57. 2020 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-58. 2020 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	38163
Bottlenose dolphins	8	0	333638
Bryde’s whales	1	5	303
Kogia spp.	429	1	4330
Short-finned pilot whales	0	0	5176
Sperm whales	0	0	7662

Table J-59. 2020 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	19012
Bottlenose dolphins	1	0	16467
Bryde’s whales	0	0	112
Kogia spp.	369	0	2225
Short-finned pilot whales	0	0	2078
Sperm whales	0	0	4117

Table J-60. 2020 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	4199
Bottlenose dolphins	0	0	3747
Bryde’s whales	0	2	25
Kogia spp.	108	0	525
Short-finned pilot whales	0	0	481
Sperm whales	0	0	1018

J.2.5. 2021

Table J-61. 2021 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-62. 2021 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	37931
Bottlenose dolphins	7	0	482438
Bryde's whales	1	5	315
Kogia spp.	416	1	4182
Short-finned pilot whales	0	0	5987
Sperm whales	1	0	7687

Table J-63. 2021 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	18306
Bottlenose dolphins	0	0	71800
Bryde's whales	0	0	116
Kogia spp.	344	0	2074
Short-finned pilot whales	0	0	2516
Sperm whales	0	0	3979

Table J-64. 2021 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	4097
Bottlenose dolphins	1	0	14715
Bryde’s whales	0	2	26
Kogia spp.	101	0	487
Short-finned pilot whales	0	0	573
Sperm whales	0	0	986

J.2.6. 2022

Table J-65. 2022 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	3883
Bottlenose dolphins	0	0	4763
Bryde’s whales	0	0	46
Kogia spp.	37	0	484
Short-finned pilot whales	0	0	448
Sperm whales	0	0	649

Table J-66. 2022 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	32147
Bottlenose dolphins	6	0	349979
Bryde’s whales	1	4	245
Kogia spp.	346	1	3549
Short-finned pilot whales	0	0	4457
Sperm whales	0	0	6506

Table J-67. 2022 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	16882
Bottlenose dolphins	0	0	16284
Bryde's whales	0	0	118
Kogia spp.	362	0	2094
Short-finned pilot whales	0	0	1923
Sperm whales	0	0	3598

Table J-68. 2022 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	3651
Bottlenose dolphins	1	0	3650
Bryde's whales	0	2	25
Kogia spp.	106	0	495
Short-finned pilot whales	0	0	442
Sperm whales	0	0	882

J.2.7. 2023

Table J-69. 2023 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1294
Bottlenose dolphins	0	0	1588
Bryde's whales	0	0	15
Kogia spp.	12	0	161
Short-finned pilot whales	0	0	149
Sperm whales	0	0	216

Table J-70. 2023 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	32147
Bottlenose dolphins	6	0	476116
Bryde's whales	1	4	245
Kogia spp.	346	1	3551
Short-finned pilot whales	0	0	4457
Sperm whales	0	0	6506

Table J-71. 2023 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	12675
Bottlenose dolphins	0	0	66961
Bryde's whales	0	0	74
Kogia spp.	246	0	1484
Short-finned pilot whales	0	0	1385
Sperm whales	0	0	2745

Table J-72. 2023 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2800
Bottlenose dolphins	0	0	13582
Bryde's whales	0	1	16
Kogia spp.	72	0	350
Short-finned pilot whales	0	0	321
Sperm whales	0	0	679

J.2.8. 2024

Table J-73. 2024 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-74. 2024 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	20301
Bottlenose dolphins	5	0	199285
Bryde's whales	0	3	178
Kogia spp.	301	1	2262
Short-finned pilot whales	0	0	2950
Sperm whales	0	0	4114

Table J-75. 2024 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	14093
Bottlenose dolphins	1	0	12062
Bryde's whales	0	0	96
Kogia spp.	369	0	1655
Short-finned pilot whales	0	0	1542
Sperm whales	0	0	3054

Table J-76. 2024 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	3100
Bottlenose dolphins	0	0	2705
Bryde’s whales	0	2	22
Kogia spp.	108	0	391
Short-finned pilot whales	0	0	355
Sperm whales	0	0	750

J.2.9. 2025

Table J-77. 2025 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	232
Bottlenose dolphins	0	0	484
Bryde’s whales	0	0	5
Kogia spp.	4	0	42
Short-finned pilot whales	0	0	35
Sperm whales	0	0	30

Table J-78. 2025 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	27492
Bottlenose dolphins	5	0	495595
Bryde’s whales	0	3	219
Kogia spp.	302	1	3059
Short-finned pilot whales	0	0	3980
Sperm whales	0	0	5555

Table J-79. 2025 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	15843
Bottlenose dolphins	0	0	69706
Bryde’s whales	0	0	93
Kogia spp.	308	0	1855
Short-finned pilot whales	0	0	1732
Sperm whales	0	0	3431

Table J-80. 2025 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	3499
Bottlenose dolphins	0	0	14206
Bryde’s whales	0	1	21
Kogia spp.	90	0	437
Short-finned pilot whales	0	0	401
Sperm whales	0	0	849

J.3. No Aversion, Alternate Marine Mammal Density Estimates

Table J-81. 2016 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2612
Bottlenose dolphins	0	0	3698
Bryde's whales	0	0	5
Kogia spp.	25	0	223
Short-finned pilot whales	0	0	380
Sperm whales	0	0	476

Table J-82. 2016 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	25648
Bottlenose dolphins	34	0	361748
Bryde's whales	0	1	52
Kogia spp.	355	0	2240
Short-finned pilot whales	0	0	5123
Sperm whales	1	0	5171

Table J-83. 2016 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	11110
Bottlenose dolphins	4	0	18713
Bryde's whales	0	0	23
Kogia spp.	357	0	1168
Short-finned pilot whales	0	0	2074
Sperm whales	0	0	2395

Table J-84. 2016 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2812
Bottlenose dolphins	2	0	4356
Bryde's whales	0	0	5
Kogia spp.	114	0	301
Short-finned pilot whales	0	0	561
Sperm whales	0	0	654

J.3.1. 2017

Table J-85. 2017 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	838
Bottlenose dolphins	0	0	2877
Bryde's whales	0	0	5
Kogia spp.	17	0	117
Short-finned pilot whales	0	0	149
Sperm whales	0	0	91

Table J-86. 2017 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	23393
Bottlenose dolphins	39	0	486653
Bryde's whales	0	1	45
Kogia spp.	330	0	2083
Short-finned pilot whales	0	0	5037
Sperm whales	1	0	4665

Table J-87. 2017 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9870
Bottlenose dolphins	4	0	73886
Bryde's whales	0	0	19
Kogia spp.	325	0	1066
Short-finned pilot whales	0	0	1959
Sperm whales	0	0	2115

Table J-88. 2017 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2491
Bottlenose dolphins	6	0	15592
Bryde's whales	0	0	4
Kogia spp.	104	0	275
Short-finned pilot whales	0	0	526
Sperm whales	0	0	573

J.3.2. 2018

Table J-89. 2018 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-90. 2018 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	23121
Bottlenose dolphins	27	0	334919
Bryde's whales	0	1	47
Kogia spp.	318	0	2009
Short-finned pilot whales	0	0	4633
Sperm whales	0	0	4675

Table J-91. 2018 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9465
Bottlenose dolphins	4	0	15943
Bryde's whales	0	0	20
Kogia spp.	303	0	990
Short-finned pilot whales	0	0	1772
Sperm whales	0	0	2042

Table J-92. 2018 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2397
Bottlenose dolphins	2	0	3717
Bryde's whales	0	0	5
Kogia spp.	96	0	255
Short-finned pilot whales	0	0	479
Sperm whales	0	0	559

J.3.3. 2019

Table J-93. 2019 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	2983
Bottlenose dolphins	0	0	7603
Bryde’s whales	0	0	13
Kogia spp.	46	0	346
Short-finned pilot whales	0	0	489
Sperm whales	0	0	420

Table J-94. 2019 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	17581
Bottlenose dolphins	46	0	505594
Bryde’s whales	0	1	43
Kogia spp.	273	0	1653
Short-finned pilot whales	0	0	4277
Sperm whales	0	0	3385

Table J-95. 2019 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	5555
Bottlenose dolphins	2	0	68225
Bryde’s whales	0	0	14
Kogia spp.	202	0	641
Short-finned pilot whales	0	0	1193
Sperm whales	0	0	1142

Table J-96. 2019 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1394
Bottlenose dolphins	6	0	14212
Bryde's whales	0	0	3
Kogia spp.	65	0	168
Short-finned pilot whales	0	0	316
Sperm whales	0	0	303

J.3.4. 2020

Table J-97. 2020 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-98. 2020 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	20995
Bottlenose dolphins	26	0	337725
Bryde's whales	0	1	53
Kogia spp.	336	0	2013
Short-finned pilot whales	0	0	4334
Sperm whales	0	0	3986

Table J-99. 2020 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9870
Bottlenose dolphins	4	0	16620
Bryde's whales	0	0	19
Kogia spp.	325	0	1065
Short-finned pilot whales	0	0	1811
Sperm whales	0	0	2115

Table J-100. 2020 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2491
Bottlenose dolphins	2	0	3835
Bryde's whales	0	0	4
Kogia spp.	104	0	274
Short-finned pilot whales	0	0	495
Sperm whales	0	0	573

J.3.5. 2021

Table J-101. 2021 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-102. 2021 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	20722
Bottlenose dolphins	40	0	488573
Bryde's whales	0	1	55
Kogia spp.	324	0	1942
Short-finned pilot whales	0	0	4778
Sperm whales	0	0	3996

Table J-103. 2021 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9465
Bottlenose dolphins	4	0	73209
Bryde's whales	0	0	20
Kogia spp.	303	0	991
Short-finned pilot whales	0	0	1920
Sperm whales	0	0	2042

Table J-104. 2021 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2397
Bottlenose dolphins	6	0	15473
Bryde's whales	0	0	5
Kogia spp.	96	0	255
Short-finned pilot whales	0	0	510
Sperm whales	0	0	559

J.3.6. 2022

Table J-105. 2022 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2144
Bottlenose dolphins	0	0	4726
Bryde's whales	0	0	8
Kogia spp.	29	0	228
Short-finned pilot whales	0	0	339
Sperm whales	0	0	329

Table J-106. 2022 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	17581
Bottlenose dolphins	33	0	354303
Bryde's whales	0	1	43
Kogia spp.	273	0	1651
Short-finned pilot whales	0	0	3853
Sperm whales	0	0	3385

Table J-107. 2022 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	8845
Bottlenose dolphins	4	0	16498
Bryde's whales	0	0	20
Kogia spp.	310	0	996
Short-finned pilot whales	0	0	1649
Sperm whales	0	0	1847

Table J-108. 2022 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2224
Bottlenose dolphins	3	0	3734
Bryde's whales	0	0	4
Kogia spp.	100	0	259
Short-finned pilot whales	0	0	450
Sperm whales	0	0	495

J.3.7. 2023

Table J-109. 2023 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	715
Bottlenose dolphins	0	0	1575
Bryde's whales	0	0	3
Kogia spp.	10	0	76
Short-finned pilot whales	0	0	113
Sperm whales	0	0	110

Table J-110. 2023 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	17581
Bottlenose dolphins	39	0	482312
Bryde's whales	0	1	43
Kogia spp.	273	0	1653
Short-finned pilot whales	0	0	4186
Sperm whales	0	0	3385

Table J-111. 2023 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	6580
Bottlenose dolphins	3	0	68346
Bryde's whales	0	0	13
Kogia spp.	217	0	711
Short-finned pilot whales	0	0	1355
Sperm whales	0	0	1410

Table J-112. 2023 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1661
Bottlenose dolphins	5	0	14313
Bryde's whales	0	0	3
Kogia spp.	69	0	183
Short-finned pilot whales	0	0	361
Sperm whales	0	0	382

J.3.8. 2024

Table J-113. 2024 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-114. 2024 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	11103
Bottlenose dolphins	26	0	202485
Bryde’s whales	0	1	36
Kogia spp.	236	0	1044
Short-finned pilot whales	0	0	2359
Sperm whales	0	0	2140

Table J-115. 2024 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	7288
Bottlenose dolphins	4	0	12190
Bryde’s whales	0	0	20
Kogia spp.	325	0	790
Short-finned pilot whales	0	0	1339
Sperm whales	0	0	1570

Table J-116. 2024 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	1835
Bottlenose dolphins	2	0	2778
Bryde’s whales	0	0	5
Kogia spp.	104	0	203
Short-finned pilot whales	0	0	364
Sperm whales	0	0	423

J.3.9. 2025

Table J-117. 2025 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	140
Bottlenose dolphins	0	0	479
Bryde's whales	0	0	1
Kogia spp.	3	0	20
Short-finned pilot whales	0	0	25
Sperm whales	0	0	15

Table J-118. 2025 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	15054
Bottlenose dolphins	46	0	502044
Bryde's whales	0	1	38
Kogia spp.	237	0	1422
Short-finned pilot whales	0	0	3878
Sperm whales	0	0	2889

Table J-119. 2025 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	8225
Bottlenose dolphins	4	0	71116
Bryde's whales	0	0	16
Kogia spp.	271	0	888
Short-finned pilot whales	0	0	1657
Sperm whales	0	0	1762

Table J-120. 2025 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2076
Bottlenose dolphins	5	0	14952
Bryde's whales	0	0	4
Kogia spp.	87	0	229
Short-finned pilot whales	0	0	443
Sperm whales	0	0	478

J.4. Aversion, Alternate Marine Mammal Density Estimates

Table J-121. 2016 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2487
Bottlenose dolphins	1	0	3690
Bryde's whales	0	0	5
Kogia spp.	14	0	229
Short-finned pilot whales	0	0	409
Sperm whales	0	0	466

Table J-122. 2016 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	23864
Bottlenose dolphins	6	0	354338
Bryde's whales	0	1	51
Kogia spp.	218	0	2390
Short-finned pilot whales	0	0	5428
Sperm whales	0	0	4945

Table J-123. 2016 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	10719
Bottlenose dolphins	1	0	18393
Bryde's whales	0	0	23
Kogia spp.	202	0	1219
Short-finned pilot whales	0	0	2187
Sperm whales	0	0	2323

Table J-124. 2016 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	2394
Bottlenose dolphins	1	0	4217
Bryde’s whales	0	0	5
Kogia spp.	59	0	287
Short-finned pilot whales	0	0	530
Sperm whales	0	0	576

J.4.1. 2017

Table J-125. 2017 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	695
Bottlenose dolphins	0	0	2875
Bryde’s whales	0	0	5
Kogia spp.	12	0	127
Short-finned pilot whales	0	0	164
Sperm whales	0	0	90

Table J-126. 2017 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	21657
Bottlenose dolphins	6	0	476179
Bryde’s whales	0	1	44
Kogia spp.	202	0	2221
Short-finned pilot whales	0	0	5303
Sperm whales	0	0	4459

Table J-127. 2017 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9490
Bottlenose dolphins	1	0	71794
Bryde's whales	0	0	19
Kogia spp.	184	0	1110
Short-finned pilot whales	0	0	2067
Sperm whales	0	0	2051

Table J-128. 2017 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2096
Bottlenose dolphins	0	0	14696
Bryde's whales	0	0	4
Kogia spp.	54	0	262
Short-finned pilot whales	0	0	497
Sperm whales	0	0	507

J.4.2. 2018

Table J-129. 2018 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-130. 2018 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	21542
Bottlenose dolphins	6	0	327973
Bryde's whales	0	1	47
Kogia spp.	195	0	2145
Short-finned pilot whales	0	0	4906
Sperm whales	0	0	4471

Table J-131. 2018 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9137
Bottlenose dolphins	0	0	15673
Bryde's whales	0	0	20
Kogia spp.	172	0	1034
Short-finned pilot whales	0	0	1868
Sperm whales	0	0	1981

Table J-132. 2018 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2045
Bottlenose dolphins	1	0	3598
Bryde's whales	0	0	4
Kogia spp.	50	0	243
Short-finned pilot whales	0	0	452
Sperm whales	0	0	491

J.4.3. 2019

Table J-133. 2019 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	2633
Bottlenose dolphins	0	0	7595
Bryde’s whales	0	0	13
Kogia spp.	30	0	368
Short-finned pilot whales	0	0	533
Sperm whales	0	0	414

Table J-134. 2019 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	16046
Bottlenose dolphins	6	0	494638
Bryde’s whales	0	1	42
Kogia spp.	173	0	1772
Short-finned pilot whales	0	0	4485
Sperm whales	0	0	3240

Table J-135. 2019 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	5263
Bottlenose dolphins	0	0	66173
Bryde’s whales	0	0	14
Kogia spp.	120	0	675
Short-finned pilot whales	0	0	1264
Sperm whales	0	0	1108

Table J-136. 2019 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1124
Bottlenose dolphins	0	0	13363
Bryde's whales	0	0	3
Kogia spp.	35	0	160
Short-finned pilot whales	0	0	299
Sperm whales	0	0	270

J.4.4. 2020

Table J-137. 2020 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-138. 2020 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	19048
Bottlenose dolphins	8	0	330616
Bryde's whales	0	1	52
Kogia spp.	214	0	2160
Short-finned pilot whales	0	0	4606
Sperm whales	0	0	3816

Table J-139. 2020 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9490
Bottlenose dolphins	1	0	16318
Bryde's whales	0	0	19
Kogia spp.	184	0	1110
Short-finned pilot whales	0	0	1914
Sperm whales	0	0	2051

Table J-140. 2020 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2096
Bottlenose dolphins	0	0	3713
Bryde's whales	0	0	4
Kogia spp.	54	0	262
Short-finned pilot whales	0	0	468
Sperm whales	0	0	507

J.4.5. 2021

Table J-141. 2021 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde's whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-142. 2021 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	18933
Bottlenose dolphins	7	0	478068
Bryde's whales	0	1	54
Kogia spp.	207	0	2086
Short-finned pilot whales	0	0	5035
Sperm whales	0	0	3828

Table J-143. 2021 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	9137
Bottlenose dolphins	0	0	71149
Bryde's whales	0	0	20
Kogia spp.	172	0	1035
Short-finned pilot whales	0	0	2022
Sperm whales	0	0	1981

Table J-144. 2021 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	2045
Bottlenose dolphins	1	0	14582
Bryde's whales	0	0	4
Kogia spp.	50	0	243
Short-finned pilot whales	0	0	480
Sperm whales	0	0	491

J.4.6. 2022

Table J-145. 2022 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1938
Bottlenose dolphins	0	0	4720
Bryde's whales	0	0	8
Kogia spp.	18	0	241
Short-finned pilot whales	0	0	369
Sperm whales	0	0	323

Table J-146. 2022 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	16046
Bottlenose dolphins	6	0	346809
Bryde's whales	0	1	42
Kogia spp.	173	0	1771
Short-finned pilot whales	0	0	4072
Sperm whales	0	0	3240

Table J-147. 2022 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	8426
Bottlenose dolphins	0	0	16136
Bryde's whales	0	0	20
Kogia spp.	181	0	1045
Short-finned pilot whales	0	0	1748
Sperm whales	0	0	1792

Table J-148. 2022 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1822
Bottlenose dolphins	1	0	3617
Bryde's whales	0	0	4
Kogia spp.	53	0	247
Short-finned pilot whales	0	0	426
Sperm whales	0	0	439

J.4.7. 2023

Table J-149. 2023 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	646
Bottlenose dolphins	0	0	1573
Bryde's whales	0	0	3
Kogia spp.	6	0	80
Short-finned pilot whales	0	0	123
Sperm whales	0	0	108

Table J-150. 2023 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	16046
Bottlenose dolphins	6	0	471803
Bryde's whales	0	1	42
Kogia spp.	173	0	1772
Short-finned pilot whales	0	0	4395
Sperm whales	0	0	3240

Table J-151. 2023 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	6326
Bottlenose dolphins	0	0	66355
Bryde’s whales	0	0	13
Kogia spp.	123	0	740
Short-finned pilot whales	0	0	1429
Sperm whales	0	0	1367

Table J-152. 2023 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	1397
Bottlenose dolphins	0	0	13459
Bryde’s whales	0	0	3
Kogia spp.	36	0	175
Short-finned pilot whales	0	0	341
Sperm whales	0	0	338

J.4.8. 2024

Table J-153. 2024 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	0
Bottlenose dolphins	0	0	0
Bryde’s whales	0	0	0
Kogia spp.	0	0	0
Short-finned pilot whales	0	0	0
Sperm whales	0	0	0

Table J-154. 2024 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	10134
Bottlenose dolphins	5	0	197480
Bryde's whales	0	1	35
Kogia spp.	150	0	1128
Short-finned pilot whales	0	0	2503
Sperm whales	0	0	2049

Table J-155. 2024 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	7034
Bottlenose dolphins	1	0	11952
Bryde's whales	0	0	21
Kogia spp.	184	0	826
Short-finned pilot whales	0	0	1414
Sperm whales	0	0	1521

Table J-156. 2024 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	1547
Bottlenose dolphins	0	0	2681
Bryde's whales	0	0	5
Kogia spp.	54	0	195
Short-finned pilot whales	0	0	344
Sperm whales	0	0	373

J.4.9. 2025

Table J-157. 2025 annual exposure estimate totals for 2-D survey (4130 in^3 airgun array, 1 vessel).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	116
Bottlenose dolphins	0	0	479
Bryde's whales	0	0	1
Kogia spp.	2	0	21
Short-finned pilot whales	0	0	27
Sperm whales	0	0	15

Table J-158. 2025 annual exposure estimate totals for 3-D NAZ survey (4130 in^3 airgun array, 2 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	13722
Bottlenose dolphins	5	0	491106
Bryde's whales	0	1	38
Kogia spp.	150	0	1526
Short-finned pilot whales	0	0	4054
Sperm whales	0	0	2766

Table J-159. 2025 annual exposure estimate totals for 3-D WAZ survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	7908
Bottlenose dolphins	0	0	69075
Bryde's whales	0	0	16
Kogia spp.	153	0	925
Short-finned pilot whales	0	0	1748
Sperm whales	0	0	1709

Table J-160. 2025 annual exposure estimate totals for Coil survey (4130 in^3 airgun array, 4 vessels).

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	1747
Bottlenose dolphins	0	0	14077
Bryde’s whales	0	0	4
Kogia spp.	45	0	218
Short-finned pilot whales	0	0	419
Sperm whales	0	0	423

Appendix K. Annual Aggregate Exposure Estimates

K.1. No Aversion, PEIS Marine Mammal Densities

Table K-1. 2016 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	84508
Bottlenose dolphins	41	0	392066
Bryde’s whales	1	7	494
Kogia spp.	1705	0	7880
Short-finned pilot whales	0	0	10175
Sperm whales	1	0	17461

Table K-2. 2017 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	73313
Bottlenose dolphins	50	0	584300
Bryde’s whales	1	6	432
Kogia spp.	1555	0	7095
Short-finned pilot whales	0	0	7772
Sperm whales	1	0	14946

Table K-3. 2018 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	70086
Bottlenose dolphins	33	0	357820
Bryde’s whales	1	6	417
Kogia spp.	1438	0	6524
Short-finned pilot whales	0	0	8870
Sperm whales	1	0	14610

Table K-4. 2019 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	55121
Bottlenose dolphins	55	0	601078
Bryde's whales	1	6	423
Kogia spp.	1177	0	5626
Short-finned pilot whales	0	0	6248
Sperm whales	1	0	10543

Table K-5. 2020 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	66828
Bottlenose dolphins	33	0	361454
Bryde's whales	1	7	444
Kogia spp.	1533	0	6720
Short-finned pilot whales	0	0	7333
Sperm whales	1	0	13400

Table K-6. 2021 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	65280
Bottlenose dolphins	49	0	582532
Bryde's whales	1	7	462
Kogia spp.	1450	0	6389
Short-finned pilot whales	0	0	8626
Sperm whales	1	0	13247

Table K-7. 2022 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	61696
Bottlenose dolphins	40	0	382727
Bryde's whales	1	6	437
Kogia spp.	1429	0	6284
Short-finned pilot whales	0	0	6885
Sperm whales	1	0	12159

Table K-8. 2023 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	53166
Bottlenose dolphins	47	0	571726
Bryde's whales	1	5	355
Kogia spp.	1140	0	5256
Short-finned pilot whales	0	0	5973
Sperm whales	1	0	10615

Table K-9. 2024 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	40504
Bottlenose dolphins	33	0	219440
Bryde's whales	1	6	298
Kogia spp.	1333	0	4084
Short-finned pilot whales	0	0	4579
Sperm whales	1	0	8299

Table K-10. 2025 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	51077
Bottlenose dolphins	56	0	593973
Bryde's whales	1	5	341
Kogia spp.	1196	0	5128
Short-finned pilot whales	0	0	5836
Sperm whales	1	0	10329

K.2. Aversion, PEIS Marine Mammal Densities

Table K-11. 2016 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	79064
Bottlenose dolphins	8	0	384117
Bryde's whales	1	6	488
Kogia spp.	988	1	8269
Short-finned pilot whales	0	0	10680
Sperm whales	1	0	16686

Table K-12. 2017 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	67992
Bottlenose dolphins	7	0	570714
Bryde's whales	1	5	427
Kogia spp.	905	1	7456
Short-finned pilot whales	0	0	8178
Sperm whales	1	0	14270

Table K-13. 2018 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	65561
Bottlenose dolphins	7	0	350418
Bryde's whales	1	6	412
Kogia spp.	836	1	6859
Short-finned pilot whales	0	0	9307
Sperm whales	1	0	13943

Table K-14. 2019 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	50217
Bottlenose dolphins	7	0	587086
Bryde’s whales	1	5	420
Kogia spp.	717	1	5963
Short-finned pilot whales	0	0	6630
Sperm whales	1	0	10106

Table K-15. 2020 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	61374
Bottlenose dolphins	9	0	353852
Bryde’s whales	1	6	439
Kogia spp.	905	1	7080
Short-finned pilot whales	0	0	7734
Sperm whales	1	0	12797

Table K-16. 2021 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier’s beaked whales	0	0	60334
Bottlenose dolphins	8	0	568953
Bryde’s whales	1	7	457
Kogia spp.	861	1	6743
Short-finned pilot whales	0	0	9077
Sperm whales	1	0	12651

Table K-17. 2022 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	56563
Bottlenose dolphins	8	0	374676
Bryde's whales	1	6	433
Kogia spp.	852	1	6622
Short-finned pilot whales	0	0	7270
Sperm whales	1	0	11636

Table K-18. 2023 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	48915
Bottlenose dolphins	7	0	558246
Bryde's whales	1	5	351
Kogia spp.	677	1	5547
Short-finned pilot whales	0	0	6312
Sperm whales	1	0	10146

Table K-19. 2024 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	37494
Bottlenose dolphins	6	0	214052
Bryde's whales	1	5	297
Kogia spp.	778	1	4307
Short-finned pilot whales	0	0	4847
Sperm whales	1	0	7918

Table K-20. 2025 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	47066
Bottlenose dolphins	6	0	579991
Bryde's whales	1	5	337
Kogia spp.	703	1	5394
Short-finned pilot whales	0	0	6148
Sperm whales	0	0	9864

K.3. No Aversion, Alternate Marine Mammal Densities

Table K-21. 2016 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	42181
Bottlenose dolphins	40	0	388515
Bryde's whales	0	1	85
Kogia spp.	851	0	3932
Short-finned pilot whales	0	0	8138
Sperm whales	1	0	8696

Table K-22. 2017 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	36593
Bottlenose dolphins	49	0	579007
Bryde's whales	0	1	74
Kogia spp.	776	0	3540
Short-finned pilot whales	0	0	7671
Sperm whales	1	0	7444

Table K-23. 2018 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	34982
Bottlenose dolphins	32	0	354578
Bryde's whales	0	1	72
Kogia spp.	717	0	3255
Short-finned pilot whales	0	0	6884
Sperm whales	0	0	7276

Table K-24. 2019 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	27513
Bottlenose dolphins	54	0	595633
Bryde's whales	0	1	73
Kogia spp.	587	0	2807
Short-finned pilot whales	0	0	6275
Sperm whales	0	0	5251

Table K-25. 2020 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	33356
Bottlenose dolphins	32	0	358180
Bryde's whales	0	1	76
Kogia spp.	765	0	3353
Short-finned pilot whales	0	0	6639
Sperm whales	0	0	6673

Table K-26. 2021 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	32584
Bottlenose dolphins	49	0	577256
Bryde's whales	0	1	79
Kogia spp.	723	0	3188
Short-finned pilot whales	0	0	7208
Sperm whales	0	0	6597

Table K-27. 2022 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	30795
Bottlenose dolphins	40	0	379260
Bryde's whales	0	1	75
Kogia spp.	713	0	3135
Short-finned pilot whales	0	0	6292
Sperm whales	0	0	6055

Table K-28. 2023 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	26537
Bottlenose dolphins	47	0	566547
Bryde's whales	0	1	61
Kogia spp.	569	0	2622
Short-finned pilot whales	0	0	6015
Sperm whales	0	0	5287

Table K-29. 2024 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	20225
Bottlenose dolphins	32	0	217453
Bryde's whales	0	1	61
Kogia spp.	665	0	2038
Short-finned pilot whales	0	0	4061
Sperm whales	0	0	4133

Table K-30. 2025 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	25495
Bottlenose dolphins	55	0	588592
Bryde's whales	0	1	59
Kogia spp.	597	0	2559
Short-finned pilot whales	0	0	6003
Sperm whales	0	0	5144

K.4. Aversion, Alternate Marine Mammal Densities

Table K-31. 2016 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	39464
Bottlenose dolphins	8	0	380638
Bryde's whales	0	1	84
Kogia spp.	493	0	4125
Short-finned pilot whales	0	0	8554
Sperm whales	1	0	8310

Table K-32. 2017 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	33937
Bottlenose dolphins	7	0	565544
Bryde's whales	0	1	73
Kogia spp.	452	0	3720
Short-finned pilot whales	0	0	8031
Sperm whales	0	0	7107

Table K-33. 2018 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	32724
Bottlenose dolphins	6	0	347244
Bryde's whales	0	1	71
Kogia spp.	417	0	3422
Short-finned pilot whales	0	0	7226
Sperm whales	0	0	6944

Table K-34. 2019 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	25065
Bottlenose dolphins	7	0	581768
Bryde's whales	0	1	72
Kogia spp.	358	0	2975
Short-finned pilot whales	0	0	6581
Sperm whales	0	0	5033

Table K-35. 2020 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	30634
Bottlenose dolphins	9	0	350647
Bryde's whales	0	1	76
Kogia spp.	452	0	3532
Short-finned pilot whales	0	0	6988
Sperm whales	0	0	6373

Table K-36. 2021 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	30115
Bottlenose dolphins	8	0	563799
Bryde's whales	0	1	79
Kogia spp.	430	0	3364
Short-finned pilot whales	0	0	7537
Sperm whales	0	0	6301

Table K-37. 2022 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	28232
Bottlenose dolphins	7	0	371282
Bryde's whales	0	1	74
Kogia spp.	425	0	3304
Short-finned pilot whales	0	0	6615
Sperm whales	0	0	5795

Table K-38. 2023 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	24415
Bottlenose dolphins	7	0	553190
Bryde's whales	0	1	60
Kogia spp.	338	0	2767
Short-finned pilot whales	0	0	6288
Sperm whales	0	0	5053

Table K-39. 2024 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	18715
Bottlenose dolphins	6	0	212113
Bryde's whales	0	1	61
Kogia spp.	388	0	2149
Short-finned pilot whales	0	0	4261
Sperm whales	0	0	3943

Table K-40. 2025 annual exposure estimate totals for all sources.

Species	Number of Level A exposures		Number of Level B exposures
	peak SPL	SEL	Step function
Cuvier's beaked whales	0	0	23493
Bottlenose dolphins	6	0	574737
Bryde's whales	0	1	58
Kogia spp.	351	0	2691
Short-finned pilot whales	0	0	6248
Sperm whales	0	0	4913