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U.S. Department of Commerce
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Executive Summary

Climate change and variability are key issues affecting the conservation and management of marine mammals. Marine mammal stocks are expected to respond to climate change and variability in a variety of ways that may manifest as shifts in distribution, abundance, and/or phenology. However, many stocks lack specific climate-related information. Vulnerability assessments can help fill that gap and identify candidate stocks for targeted climate-related research. The NOAA Fisheries Climate Science Strategy[1] and Regional Action Plans[2] call for vulnerability assessments of living marine resources including marine mammals. However, there are few methods in the literature specifically designed to assess the vulnerability of multiple marine mammal stocks. Here we present a method to assess the climate vulnerability of marine mammal stocks.

The method follows the model of the NOAA Fisheries Marine Fish and Shellfish Climate Vulnerability Assessment[3]. It uses existing information and expert elicitation to assess marine mammal stocks' exposure, sensitivity, and capacity to adapt to climate change and variability. Exposure to climate change is assessed by scoring the projected change in climate conditions within a stock's current distribution. Sensitivity and capacity to adapt to climate change are assessed based on our understanding of a stock's life history traits.

An expert working group identified relevant life history traits and climate exposure factors. A separate working group defined scoring criteria for each of the life history traits and climate exposure factors to differentiate between and among marine mammal stocks. The assessment method was pilot tested separately in the Northeast and Southeast United States. We revised and updated the approach based on input received during the pilots.

Prior to the assessment, we assembled background narratives that summarize the existing literature available for the climate-relevant life history traits for each stock. We acquired maps showing the projected change in the climate exposure factors and overlaid current stock distribution data. To evaluate sensitivity to climate change, a team of marine mammal experts individually combined that information with their own knowledge to score each life history trait using a four-point scale. The team members then individually scored climate exposure as a function of the magnitude of projected climate change within the current distribution using a similar four-point scale. Team members also assessed the quality of the underlying data used to score each attribute and exposure factor. After compiling individual scores, the team met to discuss differences in scoring and revised scores as necessary. The team identified potential differences in the interpretation of available information to ensure a common understanding of each attribute and factor but did not work toward consensus.

We then aggregated the scores and calculated a weighted mean score for each life history trait and climate exposure factor for each stock. We combined these weighted mean scores of climate exposure factors and life history traits into an overall exposure score and an overall sensitivity/adaptive capacity score, respectively, using a logic model. Finally, we calculated a

[1] https://www.st.nmfs.noaa.gov/ecosystems/climate/national-climate-strategy
[2] https://www.st.nmfs.noaa.gov/ecosystems/climate/rap/index
[3] https://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/documents/TM%20OSF3.pdf

climate vulnerability score for each stock by combining a stock's overall climate exposure score and overall sensitivity/adaptive capacity score using a vulnerability matrix.

The assessment method will be first applied to marine mammal stocks in the western North Atlantic, Gulf of Mexico, and Caribbean and next to stocks in the Pacific and Arctic. Regional assessments will produce a list of stocks ranked by vulnerability to climate change. Each stock will have a vulnerability profile that summarizes the distribution of expert scores for each life history attribute and exposure factor, and identify variables that contribute the most to the stock's vulnerability. Stock-specific profiles will support management decision-making by identifying stocks vulnerable to climate change and the potential causes of that vulnerability. Similarly, researchers could use assessment results to target research toward specific stocks, regions, or attributes to expand our understanding of marine mammal stock responses to climate change and the consequences to the broader marine ecosystem.

1 Background

The impacts of climate variability and change have been observed in coastal and marine species, with range shifts, changes in local abundance, and variation in timing of life history events detected in various regions (Pinsky et al. 2013, Poloczanska et al. 2013, Brown et al. 2016, Staudinger et al. 2019). Marine mammal populations have been, and are expected to continue to be, affected by changing climate conditions (Learmonth et al. 2006, Macleod 2009, Schumann et al. 2013). Some marine mammal populations show climate-related shifts in distribution (Kovacs et al. 2011; Clarke et al. 2013). Predicting marine mammal distribution under changing climate conditions is challenging (Silber et al. 2017), though analytical techniques are now available to predict distribution changes (Gilles et al. 2011, Becker et al. 2012, Pendleton et al. 2012, Mannocci et al. 2014, Becker et al. 2018). Predicting changes in phenology and abundance (Becker et al. 2018) is similarly challenging. Generally, climate impact studies are limited to a few marine mammal stocks globally.

The National Marine Fisheries Service (NMFS) has mandates to protect and recover species under the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA). These mandates include the issuance of MMPA permits and authorizations, ESA Section 7 consultations, recovery planning, species listing and delisting, and status reviews. Consideration of potential climate change effects is necessary to understand the impacts of all possible natural and man-made stressors on population viability (McClure et al. 2013, NMFS 2016). An improved understanding of species responses to altered climate states, including the magnitude and direction of the effect, is important to help inform various MMPA and ESA activities.

Climate vulnerability assessments (CVAs) provide a rapid, but generalized approach to identify species that may be most vulnerable to climate change and the potential factors contributing to their vulnerability. Typically, CVAs follow a similar framework or structure that combines exposure, sensitivity, and adaptive capacity (Glick et al. 2011, Foden et al. 2016, Foden et al. 2018). To maximize their utility, many CVAs also quantify or qualify the uncertainty associated with the assessment (Foden et al. 2018).

There have been numerous CVA studies of terrestrial species since the 1990s (e.g., Herman and Scott 1994; see Staudinger et al. 2015) but they are less common for marine ecosystems (Pacifici et al. 2015), with marine fisheries and habitats receiving the most attention to date (e.g., Chin et al. 2010, Johnson and Welch et al. 2010, Foden et al. 2013, Pecl et al. 2014, Hare et al. 2016b). Similar studies for non-fish protected species are further limited in number and scope (e.g., Lawler et al. 2007, Hamann et al. 2007, Laidre et al. 2008, Fuentes et al. 2011). A recent effort, developed concurrently with our method, assessed the climate vulnerability of cetaceans in the Madeira Archipelago following a similar approach presented here (Sousa et al. 2019).

Other types of studies (e.g., modeling) can offer insight into potential species-specific responses to climate change. However, those approaches are generally resource and data intensive and impossible to perform for multiple species concurrently. Using CVAs to identify those species that are most vulnerable to climate change can help prioritize species selection for modeling initiatives (Silber et al. 2017), assuming sufficient data exist to undertake modeling exercises for the species.

The NMFS Climate Science Strategy (Link et al. 2015) and other high-level strategies developed with NMFS participation (e.g., National Fish, Wildlife and Plants Climate Adaptation Partnership 2012) call for vulnerability assessments as a first step to gauge the likelihood of multiple species being impacted by climate change impacts. CVAs have been included in all draft Regional Action Plans (Gulf of Mexico Regional Action Plan Team 2016, Hare et al. 2016a, Northwest and Southwest Fisheries Science Centers 2016, Polovina et al. 2016, Sigler et al. 2016) developed to implement the Climate Science Strategy.

To address the needs of protected species managers and to provide relevant climate-related information, we developed a targeted methodology to assess the vulnerability of marine mammals to climate change. We followed the general approach of the recently developed and implemented Marine Fish and Shellfish Climate Vulnerability Assessment (FCVA) (Morrison et al. 2015, Hare et al. 2016a), using a similar development process and framework. We adapted the life history attributes and scoring criteria to reflect the life histories of cetaceans and pinnipeds for the Marine Mammal Climate Vulnerability Assessment (MMCVA). Here we present the method and describe its future application.

2 Assessment Methodology

2.1 Framework overview and development

The MMCVA was designed using a similar structure and expert-based scoring approach as the FCVA and the same nomenclature (i.e., exposure factors, sensitivity/adaptive capacity attributes) as the FCVA and Chin et al. (2010). Our method scored multiple features for two separate components: 1) *exposure to climate change* and 2) *adaptive capacity and sensitivity to climate change*. The framework then combines those separate component scores into a *relative vulnerability score* (Fig. 1).

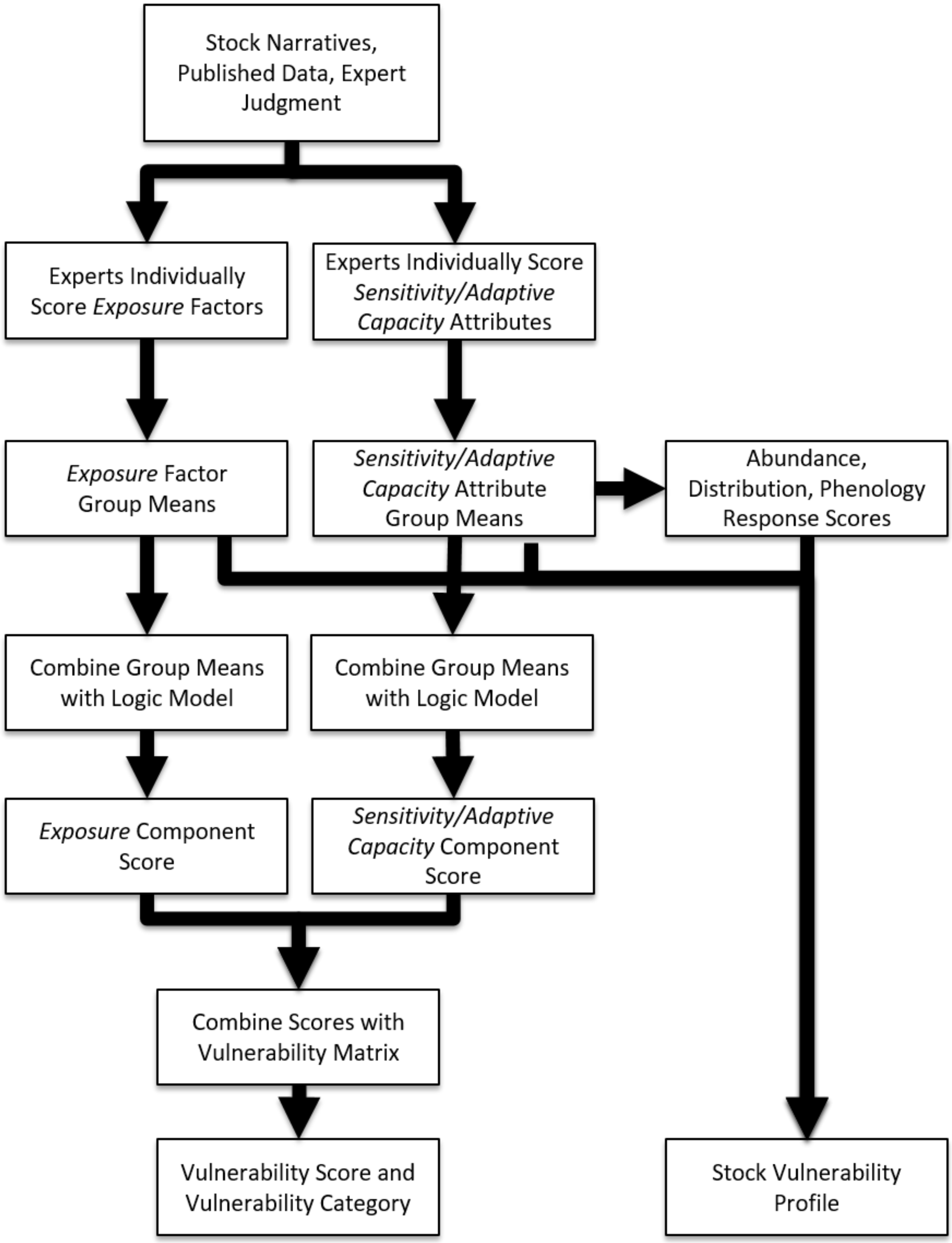

Fig. 1. Climate vulnerability assessment process from information gathering to final products.

2.1.1 Sensitivity and Adaptive Capacity Component

We defined sensitivity as the ability of a stock to tolerate climate-driven changes in environmental conditions and adaptive capacity as the ability to modify intrinsic characteristics (e.g., behavior, physiology, habitat usage) to cope with climate-driven changes in environmental conditions (Glick et al. 2011). Since tolerance of a condition and adapting to a condition exist along a spectrum of possible responses to that condition, we combined sensitivity and adaptive capacity since many attributes that could be categorized as one could be categorized as the other with simple changes in wording (Williams et al. 2008, Hare et al. 2016b).

We considered whether each sensitivity/adaptive capacity attribute related to potential responses in stock abundance, geographic distribution, and phenology. Some attributes influenced all three response categories, while other attributes only influenced one or two response categories. Potential responses of sensitivity/adaptive capacity included: 1) changes in abundance resulting in declines or increases in population number, 2) changes in distribution resulting in climate-driven changes in geographic ranges, including range expansion, contraction, or shift, and 3) changes in phenology resulting in seasonal shifts (either earlier or later in the year) or changes in duration (prolonged or shortened) of life history events such as breeding or migration.

2.1.2 Exposure Component

We defined exposure factors as measures of the magnitude of climate change a stock is expected to experience. We scored exposure factors as a function of the degree of change expected for that factor in areas that overlap with the stock's current distribution. For those exposure factors that could be modeled spatially, exposure was scored by overlaying current range maps with the modeled magnitude of exposure.

Per NMFS policy guidance, NMFS uses representative concentration pathway (RCP) 8.5, the business-as-usual scenario (Riahi et al. 2011), when considering the treatment of climate change in ESA activities (NMFS 2016). To maximize the utility of the information produced, the MMCVA followed NMFS policy guidance and used RCP 8.5 for projected climate conditions.

2.1.3 Identifying Attributes and Establishing Scoring Criteria

An expert working group composed of representatives from NOAA, other federal agencies, non-governmental organizations (NGOs), and academia guided the selection of relevant marine mammal life history traits and climate exposure factors.

We identified 11 life history attributes relevant to climate change that were used to score sensitivity and adaptive capacity components (Table 1). We assessed each attribute independently and treated all attributes as equal. For example, when considering two nearly identical species in which the only attribute that differed was the number of offspring produced, the species that produced more offspring was considered to have a lower sensitivity/higher adaptive capacity to climate change. Although many of these attributes are correlated, we made efforts to reduce "double counting" by describing those situations in which an attribute may be bundled into another and selecting attributes with minimal overlap. For example, we did not include protected status (e.g., Threatened, Endangered) since population abundance and population trend were considered as part of status determination.

Table 1. List of sensitivity attributes included in the MMCVA.

Sensitivity Attribute	**Description**
Prey/Diet Specificity	The breadth of a stock's diet and the ability of individuals to shift foraging strategy and/or diet under changing conditions
Habitat Specificity	The breadth of habitat used by a stock and estimate of the ability of individuals to shift habitat use under changing conditions
Site Fidelity	The degree to which individuals utilize the same sites year after year
Lifetime Reproductive Potential	The ability of an individual (and by extension, stock) to produce offspring that facilitate population growth and avoid declines in abundance
Generation Length	The time between generations in a stock that facilitates the potential for evolutionary adaptation
Reproductive Plasticity	The ability of a stock to adapt aspects of its reproductive strategy to changing conditions
Migration	Annual and seasonal movements of a stock, including the associated behaviors, patterns, and pathways
Home Range	The spatial extent of individuals within a stock
Stock Abundance	The current abundance estimate of a stock
Stock Abundance Trend	The change in a stock's abundance through time
Cumulative Stressors	The level to which a stock is impacted by non-climate stressors

We identified nine climate factors to score climate exposure (Table 2). We selected the same climate exposure factors that were used in the FCVA, recognizing the importance of exposure factors that are likely to directly affect marine mammals and also those that are likely to affect marine mammal prey or marine mammal habitat.

A separate working group comprising NMFS and non-governmental marine mammal experts defined scoring criteria for each of the life history traits and climate exposure factors. The group aimed to establish criteria to compare marine mammal stocks using commonly studied metrics (e.g., diet composition, vital rates). The criteria were established to consider the unique life histories of marine mammals and are not appropriate for cross-taxa assessment.

Table 2. Climate exposure factors included in the MMCVA.

Climate Exposure Factor	Description
Sea Surface Temperature	The temperature of the upper water column (the mixed layer) may have direct physiological effects on marine mammals and/or prey
Air Temperature	The near-surface air temperature may have direct physiological effects on marine mammals and/or prey and serves as a useful proxy for estuarine water temperature
Precipitation	Rain, snow, and ice that affects salinity and serves as a delivery mechanism for pollutants and contaminants
Salinity	Surface salt content that can affect marine mammal health and/or prey
Ocean Acidification	The decreasing of the ocean's pH that may affect marine mammal acoustic habitat and/or prey
Sea Ice Cover	The percent of sea surface covered by any type of ice, which serves as habitat for some marine mammal stocks
Dissolved Oxygen	The amount of oxygen in surface waters, which may affect marine mammal prey
Circulation	The movement of water masses, which may affect marine mammal movement and/or prey
Sea Level Rise	The relative change in sea level, which may affect marine mammal and/or prey habitat

We established criteria to guide the scoring using four bins for each attribute and factor, with Bin 1 corresponding to "Low" sensitivity or exposure and Bin 4 corresponding to "Very High" sensitivity or exposure.

Other CVAs and frameworks have included a weighting factor to emphasize attributes that are disproportionately impactful for a species (e.g., Thomas et al. 2011, Reece and Noss 2014); however, we omitted a weighting factor in the MMCVA to reduce complexity.

2.2 *Preparing to Implement the Assessment*

2.2.1 Scale and Scope

We designed the MMCVA for application to marine mammal stocks or similar population-level units at the region or ocean-basin scale. The assessment considered the entire life cycle and known or available geographic range of the stocks. We used climate exposure factors projected 40 years into the future. This timeframe was long enough for climate projections to capture climate trends and decadal variability while still near-term enough to provide management-relevant information.

2.2.2 Stock Background Narratives

We assembled information about each stock’s life history attributes, distribution, and any studies about the stock relating to climate change. We organized this information as stock narratives, similar to other CVAs (e.g., Chin et al. 2010, Pecl et al. 2014, Hare et al. 2016b). The background narratives included information describing the current state of knowledge about each of the life history attributes. When available, the background narratives also highlighted studies documenting stocks’ responses to climate change. For poorly studied stocks, we included related stocks’ or species’ life history information. For example, if information was lacking for a Bay, Sound, and Estuary common bottlenose dolphin stock, information from a neighboring common bottlenose dolphin stock may have been included.

2.2.3 Exposure Maps

Climate exposure factors have been projected and presented in a variety of studies and formats (IPCC 2013, Hayhoe et al. 2017). We obtained climate projections for each climate exposure factor across the entire geographic scope of the assessment from the Earth Systems Research Laboratory (ESRL) web portal (ESRL 2014), following the established approach used in the FCVA. The ESRL web portal provided projections for many of the exposure factors scored in this assessment (see Appendix B. Climate Exposure Factors). Using the ESRL projections maximized the number of climate exposure factors in the assessment that were modeled using the same climate models, timeframe, and spatial resolution.

We used the settings in Table 3 to customize the ESRL web portal projections. The results on the ESRL portal are displayed with a consistent template of a grid of four maps (Fig. 2). The upper left map shows the historical mean during the period 1956-2005. The upper right map shows the projected future standard anomaly, which compares projected future conditions (during the period 2006-2055) to historical conditions by subtracting the historical mean from the projected future mean and then dividing the difference by the historical standard deviation. The lower left map shows the average historical inter-annual standard deviation. The lower right map shows change in variability, calculated as future variance divided by past variance. Scores for projected mean versus historical variance are derived using the top right map. Scores for projected change in future variability are derived using the lower right map. The two maps on the left side of the grid were not used for scoring in this assessment, but provide additional context. The range of the maps can be adjusted to the specific basin or region being assessed to provide greater resolution.

Table 3. Settings used for ESRL Climate Change Web Portal for each climate exposure factor.

Field	Value
Experiment	RCP 8.5
Model	Average of All Models
Variable	[based on climate exposure factor]
Statistic	Standard Anom (avg historical)
Season	Entire year OR specific season for highly migratory stocks
21st Century Period	2006-2055
Region	scale to fit entire stock distribution

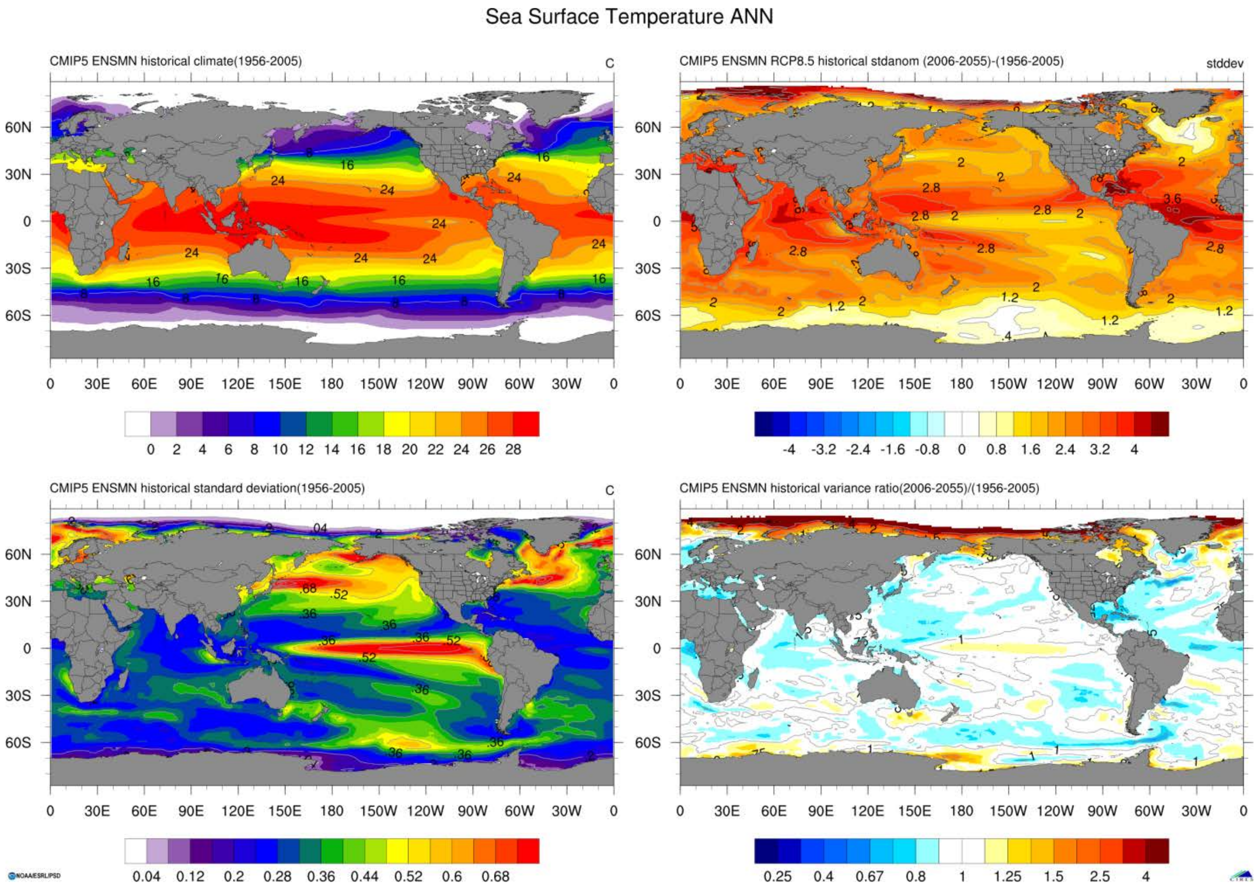

Figure 2. Sample output from ESRL Climate Change Web Portal. This figure uses the following settings: model = average of all models, variable = sea surface temperature, statistic = standard anom (avg historical), season = entire year, 21st century period = 2006-2055, region = global. (http://www.esrl.noaa.gov/psd/ipcc/ocn/)

These maps can be used as-is, however we downloaded and processed the data to show the exposure scaled to the criteria of scoring bins. Doing so presented the exposure maps categorized by bin and eliminated the need for experts to interpret the exposure factor and the scoring criteria simultaneously.

Projections obtained from downscaled models or peer-reviewed studies are useful, but the same projections for each individual attribute must be used for all stocks that are assessed. For most marine mammal stocks covering vast geographic areas, finer resolution models are difficult to generate, and are not necessary for a coarse resolution CVA such as the MMCVA.

We supplemented the exposure maps with additional information, such as stock boundaries, sighting data, or density estimates. Range maps were obtained from a variety of sources such as stock assessment reports (NOAA 2016c), recovery plans (NOAA 2016b), status reviews (NOAA 2016b), OBIS SEAMAP (Halpin et al. 2009), CetMap (NOAA 2016a), and the International Union for the Conservation of Nature Redlist (IUCN 2016).

2.2.4 Expert Selection

We selected expert scorers to score the MMCVA that were familiar with a broad set of stocks in the region. Each expert had field or other research experience across multiple stocks. While expertise in any given stock was valuable, having experts that could score a variety of stocks allowed us to compare scores across stocks. If each expert only scored one stock, we would have had difficulty attributing scores to the stock instead of the scorer. We included experts from NOAA, other government agencies, NGOs, and universities.

2.3 The Expert Scoring Process

Each exposure factor and sensitivity/adaptive capacity attribute was scored individually by each member of a group of experts for a given stock. Expert elicitation is an accepted technique with established protocols (EPA 2009) that have been utilized in NOAA efforts (e.g., Good et al. 2005, Brainard et al. 2011, Hare et al. 2016a). The optimal number of scorers depends on multiple factors and the literature provides no specific number (Linstone and Turoff 2002, Hsu and Sandford 2007, Mukherjee et al. 2015). To ensure a sufficient number of reviews while maintaining a reasonable workload for the expert scorers, we aimed to have a minimum of three expert reviews per stock.

For each exposure factor and sensitivity/adaptive capacity attribute, experts scored by allocating five tallies across four scoring bins according to the established bin criteria for that factor or attribute. These five tallies were distributed among the scoring bins for which supporting evidence matched the established criteria. For example, if all supporting evidence matched the criteria in “Bin 4”, the experts placed all five tallies in “Bin 4.” If evidence for a stock ranged across several bins, experts could spread their tallies across multiple bins based on the supporting evidence; the most tallies were placed in the bin with greatest support from the literature or the expert’s experience. Alternatively, if data quality was low, tallies could be spread across more bins, reflecting uncertainty for this factor/attribute. For attributes with multiple metrics for selecting bins, experts used their best judgement to place primary emphasis on those metrics with higher quality data and secondary emphasis on other metrics less supported by data.

2.3.1 Scoring Sensitivity/Adaptive Capacity Attributes

Experts used their knowledge and stock-specific experience combined with the stock narratives to place their five tallies into each attribute's four bins based on the bin criteria described in Appendix A. Appendix A provides definitions, background, and scoring criteria for each attribute. The relationships between each attribute and the response in abundance, distribution, and phenology are also characterized in Appendix A.

2.3.2 Scoring Climate Exposure Factors

Experts compared the range maps of each stock to the projected exposure level for each factor. They then scored each factor by placing five tallies across four bins according to the magnitude of exposure projected across the entirety of the stock's current distribution. For example, if the magnitude of exposure within an entire stock's distribution matched the criteria for "Bin 4", all five tallies were placed in "Bin 4". If the magnitude of exposure in part of a stock's distribution matched the criteria for "Bin 4" and part matched the criteria for "Bin 3", experts placed tallies according to the proportion of the distribution that matched each bin.

Some factors did not have modeled projection maps (e.g., circulation), and experts scored these factors using expert judgement based on the literature about projected impacts.

2.3.3 Assessing Data Quality

Similar to the FCVA, experts provided a data quality score for each attribute and factor. The data quality score represents how much evidence supports the placement of the tallies. Naturally, factor/attribute scores that are associated with higher data quality yield results with higher confidence.

Data quality was scored a "3" if there were observed, modeled, or measured data to support the placement of tallies. Data quality was scored a "2" if the score was based on the subject stock but outside of the specified study area, if the score was based on a related stock or species, or if conflicts existed in the supporting information that complicated the ability to assign scores. Data quality was scored a "1" if the expert's knowledge of and experience with the stock was the sole basis for the score. Data quality was scored a "0" if there was no data on which to score, and the expert's familiarity with the stock was insufficient to provide expert judgment. Experts scored data quality for sensitivity/adaptive capacity attributes based on their own knowledge and on the data provided to experts in the stock narratives. Experts scored data quality for exposure factors based on the underlying information about the stock distribution. The marine mammal experts were not asked to assess the data quality of the climate models.

2.4 Calculating Scores

2.4.1 Attribute and Factor Means

We computed mean scores for each exposure factor and sensitivity/adaptive capacity attribute through a three-step process.

1) We combined the tallies from all experts to produce weighted mean scores for each exposure factor and each sensitivity/adaptive capacity attribute. Here, the weighting is for the bins within a factor or attribute and does not refer to individual factors or attributes weighting as discussed above. Within each factor and attribute, bins are weighted according to how the criteria for the

bin influences the factor or attribute. On either extreme, criteria for “Bin 1” correlate to low exposure, low sensitivity, and high adaptive capacity while criteria for “Bin 4” correlate to high exposure, high sensitivity, and low adaptive capacity. We calculated weighted mean scores with bin weights corresponding to bin number, using the following equation:

$$Factor\ or\ Attribute\ Weighted\ Mean = \frac{((B_1 * 1) + (B_2 * 2) + (B_3 * 3) + (B_4 * 4))}{(B_1 + B_2 + B_3 + B_4)}$$

where B_n is the number of tallies in bin n.

2) For the exposure factors that scored both change in variability and change in mean (e.g. sea surface temperature), we used the greater of the two factor means as the mean score for that factor.

3) We placed mean sensitivity/adaptive capacity attribute scores with the response categories (abundance, distribution, and phenology) identified as relevant to that attribute. For example, if a given attribute had influence over all three response categories, then the mean attribute score applied to each response category. Alternatively, if a given attribute had influence over only abundance, the mean attribute score was applied to abundance, but not to distribution and phenology for that attribute. The three response categories remained independent of one another and were supplemental to the mean sensitivity/adaptive capacity attribute score.

2.4.2 Component Scores: Sensitivity/Adaptive Capacity and Exposure

We determined sensitivity/adaptive capacity and exposure component scores using the logic model from the FCVA (Table 4) and the attribute and factor mean scores for each stock.

Table 4. Logic model used to determine sensitivity/adaptive capacity attribute component score and exposure factor component score.

Component Score	Criteria
Very High (4)	3 or more attribute or factor mean scores ≥ 3.5
High (3)	2 or more attribute or factor mean scores ≥ 3.0, but does not meet threshold for “Very High”
Moderate (2)	2 or more attribute or factor mean scores ≥ 2.5, but does not meet threshold for “High” or “Very High”
Low (1)	Less than 2 attribute or factor mean scores ≥ 2.5

2.4.3 Overall Vulnerability

We determined the overall vulnerability for a stock by multiplying exposure scores and sensitivity/adaptive capacity component scores to generate a vulnerability rank and place the stock into a vulnerability category. Higher scores correlated with greater vulnerability. Stocks were placed into vulnerability categories using exposure component score and sensitivity/adaptive capacity component score cross-referenced with a vulnerability matrix derived from the FCVA (Fig. 3).

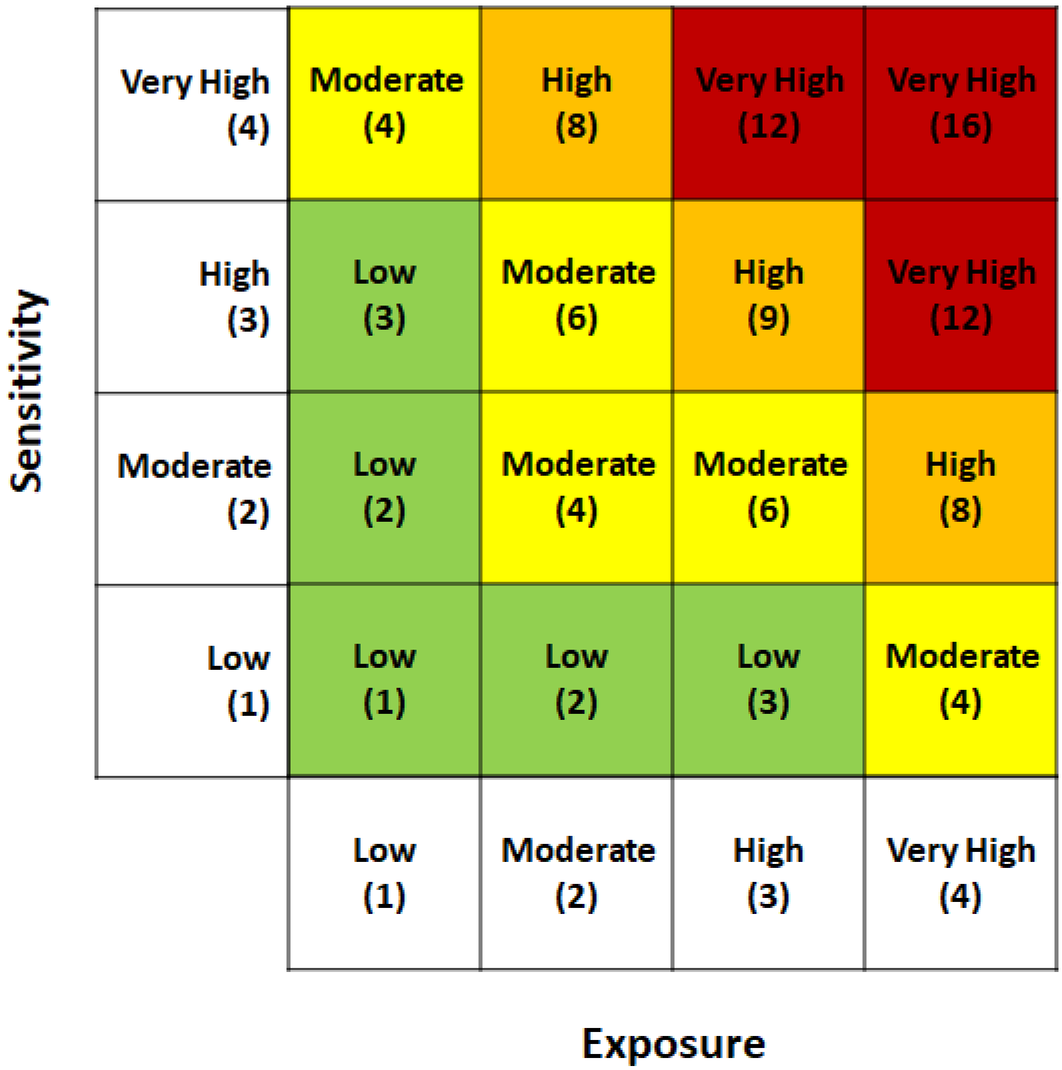

Figure 3. Vulnerability matrix derived from FCVA used to combine sensitivity/adaptive capacity category component score and exposure component score to determine overall vulnerability category. Numbers in parenthesis represent the factors and product of multiplying sensitivity and exposure. Low vulnerability (1-3), moderate vulnerability (4-6), high vulnerability (8-9), and very high vulnerability (12-16) can results from multiple combinations of sensitivity and exposure.

2.4.4 Response Category Score

Within the sensitivity/adaptive capacity component, the three response categories provide additional information about anticipated responses. We calculated each stock’s response category score similarly as overall sensitivity, using the weighted means of the individual attribute scores for that stock while ignoring values of “N/A”. As different attributes influence abundance, distribution, and phenology, comparisons were not made across response categories within a stock.

3 Next Steps

3.1 Regional Implementation

With the method developed and tested, we plan to apply the method to stocks at the regional scale. First, we will apply the method to stocks in the western North Atlantic, Gulf of Mexico, and Caribbean. Later, we will apply the method to stocks in the Pacific and Arctic.

The outputs from these regional applications of the MMCVA will include a ranked vulnerability index, response category scores, and stock-specific vulnerability profiles. Stocks will be categorized and ranked by overall vulnerability to support managers. Each stock will have its own graphical representation of sensitivity/adaptive capacity and exposure scores. Corresponding profiles will describe the attributes and factors contributing to vulnerability and identify data gaps such as attributes and factors with weak supporting evidence. Researchers can use the vulnerability profiles to target research toward specific attributes that may be driving the vulnerability of a given stock to explore responses to varying magnitudes of change in that driver. Managers can use the vulnerability profiles to identify the attributes that contribute most to stock sensitivity/adaptive capacity and the types of climate change impacts expected to most impact the stock. This information can be used to design management strategies and focus efforts on those attributes and factors that could most reduce vulnerability.

3.2 Interfacing with Other CVAs

We encourage future iterations of this assessment to interface with other CVAs that characterize the vulnerability of prey and habitat. NMFS is in the process of applying the FCVA to fish stocks across all regions. NMFS is also currently developing a Habitat Climate Vulnerability Assessment (HCVA). Including the results of regional applications of the FCVA and HCVA as input to the MMCVA's Prey/Diet Specificity and Habitat Specificity attributes would strengthen the MMCVA by reflecting the vulnerability of the prey and habitat that marine mammals depend on. Developing a plan to integrate the results of the different CVAs will help to describe interconnected and cascading effects of climate change.

4 Conclusion

Marine mammal stocks are expected to respond to changing climate conditions in a variety of ways through range shifts, declining or increasing abundance, and/or phenological shifts. Climate-related information can help inform management activities under the ESA and MMPA, and CVAs can provide important information for consideration. Our method is an early step to inform marine mammal management under changing climate conditions. It operates at the stock level to describe climate vulnerability on a management-relevant scale, although this method may be modified to operate on finer or coarser scales. Similar to the FCVA, the method is designed to be repeated at regular intervals to incorporate updated climate projections from new Intergovernmental Panel on Climate Change reports and National Climate Assessments. Additional attributes described in Appendix A may be added to future iterations of the assessment as necessary. The results of the MMCVA can prioritize research toward data gaps, and as stock-specific biological information improves that information can be incorporated into future assessments. Improved understanding of the climate vulnerability of marine mammal stocks will help and inform activities to aid in the management and recovery of these protected species.

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Appendix A Life History Attributes

A.1 Prey/Diet Specificity A-2
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A.1 Prey/Diet Specificity

Goal: To estimate the breadth of a stock's diet and the ability of individuals to shift foraging strategy and/or diet under changing conditions.

Background: Foraging behavior and prey of individuals within a species varies greatly in terms of timing, location, age, reproductive status, and other variables (Pauly et al. 1998, Ford et al. 1998, Le Boeuf et al. 2000, Bowen et al. 2002). The diet specificity of a stock is described by the diversity of prey the stock typically consumes. We assess the ability to switch prey by considering the variety of prey types historically consumed. Generalist foragers that can target a variety of prey types and prey sizes, utilizing multiple foraging locations, times, and/or strategies, are more adaptive and resilient to direct and indirect impacts from climatic changes (Clavel et al. 2011, Young et al. 2015, Beever et al. 2016).

Variability exists among other frameworks as to what constitutes a diet specialist. Laidre et al. (2008) and Sousa et al. (2019) used a threshold of one prey type comprising 20% or more of marine mammal diets as criteria for the most sensitive species. Other non-taxa specific climate vulnerability and sensitivity frameworks (e.g., Cabrelli et al. 2014, Young et al. 2015) use a threshold of a prey type comprising 90% or more of a species' diet to define a diet specialist. The differences in definition of 'prey type' each framework uses may account for some of this variation and highlights the necessity for consistent usage of terminology among scorers.

We consider the number of prey types and the size of prey as primary factors in prey diversity. We define 'prey type' in terms of broad taxonomic groups, generally on the taxonomic level of a single order (e.g., crabs, clams, squid, flatfish, clupeid fish, sciaenids (i.e., drums and croakers), calanoid copepods). Here, *diet specialists* are stocks that consume a narrow range of prey types. Those stocks with more specialized diets often consume prey of a single genus or family within a given Order. Stocks that are loosely specialized show strong preference for a single prey type for the majority of their caloric intake but are known to consume other prey types on occasion. *Diet generalists* are stocks that consume a wide variety of prey types (i.e., across multiple Orders). Stocks with the most generalized diets consume prey from several Orders while other generalist stocks may have diets limited to two or three Orders but consume a broad variety of species and sizes within those Orders.

A stock that consumes a broad assortment of prey species should be more adaptive to climate-driven shifts in prey availability because it should be able to more easily switch among prey, particularly if any one of its prey species is impacted by climate change (Laidre et al. 2008, Silber et al. 2017). A prey specialist would likely struggle to find new sources of nourishment if its preferred prey types are impacted by climate change and any new species that fill the vacated niche are unsuitable.

The duration over which the stock overlaps in space and time with the prey species also impacts the sensitivity of the stock. If a predatory stock and its forage species overlap for only a short duration in time and space, climate impacts may create a timing/spatial mismatch and increased vulnerability of the predator species to climate-driven impacts is expected.

Species with abundant and widespread prey are more resilient to climate impacts as the prey species itself is likely to be more resilient to environmental changes (Morrison et al. 2015).

While not formalized here, we encourage future iterations of this assessment to interface with vulnerability assessments that score the vulnerability of prey species to climate change.

If a species undergoes a shift in diet between life stages or life history stages, experts score the stage that has the most constrained diet. For dependent young, experts do not consider the time during which a calf or pup is nursing.

Relationship to abundance: Individuals of a species with a more specialized diet are more likely to experience declines in abundance due to climate-driven shifts in prey.

Relationship to distribution: Individuals of a species with a more specialized diet are more likely to experience shifts in distribution due to climate-driven shifts in prey.

Relationship to phenology: Individuals of a species with a more specialized diet are more likely to experience shifts in phenology due to climate-driven shifts in prey.

Prey/Diet Specificity Scoring:
Bin 1 (Low): Generalist; feeds on a wide range of prey types and sizes
Bin 2 (Moderate): Generalist; feeds on a limited number of prey types or sizes, but a wide variety of species within those types
Bin 3 (High): Specialist; exhibits strong preference for one prey type for the majority of its caloric intake, but is capable of switching prey types
Bin 4 (Very High): Specialist; reliant on one prey type, often a single genus or family, for the majority of its caloric intake, and is unable to switch to other prey types

A.2 Habitat Specificity

Goal: To determine the breadth of habitat used by a stock and estimate the ability of individuals to shift habitat use under changing conditions.

Background: Marine mammals rely on biophysical features (*i.e.*, habitat) for shelter, foraging, resting, and breeding throughout various life stages. Species that rely on specific physical and biological features are more likely to be sensitive to climate change (Laidre et al. 2008), especially if the features are vulnerable to climate-driven changes (Morrison et al. 2015). Reliance on different types of features is expected to result in different levels of sensitivity (Silber et al. 2017).

For the purpose of this assessment, we consider three types of habitat: physical habitat expected to be resilient to changing climate conditions, physical habitat expected to be vulnerable to changing climate conditions, and biogenic habitat, which is expected to be vulnerable to climate change.

Physical features such as depth, bathymetry, and rocky shorelines are expected to be resilient to climate change and therefore would result in lower sensitivity for those species that rely on those types of habitat. Other physical features that are more vulnerable to climate changes (e.g., sea ice, beach topography, fronts, eddies, upwelling) will produce greater impacts to species that rely on those types of features. We consider the physical and chemical characteristics of the water column as habitat features, which are more dynamic than persistent geologic features.

Biogenic habitat – habitat created by or consisting of organisms or organism remains – may undergo the greatest changes from a changing climate, as both the ecosystem engineers and underlying physical conditions may be impacted by changing conditions (e.g., Nelson 2009, Doney et al. 2012, Harley et al. 2012). Examples of biogenic habitat include kelp forests, mangroves, salt marshes, coral reefs, and seagrass beds (Teck et al. 2010, Okey et al. 2015). Thus, species that depend on biogenic habitats are likely more vulnerable to climate change.

While the presence of suitable prey plays a key role in defining a species' habitat, we consider the prey and diet specificity of the species in a separate attribute.

Similar to the prey/diet specificity attribute, we encourage future iterations of this assessment to interface with vulnerability assessments that score the vulnerability of habitat to climate change.

All aspects of a stock's life history within and outside of US waters should be considered when scoring this attribute.

Relationship to abundance: A stock with greater habitat specificity is more likely to experience declines in abundance due to climate-driven habitat alterations.

Relationship to distribution: A stock with greater habitat specificity is more likely to experience shifts in distribution due to climate-driven habitat alterations.

Relationship to phenology: A stock with greater habitat specificity is more likely to experience shifts in phenology due to climate-driven habitat alterations.

Habitat Specificity Scoring:
Bin 1 (Low): Stock exclusively utilizes physical features resilient to climate conditions
Bin 2 (Moderate): Stock utilizes a variety of features, but is not reliant on physical features vulnerable to climate conditions and/or biogenic habitat for specific life stages

Bin 3 (High): Stock relies on biogenic habitat or physical features vulnerable to climate conditions for one life stage or event
Bin 4 (Very High): Stock relies on biogenic habitat or physical features vulnerable to climate conditions for multiple life stages or events, or for any one particularly critical life stage or event

A.3 Site Fidelity

Goal: To assess the degree to which individuals utilize the same sites year after year.

Background: Site fidelity is defined as the tendency to remain in, or return to, the same site year after year (Switzer 1993). Individuals that remain in or return to the same locations (e.g., breeding grounds, foraging grounds, haul-out sites) display high site fidelity. Natal philopatry is a specific type of site fidelity in which individuals regularly return to breed at the same site where the individual was born. If a site that individuals return to is impacted by climate change, those individuals are expected to be impacted as well (Laidre et al. 2008). Stocks that exhibit weak site fidelity may be better suited to adapt to changing climate conditions and increased climate variability than stocks with strong site fidelity (Abrahms et al. 2018). Stocks with strong site fidelity are more likely to require shifts in distribution beyond their traditional sites to adapt to climate-driven changes that impact those sites.

Here we assess site fidelity as the precision to which individuals remain in or return to the same geographic areas year after year. Individuals that remain in or return to a smaller, or more precise, area (such as specific beaches, islands, or bays) exhibit a higher degree of site fidelity. Those individuals that remain in or return to the same general region with less precision exhibit a lower degree of site fidelity. Remaining in or returning to specific conditions (e.g., eddies, fronts) that shift in space fits better with the habitat specificity attribute than with site fidelity.

Beyond the degree of site fidelity, the number of sites that the individuals of a stock show fidelity toward has an impact on the sensitivity of the stock to climate change. Stocks that show a high degree of site fidelity to a single, same site are highly sensitive to climate change. As the proportion of individuals within a stock exhibiting high site fidelity to the same single site increases, the sensitivity to climate change also increases. Stocks that show a high degree of site fidelity, but the individuals of the stock show fidelity to different locations from the other individuals, are also sensitive to climate change, but to a lesser degree than stocks with fidelity to one or two locations. A greater number of unique sites that the stock shows fidelity toward reduces the impact of high site fidelity on sensitivity to climate change.

All aspects of a stock's life history within and outside of US waters should be considered when scoring this attribute.

Relationship to abundance: A stock with greater site fidelity is more likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: A stock with greater site fidelity is less likely to experience shifts in distribution due to climate-driven changes.

Relationship to phenology: N/A. Site fidelity is unlikely to affect a stock's phenology.

Site Fidelity Scoring:
Bin 1 (Low): Individuals display no site fidelity
Bin 2 (Moderate): Individuals display a low degree of site fidelity (i.e., archipelagos or coastlines of a general region)
Bin 3 (High): Individuals display a high degree of site fidelity (i.e., specific islands or bays) for either foraging or breeding
Bin 4 (Very High): Individuals display a high degree of site fidelity (i.e., specific islands or bays) for both foraging and breeding

A.4 Lifetime Reproductive Potential

Goal: To estimate the ability of an individual (and by extension, species) to produce offspring that facilitate population growth and avoid declines in abundance.

Background: The ability of a species to recover from disturbance and to increase its abundance depends on the ability of its individuals to reproduce and replace individuals lost to mortality (Lande 1993). Species with lower reproductive potential would generally be expected to recover more slowly than other stocks that are faster-maturing, breed more frequently, and/or produce larger "litters."

The reproductive potential of an individual marine mammal is influenced by how frequently it can reproduce and for how long it can remain reproductively active, effectively describing how many times it can reproduce. The characteristics and processes that determine the number of offspring that an individual produces over its lifetime are described by metrics such as reproductive lifespan and reproductive interval. Litter size also affects lifetime reproductive potential, but, in almost all circumstances, marine mammals have just one offspring per reproductive event.

The **reproductive lifespan** of an individual is the difference between age at sexual maturity/first reproduction and age at last reproduction. All other factors being equal, individuals with a longer reproductive lifetime will produce more offspring and would be expected to be less sensitive to climate change.

Reproductive interval is the time between offspring births, and is also called the interbirth interval. All other factors being equal, individuals with a shorter reproductive interval will produce more offspring and would be expected to be less sensitive to climate change.

Relationship to abundance: A stock with greater lifetime reproductive potential is less likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: N/A. Range expansion, contraction, or shift may occur based on population sizes, which are mediated by reproductive potential. Therefore, the relationship between this attribute and distribution is secondary or unrelated. Changes in distribution are considered with the species abundance attribute rather than here.

Relationship to phenology: N/A. Shifts in the timing of life history events may occur based on population sizes, which are mediated by reproductive potential. Therefore, the relationship between this attribute and phenology is secondary. Changes in phenology are considered with the species abundance attribute rather than here.

Lifetime Reproductive Potential Scoring:

		Female Reproductive Lifespan			
		≥ 25 yr	**20 yr ≤ x < 25 yr**	**15 yr ≤ x < 20 yr**	**< 15 yr**
Female Reproductive Interval	**≤ 2 yr**	Bin 1	Bin 1	Bin 1	Bin 2
	2 yr < x ≤3 yr	Bin 1	Bin 2	Bin 2	Bin 3
	3 yr < x ≤ 4 yr	Bin 1	Bin 2	Bin 3	Bin 4
	>4 yr	Bin 2	Bin 3	Bin 4	Bin 4

A.5 Generation Length

Goal: To estimate the time between generations in a stock that facilitates the potential for evolutionary adaptation.

Background: Generation length represents the age at which an individual has achieved half of its reproductive potential (Pacifici et al. 2013) and has been defined as the average age of parents of the current cohort (Taylor et al. 2007, IUCN 2012).

All other factors being equal, individuals with a shorter generation length will produce offspring more rapidly and would be expected to be less sensitive to climate change. Short generation lengths provide greater opportunity for genetic adaptation than long generation lengths (Pearson et al. 2014, Nogués-Bravo et al. 2018). While marine mammal stocks have considerably longer generation lengths compared to viruses, bacteria, and insects, the rate of climate change may be fast enough for variable adaptation among marine mammal stocks.

A species with a longer generation length may be able to delay reproductive activities until favorable conditions occur (Pearson et al. 2014), but runs the risk of reproducing at too slow of a rate to maintain a viable population.

Although similarities exist between the 'generation length' attribute and the 'lifetime reproductive potential' attribute, they remain separate. The 'generation length' attribute more closely tracks with a species' ability to undergo evolutionary adaptation relative to the timescale of climate change while 'lifetime reproductive potential' represents the ability to produce offspring.

Relationship to abundance: A stock with a longer generation length is more likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: N/A. Range expansion, contraction, or shift may occur based on population sizes, which are mediated by generation length. Therefore, the relationship between this attribute and distribution is secondary or unrelated. Changes in distribution are considered with the species abundance attribute rather than here.

Relationship to phenology: N/A. Shifts in the timing of life history events may occur based on population sizes, which are mediated by generation length. Therefore, the relationship between this attribute and phenology is secondary. Changes in phenology are considered with the species abundance attribute rather than here.

Generation Length Scoring:
Bin 1 (Low): < 10 years
Bin 2 (Moderate): 10 years ≤ x < 20 years
Bin 3 (High): 20 years ≤ x <30 years
Bin 4 (Very High): ≥ 30 years

A.6 Reproductive Plasticity

Goal: To estimate the ability of a stock to adapt aspects of its reproductive strategy to changing conditions.

Background: Marine mammals exhibit a variety of reproductive strategies, systems, and patterns. Reproductive activities and events in which marine mammal species engage include mating, gestation, pupping/calving, nursing (lactation), and weaning. Reproductive activities are often associated with particular times of year, habitats, and geographic locations and are characterized by behavioral or physiological traits (see Fedak et al. 2018). Those species for which reproductive events are highly correlated with a specific time frame, habitat, behavioral trait, physical trait, or geographic location are expected to be more sensitive to changes in environmental conditions, while those species with reproductive events that are loosely correlated to time frames, habitats, behavioral traits, physical traits, or geographic locations are expected to be more adaptable (Morrison et al. 2015).

Species for which multiple reproductive activities are highly correlated with time frames, habitats, or locations (e.g., ice seals requiring ice for pupping and nursing; mysticetes with consistent breeding locations and seasons) would be more sensitive compared to species for which fewer reproductive activities are correlated with time frames, habitats, or locations (e.g., odontocetes).

The proportion of the species that uses habitat at a specific location and given timeframe compounds the magnitude of influence of this attribute. A species that has a majority of its individuals utilizing a discrete location within its range concurrently for reproductive activities is more sensitive compared to a species using a breeding habitat over broader spatial and temporal scales. For the purposes of this attribute, “location” refers to a small portion of the overall stock distribution and includes features such as bays or island complexes and smaller geographic features within the distribution.

A species that can shift reproductive events to track environmental variables in time and space is better able to adapt. Reproductive activities that occur over shorter durations or that are highly synchronized between individuals are more susceptible to being disrupted by environmental changes than those for which reproductive activities are more spread out in time over the course of a year. Reproductive activities that occur at specific locations are more susceptible to being disrupted by environmental changes than those that are spread out geographically.

Breeding for some species is constrained by ephemeral (e.g., sea ice) or space-limited habitat (e.g., islands). Some species exhibit a seasonal-specific behavior or physical trait that entails significant metabolic or time preparation requirements for successful mating, birth, or nursing (e.g., blubber stores of elephant seals to remain onshore defending territory or of migratory baleen whales to fast while nursing young on calving grounds).

Other aspects of reproductive plasticity include shifts in life history strategies (e.g., breeding earlier in life when environmental conditions are good, investing more in survival rather than reproduction when environmental conditions are bad), or changes to the mating system structure (e.g., monogamy *vs* polygamy). These aspects of the reproductive strategy may change in response to climate change, but are beyond the scope of this assessment.

Relationship to abundance: A stock with greater reproductive plasticity is less likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: A stock with greater reproductive plasticity is more likely to experience shifts in distribution due to climate-driven changes.

Relationship to phenology: A stock with greater reproductive plasticity is more likely to experience shifts in phenology due to climate-driven changes.

Reproductive Plasticity Scoring:
Bin 1 (Low): Reproduction of the stock is described by **all** of the following:

a) pupping/calving season is 4 months or longer;
b) mating and pupping/calving do not require ephemeral or space-limited habitat;
c) less than half of the stock mates or gives birth in the same location; and
d) a seasonal-specific behavior or physical trait entailing significant metabolic or time preparation is not required for successful mating, birth, or nursing

Bin 2 (Moderate): Reproduction of the stock is described by **all** of the following:

a) pupping/calving season is greater than 1 month but less than 4 months; and
b) more than half of the stock mates or gives birth in the same location

Bin 3 (High): Reproduction of the stock is described by **only one** of the following:

a) pupping/calving season is 1 month or less;
b) mating or pupping/calving requires ephemeral or space-limited habitat;
c) entire stock mates or gives birth in the same location; or
d) a seasonal-specific behavior or physical trait entailing significant metabolic or time preparation is required for successful mating, birth, or nursing

Bin 4 (Very High): Reproduction of the stock is described by **more than one** of the following:

a) pupping/calving season is 1 month or less;
b) mating or pupping/calving requires ephemeral or space-limited habitat;
c) entire stock mates or gives birth in the same location; or
d) a seasonal-specific behavior or physical trait entailing significant metabolic or time preparation is required for successful mating, birth, or nursing

A.7 Migration

Goal: To estimate the migratory behaviors, patterns, and pathways of a stock

Background: The impact of migration on a species' or population's sensitivity and vulnerability to climate change is likely the most difficult to characterize of the attributes we assess. Other frameworks considered migration as a factor contributing to climate sensitivity and/or adaptive capacity for various reasons. We considered the approaches and rationale other assessments used for migration and found that many aspects are covered by other attributes and components of our method.

Migration is characterized by regular, repeated, long-distance linear movement (Dingle 1996, Stern and Friedlaender 2018) such as between breeding and foraging grounds. Migratory species are often seeking specific conditions or abandoning areas that become unsuitable for parts of the year. Species may engage in annual or seasonal migrations. Dingle and Drake (2007) define annual migrations as round-trip movements synchronized with a yearly pattern and seasonal migrations as the individual stages of those annual patterns. Here, we consider seasonal migrations more closely defined as what Dingle and Drake (2007) refer to as "commuting," movements between discrete areas on a more frequent basis than annual migrations.

Migratory species are often considered to be more vulnerable to climate change due to a specific temporal or seasonal reliance on a certain habitat (Laidre et al. 2008, ZSL 2010). The reliance on specific habitat (see Habitat Specificity) or specific sites (see Site Fidelity) is considered elsewhere in this assessment, but the temporal aspect and potential for mismatches between the migrant and habitat conditions remain important (Laidre et al. 2008, Chin et al. 2010, Gardali et al. 2012, Pecl et al. 2014, Sousa et al. 2019). Environmental cues play a greater role in the life history of migratory species than non-migratory species, therefore making migratory species more sensitive to climate-driven shifts in phenology. However, climate-driven shifts in the phenology of predators and/or prey may have cascading effects on both migratory and non-migratory species.

Some frameworks only assessed part of a species' range and used the migration attribute to account for potential impacts in other regions (e.g., Chin et al. 2010, Bagne et al. 2011). Migratory species may experience varying levels of climate change across their ranges thereby compounding their exposure to climate change. Here we consider the entire annual range of the species and therefore do not need to use a proxy for areas outside of the scope of the assessment. Those potential changes outside the scope of other assessments are explicitly considered in the exposure score of this assessment.

Several frameworks use migration as a proxy for dispersal ability (e.g., Gardali et al. 2012, ZSL 2010). While we also consider the home range of individuals of a species (see Home Range), the fact that a species undergoes a long distance migration and the diversity of the pathways the species uses within and between years confer a degree of adaptive capacity. Climate-driven impacts to a migratory pathway could have devastating effects on a species that relies solely on that pathway, while a species that utilizes a variety of pathways would see a reduced impact on the overall population.

Finally, migratory species may be able to escape unfavorable conditions and find new habitat more easily than non-migratory species. While most marine mammals are highly mobile and capable of traveling long distances, migratory species tend to engage in behavior that would encourage the discovery of new suitable areas.

All aspects of a stock's life history within and outside of US waters should be considered when scoring this attribute.

Relationship to abundance: N/A. A clear and consistent directional relationship between migratory behavior and abundance was not established.

Relationship to distribution: Migratory species are more likely to experience shifts in distribution than non-migratory species.

Relationship to phenology: Migratory species are more likely to experience shifts in phenology than non-migratory species.

Migration Scoring:
Bin 1 (Low): Annual migration; multiple migratory pathways
Bin 2 (Moderate): Annual migration; single migratory pathway
Bin 3 (High): Seasonal migration
Bin 4 (Very High): No migration; local movement only

A.8 Home Range

Goal: To estimate the spatial extent of individuals within a stock.

Background:

The home range of an individual includes the areas regularly visited to forage, breed, and care for young (Burt 1943). Home range differs between individuals of a species and is generally smaller than the geographic extent of the species. Species that have a broad home range can escape unfavorable conditions and find new habitat more easily than species with a narrow home range. The new habitat may be used for a multitude of life history stages that have direct implications on abundance such as breeding, calving/pupping, and foraging.

Other frameworks use discrete areal extents (Thomas et al. 2011, Pecl et al. 2014), latitudinal (Chin et al. 2010, Stortini et al. 2015), or longitudinal (Laidre et al. 2008) extents to describe the geographic extent of a population. We use broader terms similar to Sousa et al. (2019) to define the home range of individuals to gain a sense of their potential connectivity with other suitable habitat.

Considering that marine mammals are long-lived, highly mobile species, the home range of the individual is more important than geographic extent of the stock for the time frame considered in this assessment.

All aspects of a stock's life history within and outside of US waters should be considered when scoring this attribute.

Relationship to abundance: A stock consisting of individuals with large home ranges is less likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: A stock consisting of individuals with small home ranges is more likely to experience shifts in distribution due to climate-driven changes.

Relationship to phenology: N/A.

Home Range Scoring:
Bin 1 (Low): Individuals' home ranges are broad (e.g., include much of an ocean basin)
Bin 2 (Moderate): Individuals' home ranges are moderate to large (e.g., spend the majority of time along coasts, within continental shelf waters, or along the continental slope, but may utilize deeper waters)
Bin 3 (High): Individuals typically remain in bays or archipelagos and seldom travel farther but could if needed
Bin 4 (Very High): Individuals' home ranges are relatively small (e.g., confined to bays or archipelagos) and are limited from traveling farther by a combination of geographic features, physical capabilities, and behaviors

A.9 Stock Abundance

Goal: To estimate a stock's current abundance

Background: Smaller population sizes have an implied reduced genetic diversity (Frankham 1996), reduced behavioral and cultural diversity (Whitehead et al. 2004), experience more demographic stochasticity (Purvis et al. 2000), and are generally at greater extinction risk (Purvis et al. 2000). Greater diversity (genetic, behavioral, cultural, etc.) confers a greater ability to adapt to changing conditions (Morrison et al. 2015). Larger populations are better poised to colonize new areas or re-establish in formerly occupied extirpated areas (Laidre et al. 2008) and buffer inter-annual variability in population size through potentially smaller percentage declines in species abundance when experiencing a disturbance.

Other frameworks use a wide variety of population size values to determine climate sensitivity for marine mammals (Laidre et al. 2008, Sousa et al. 2019). Laidre et al. (2008) considered the worldwide abundance of the species. We take a stock-centric approach and only consider the abundance of the stock being scored. We established our bins by considering ESA downlisting criteria, ESA delisting criteria, and International Union for the Conservation of Nature (IUCN) red list criteria and setting bin breaks as order of magnitude differences in population size.

For stocks that have a high degree of uncertainty surrounding abundance values, experts should consider sampling methods, sampling frequency, and historical abundances when scoring.

Relationship to abundance: A stock with high abundance is less likely to experience declines in abundance due to climate-driven changes

Relationship to distribution: A stock with high abundance is less likely to experience large relative shifts in distribution due to climate-driven changes

Relationship to phenology: A stock with high abundance is less likely to experience large relative shifts in phenology due to climate-driven changes

Stock Abundance Scoring:
Bin 1 (Low): Stock comprises > 10,000 individuals
Bin 2 (Moderate): Stock comprises 1,001-10,000 individuals
Bin 3 (High): Stock comprises 101-1,000 individuals
Bin 4 (Very High): Stock comprises < 100 individuals

A.10 Stock Abundance Trend

Goal: To identify the trend of a stock's abundance through time

Background: Stocks with declining abundance have a reduced ability to recover from disturbances and are more likely to be sensitive to climate change. Climate change would likely place additional stress on already declining stocks, unless that change was favorable. The "Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change" (Galbraith and Price 2009) assesses population size reduction over a 10-year or three-generation period, derived from one of the criteria used to determine the IUCN red list status (IUCN 2012). Here, we follow the model of Thomas et al. (2011) to establish scoring bins. Thomas et al. (2011) use a criterion of 7.5% rate of decline to differentiate between 'declining' and 'rapidly declining'. We realize that such precision is not available for many marine mammal stocks and simply use that figure as a guideline for distinguishing between declining and rapidly declining abundances. We acknowledge that in the Stock Assessment Reports (SARs) of many species, the trend is unknown. In these circumstances, we anticipate experts will use professional opinion and encourage the use of other published trend papers.

Relationship to abundance: A stock with a rapidly declining abundance is more likely to experience declines in abundance due to climate-driven changes

Relationship to distribution: A stock with a rapidly declining abundance is more likely to experience shifts in distribution due to climate-driven changes

Relationship to phenology: A stock with a rapidly declining abundance is more likely to experience shifts in phenology due to climate-driven changes

Stock Abundance Trend Scoring:
Bin 1 (Low): Increasing abundance trend over past 10-year period
Bin 2 (Moderate): Stable abundance trend over past 10-year period
Bin 3 (High): Declining abundance trend over past 10-year period
Bin 4 (Very High): Rapidly declining abundance trend over past 10-year period

A.11 Cumulative Stressors

Goal: To estimate the level to which a stock is impacted by non-climate stressors.

Background: Climate change is expected to exacerbate other stressors that already impact marine mammals. Non-climate stressors are interactions experienced by individuals that reduce fitness.

Species that experience stress from non-climate sources (such as disease, direct and indirect anthropogenic effects, and natural interactions such as competition and predation) will be at a reduced capacity to adapt to climate change (Staudt et al. 2013, Morrison et al. 2015, Sousa et al. 2019). The magnitude of impact experienced by additional stressors will vary by species and region (NASEM 2017).

Many of the stressors that stocks experience may be exacerbated or modified by climate change. Anticipating the degree to which these stressors may react under climate change and the ensuing impact to marine mammals is challenging and beyond the scope of this assessment. Here, we assess the degree to which stocks are *currently* affected by additional, non-climate stressors.

While any level of a stressor can result in negative impacts on a stock, for the purposes of this assessment experts are guided to consider a stressor as anything that accounts for roughly 10% or greater of annual mortality or has sublethal impacts on at least half of the population.

Examples of non-climatic additional stressors include:

- Bycatch or competition with fisheries
- Vessel-strike
- Habitat degradation and modification not due to climate change
- Disease, parasites, and harmful algal bloom exposure not due to climate change
- Sound/noise
- Predation
- Pollutants/toxins
- Marine debris
- Ecotourism

Relationship to abundance: A stock that currently experiences many non-climate stressors is more likely to experience declines in abundance due to climate-driven changes.

Relationship to distribution: A stock that currently experiences many non-climate stressors is more likely to experience shifts in distribution due to climate-driven changes.

Relationship to phenology: A stock that currently experiences many non-climate stressors is more likely to experience shifts in phenology due to climate-driven changes.

Scoring:
Bin 1 (Low): Stock currently experiences 1 or fewer additional stressors
Bin 2 (Moderate): Stock currently experiences 2 or 3 additional stressors
Bin 3 (High): Stock currently experiences 4 or 5 additional stressors
Bin 4 (Very High): Stock currently experiences greater than 5 additional stressors or has one additional stressor that accounts for more than half of annual mortality

A.12 Attributes considered but omitted

During the development of this framework, a number of potential attributes were considered to score sensitivity and adaptive capacity. We list those that were considered but ultimately omitted from the framework such that future iterations may include these attributes if appropriate. Many of these attributes were omitted because of a lack of available information or a lack of meaningful differentiation in how the attribute would score between species and populations.

Prey availability

Predictability of prey in time and space is an important consideration. Decreased predictability would increase sensitivity, making it important to consider search strategies. The attribute is not intrinsic to the subject species and would require data on all prey species.

The availability of other prey species of roughly equivalent energetic/nutrient composition adds a layer of complexity. If a species is capable of foraging on other species but none are available, or only those of considerably deficient nutrient or energetic content, the species would be more sensitive to climate impacts. Similarly, if the traditionally targeted prey consists of fewer but larger prey items and can only be replaced by smaller prey, additional or different pressures to capture more prey items may come at a higher cost to the predator in time, energy, or risk of predation. The availability of prey and the relative availability of comparable alternative prey are important considerations but beyond the scope of this attribute and therefore not included in the scoring.

Population trend of prey

Species that forage on prey with high variability in abundance may have relatively high sensitivity to climate change. The attribute is not intrinsic to the subject species and would require data on all prey species.

Distribution trend of prey

Species that forage on prey with high variability in distribution may have relatively high sensitivity to climate change. The attribute is not intrinsic to the subject species and would require data on all prey species.

Mean Trophic Level

The primary productivity required to sustain a population can be estimated and may be an indicator of sensitivity. While a species that feeds on high trophic levels (e.g., other marine mammals and fish) would likely have a different sensitivity than a species that feeds on a lower trophic level (e.g., krill), we struggled to formalize the relationship between trophic level and sensitivity. This attribute was determined to be similar to the more easily measured and qualified metric of ‘prey/diet specificity.’

Influences of changes in trophic web

Climate change could lengthen or shorten the food chain, resulting in changing amounts of energy available at the apex levels. Other assessments (see NatureServe’s CCVI[4]) include interspecific interactions but the attribute was deemed too complex for this application.

[4] http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index

Social Structure

Social structure is a significant component of delphinid ecology. Strong social systems are key to their resilience and adaptive capacity. We could not operationalize a metric for this attribute and encourage further examination in future iterations of the vulnerability assessment.

Complexity in reproductive strategy

Species with highly complex reproductive strategies are more likely to have at least one aspect of the strategy impacted by climate change. A lack of variability among taxa rendered this attribute impractical.

Environmental variable(s) as a phenological cue for breeding

The triggers/cues for many species are likely unknown. As more data become available, this attribute could be reconsidered.

Early Life History Survival Requirements

This attribute was considered too correlated with other attributes, particularly habitat sensitivity and reproductive plasticity.

Physiological Tolerances

This attribute was considered too general and overlapping with other attributes. Marine mammals generally have broad tolerances, with calves serving as the main exception.

Sensitivity to Temperature

This attribute was seen overlapping with ‘physiological tolerances’ and less applicable to marine mammals than to sea turtles.

Sensitivity to Ocean Acidification

Experts could not recall studies determining whether marine mammals are sensitive to the pH of their waters, though the experts suspected marine mammals and sea turtles have few direct impacts from ocean acidification. Marine mammals and sea turtles are assumed to be tolerant, or at least more tolerant than their prey.

Proximity to limit of thermal tolerance

Separating species physiological tolerance from prey tolerance is difficult, at least in terms of proximity to a threshold.

Spatial availability of unoccupied habitat for most critical life stage

This attribute most applies for species recovering from past declines with the potential for recovering populations to recolonize historical areas where they were previously extirpated or to colonize new areas beyond historical ranges. Most populations are not at their carrying capacity, suggesting there is unoccupied habitat. This attribute is not intrinsic to the species and would be difficult to quantify.

Genetic Diversity

Generally, the more genetically diverse the species, the less sensitive the species is to ecosystem perturbations. Sufficient data likely exist for some marine mammals since genetics is a primary tool for identifying stock structure and delineating stocks, but consistency and availability across species is problematic. We encourage future iterations of this assessment to consider incorporating this attribute.

Temporal mismatches of life-cycle events

This attribute has been incorporated into other attributes through the use of the phenology response category.

R_{Max}

Initially included due to its availability for all species/stocks, this attribute was removed because it was presented as a default value for many species/stocks and did not provide meaningful differentiation between species/stocks. Stocks that are more productive typically exhibit greater resilience to disturbances and long-term changes in environmental conditions (Lande 1993, Pecl et al. 2014, Morrison et al. 2015).

A.13 Appendix A References

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Appendix B Climate Exposure Factors

Appendix B Climate Exposure Factors B-1
B.1 Sea Surface Temperature B-2
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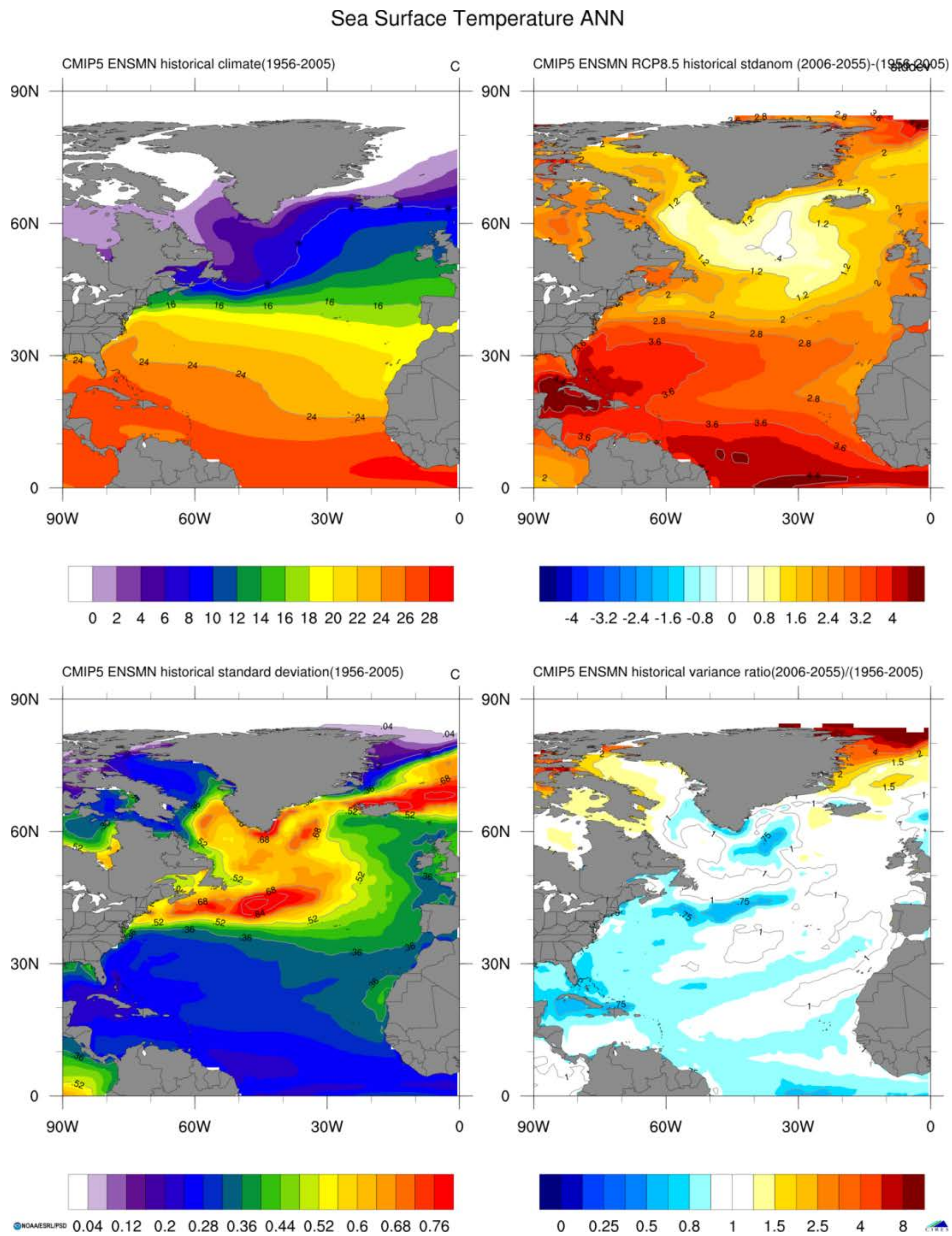
B.1 Sea Surface Temperature

Background: Sea surface temperature (SST) is measured using a variety of methods and corresponding depths. For the purpose of this assessment, SST refers to the temperature of the upper water column, or the mixed layer. Marine mammals necessarily exist in this depth zone to facilitate breathing, though some spend considerable time foraging at deeper depths. Species distributions have been correlated with SST for both cetaceans and pinnipeds (e.g., Sydeman and Allen 2006, MacLeod 2009). Prey abundance and distribution also have been correlated with SST (Rutherford et al. 1999).

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\|x\| < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \|x\| < 1.5$ std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \|x\| < 2.0$ std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\|x\| \geq 2.0$ std dev	≥ 1.78



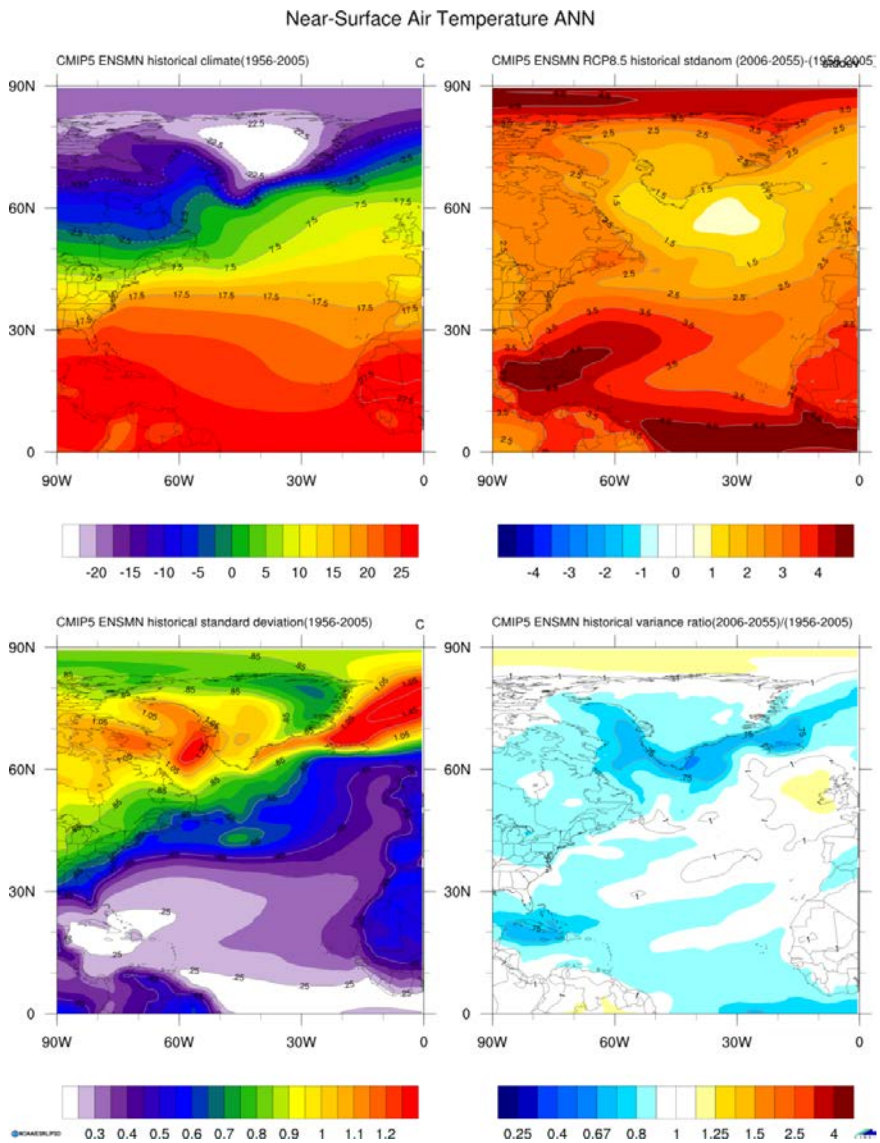
(source: Earth Systems Research Laboratory 2014)

B.2 Air Temperature

Background: Near-surface air temperature has been shown to have physiological impacts on some marine mammals (Castellini 2018). Pinnipeds utilize differences between water temperature and air temperature for thermoregulatory processes (White and Odell 1971, Odell 1974, Whittow 1978, Twiss et al. 2002, Khamas et al. 2012). Similar physiological impacts of air temperature on cetaceans have not been observed (e.g., Meagher et al. 2002, Barbieri et al. 2010). Air temperature can also serve as a valuable proxy for water temperature in estuaries and shallow coastal areas that are typically not resolved by projections of sea surface temperature (Roelofs and Bumpus 1953, Hare and Able 2007, Hare et al. 2010, Galbraith et al. 2012).

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert < 1.5$ std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert < 2.0$ std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev	≥ 1.78



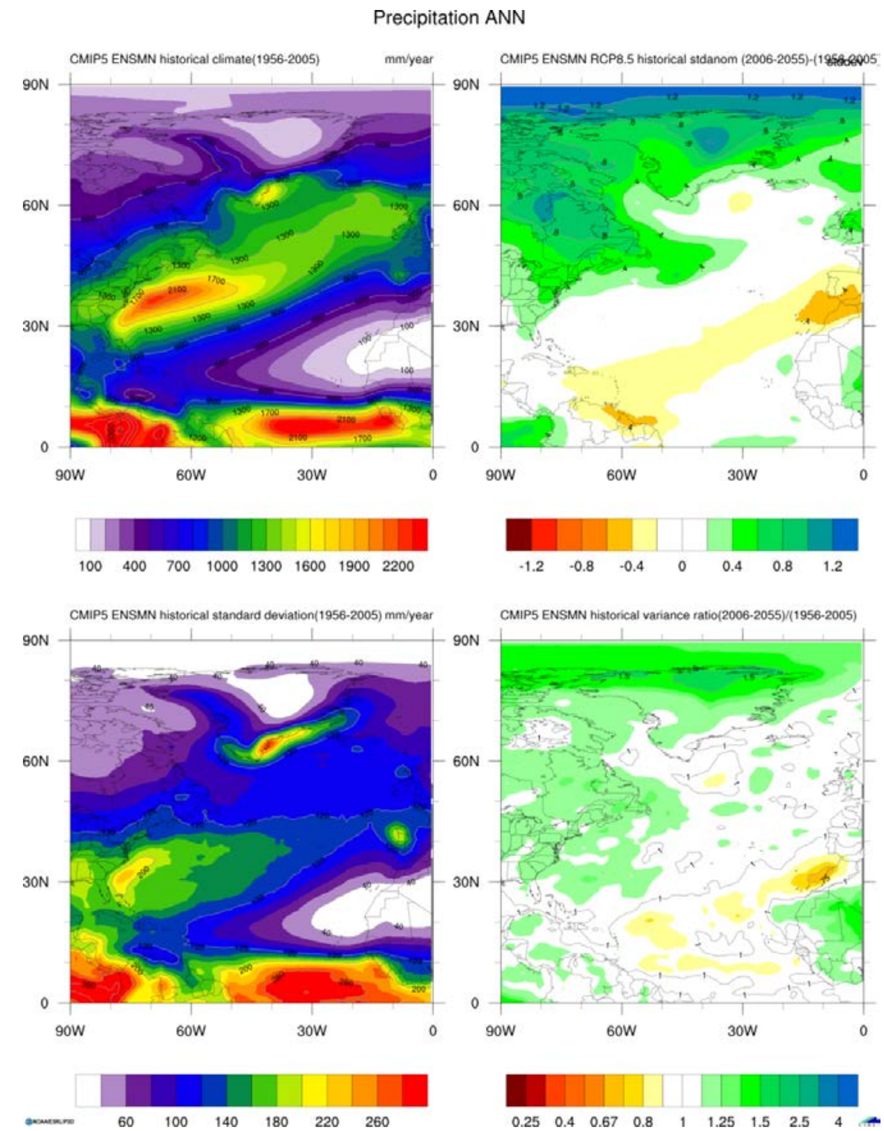
(source: Earth Systems Research Laboratory 2014)

B.3 Precipitation

Background: Precipitation affects surface salinity both in the open ocean and coastal areas. Precipitation is not expected to have a direct physiological impact on marine mammals, though changes in salinity (measured elsewhere in this assessment) may impact certain stocks. Precipitation, along with the ensuing runoff, serves as a delivery mechanism for pollutants and debris from land-based sources, particularly in coastal areas. Additionally, precipitation changes outside of estuarine and coastal stock distributions may have profound impacts on those stocks, depending on the size and development of the watershed that feeds the estuary or coastal region.

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert < 1.5$ std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert < 2.0$ std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev	≥ 1.78



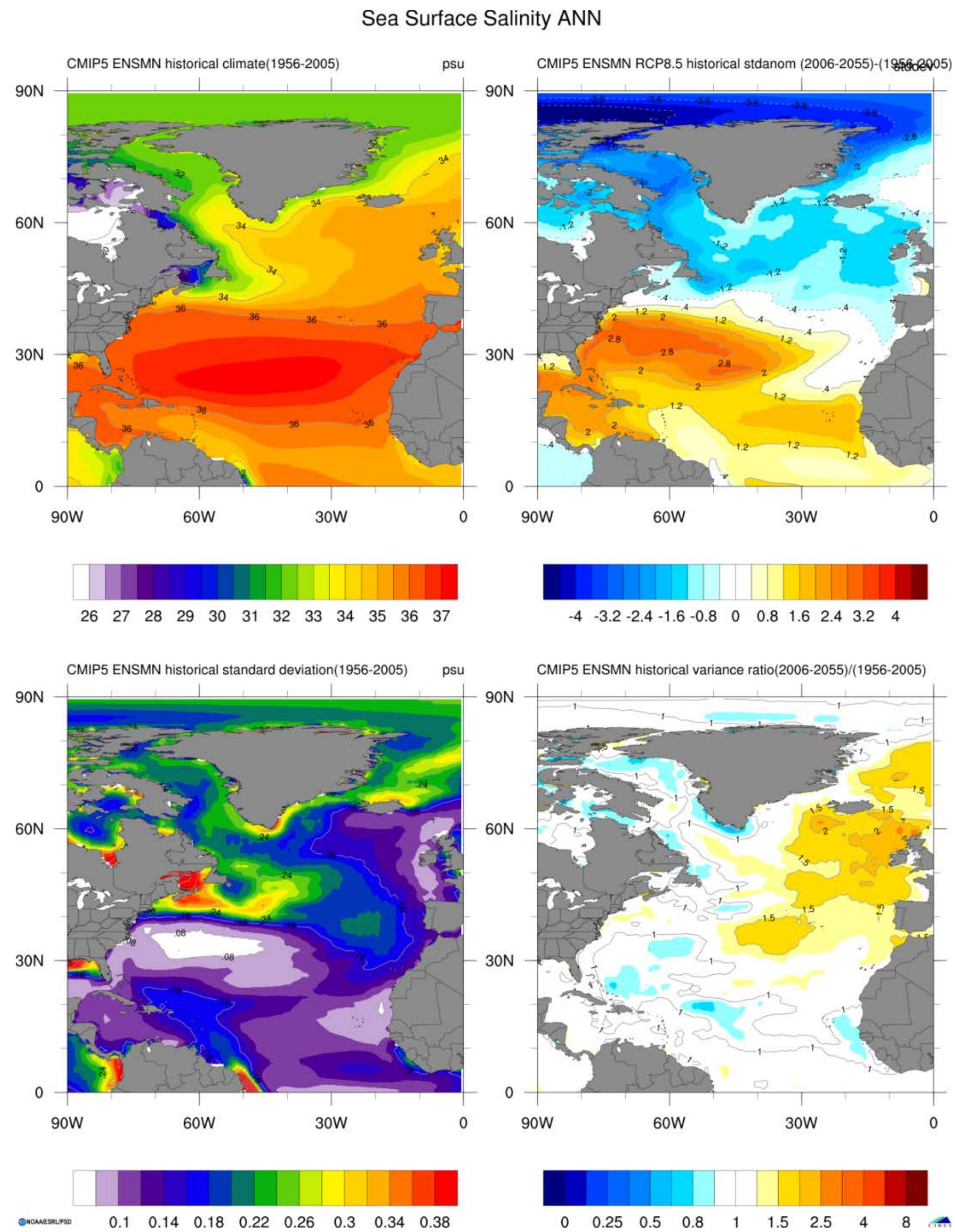
(source: Earth Systems Research Laboratory 2014)

B.4 Salinity

Background: Surface salinity is a dynamic property that affects ocean circulation. Prolonged exposure of dolphins to lower salinity waters has been shown to result in skin lesions (Mullin et al. 2015) and affect biochemistry (Ewing et al. 2017). Salinity influences marine mammal prey species (Learmonth et al. 2006). Many of the bay, sound, and estuary stocks have distributions that are smaller than the climate models can resolve, and changes in precipitation may better represent the exposure to changes in salinity for those areas.

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert <$ 1.5 std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert <$ 2.0 std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev	≥ 1.78



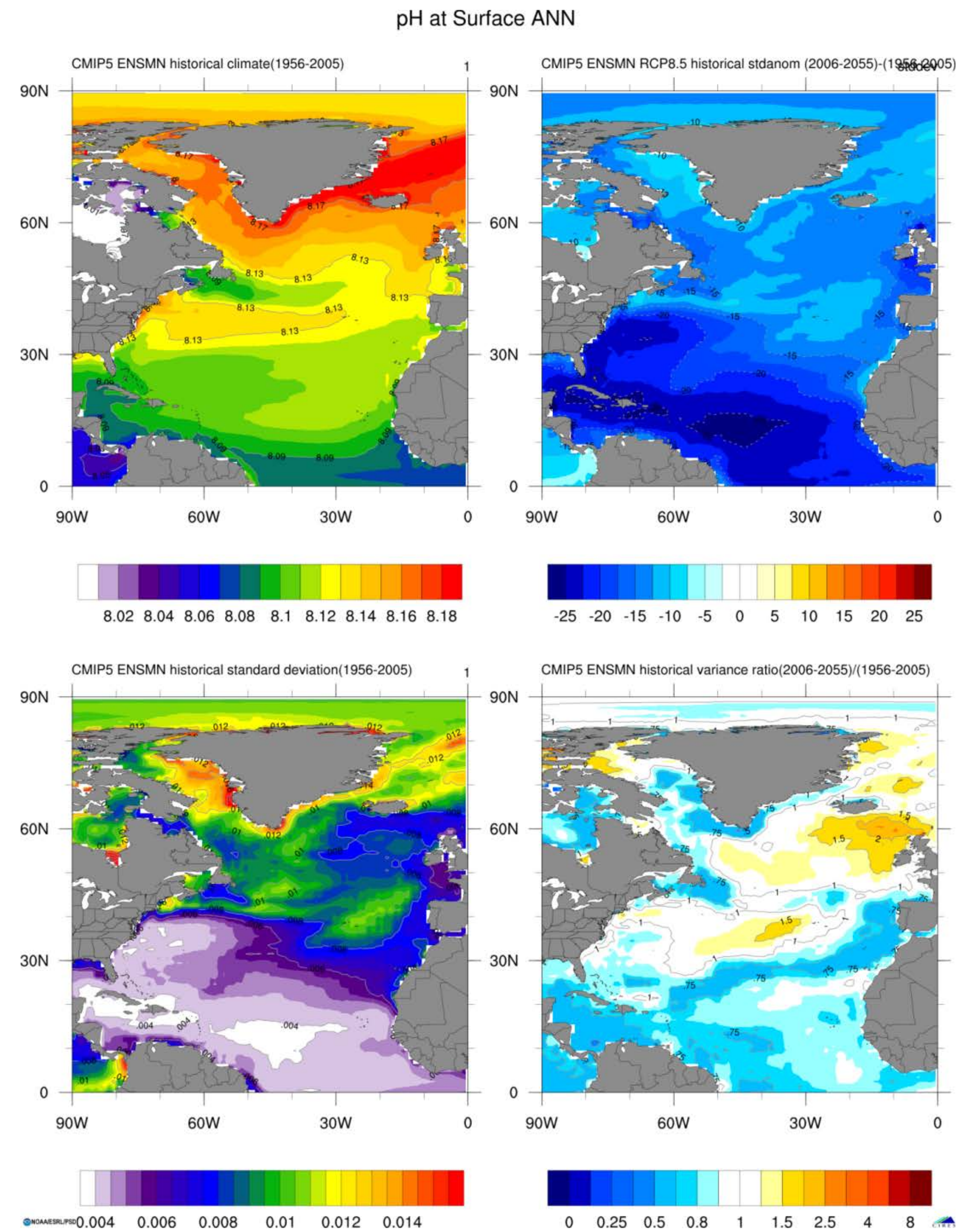
(source: Earth Systems Research Laboratory 2014)

B.5 Ocean Acidification

Background: Ocean acidification refers to the decreasing of the ocean's pH through chemical reactions resulting from increased atmospheric carbon dioxide. While no direct physiological effects of pH have been documented for marine mammals, changes in pH have been shown to impact habitats (e.g., coral reefs) and prey species (Learmonth et al. 2006). More acidic water allows low-frequency sound to travel farther, which may interfere with the acoustic habitat of marine mammals (Hester et al. 2008, Brewer and Hester 2009, Ilyina et al. 2010).

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\|x\| < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \|x\| < 1.5$ std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \|x\| < 2.0$ std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\|x\| \geq 2.0$ std dev	≥ 1.78



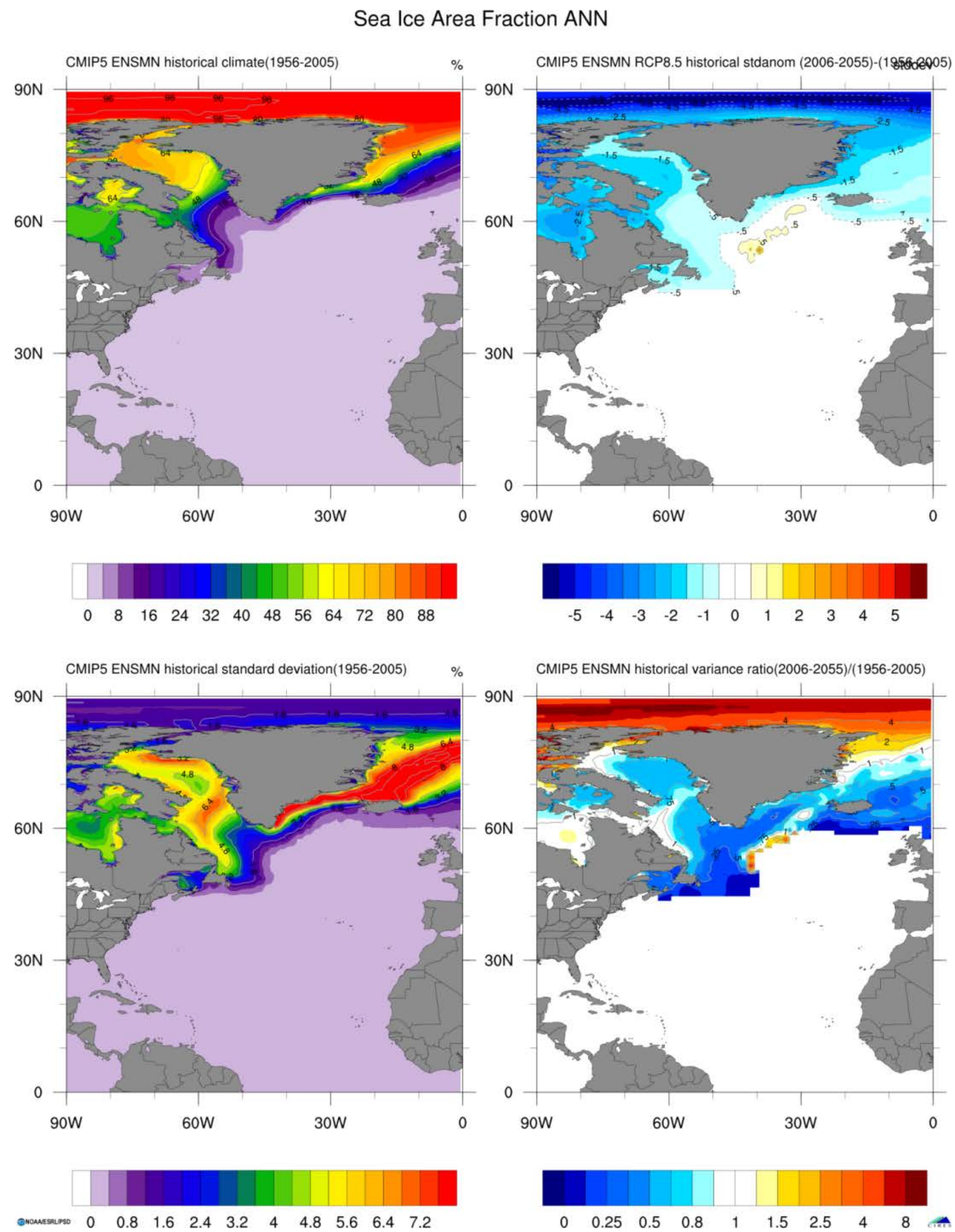
(source: Earth Systems Research Laboratory 2014)

B.6 Sea Ice Cover

Background: Sea ice cover is the percent of sea surface covered by any type of ice. Carnivora species have been shown to use ice for hunting, resting, and breeding (Moore 2009). Cetacean species have been observed foraging along ice fronts (Asselin et al. 2012). Areas in which sea ice is not found should be scored in Bin 1.

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert < 1.5$ std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert < 2.0$ std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev	≥ 1.78



(source: Earth Systems Research Laboratory 2014)

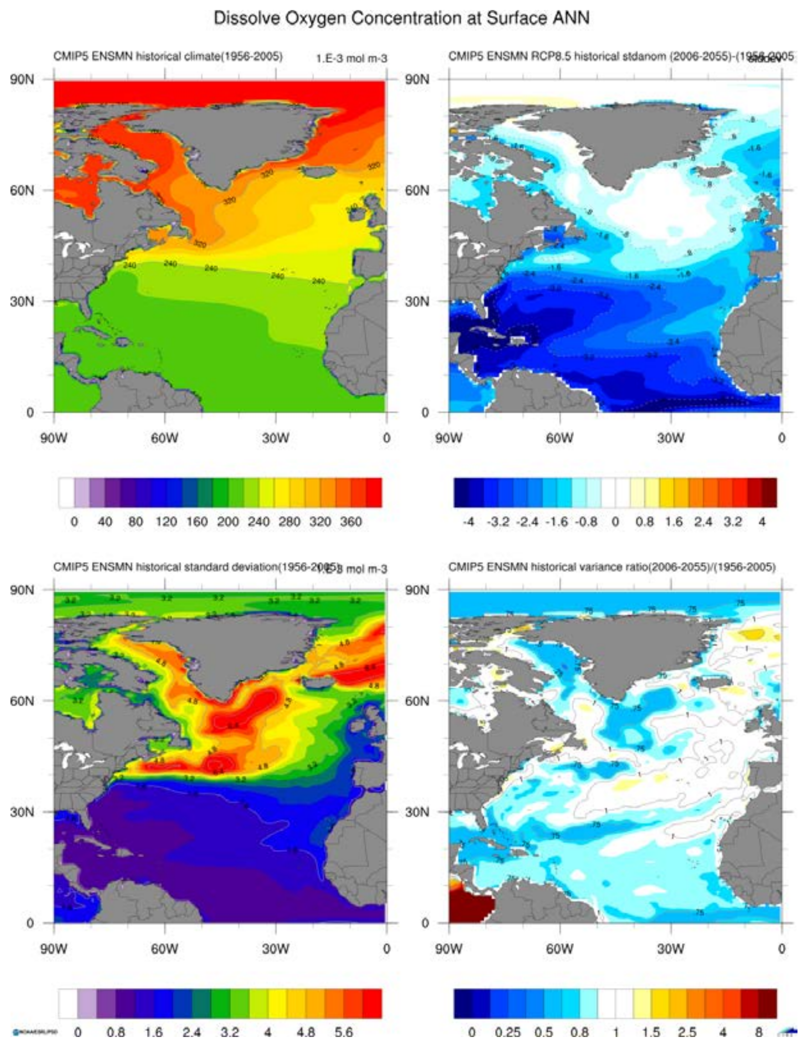
B.7 Dissolved Oxygen

Background: Dissolved oxygen in the surface water varies with temperature, utilization, and stratification (Matear et al. 2000, Bopp et al. 2002, Keeling and Garcia 2002, Matear and Hirst 2003, Keeling et al. 2010). Eutrophication in coastal waters drives oxygen utilization, resulting in hypoxic and anoxic conditions, with notable examples in the northern Gulf of Mexico (Rabalais et al. 2010, Zhang et al. 2010). While no physiological effects of dissolved oxygen have been observed for marine mammals, changes in dissolved oxygen impact prey species (Townhill et al. 2017).

Many marine mammal species feed at considerable depth below the surface layer, but we were unable to obtain spatial projections of dissolved oxygen at depth. Oxygen minimum zones typically occur at depths of 400 to 1200m (Keeling et al. 2010) and studies suggest that dissolved oxygen may decline in deep regions of the North Atlantic as a result of decreased North Atlantic Deep Water formation (Plattner et al. 2001, Frölicher et al. 2009, Keeling et al. 2010).

Scoring:

	Projected mean vs historical variance	Projected change in variability
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev	<1.15
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert <$ 1.5 std dev	$1.15 \leq x < 1.54$
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert <$ 2.0 std dev	$1.54 \leq x < 1.78$
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev	≥ 1.78



(source: Earth Systems Research Laboratory 2014)

B.8 Circulation

Background: Circulation refers to the movement of water masses. It occurs on the scale from major currents to estuarine mixing and includes processes such as upwelling, Ekman transport, and eddies. Changes in circulation are difficult to project, and therefore we use a qualitative approach modeled after Morrison et al. (2015) and Hare et al. (2016).

Boundary currents are the eastern and western branches of subtropical gyres. Western boundary currents such as the Gulf Stream are characterized by fast ocean velocities and sharp sea surface temperature (SST) fronts (Yang et al. 2016). Globally, western boundary currents are expected to strengthen under climate change. However, the Gulf Stream is expected to weaken due to a weakening Atlantic Meridional Overturning Circulation (Caesar et al. 2018). Within the Gulf of Mexico, the Loop Current is also expected to weaken during the 21st century (Liu et al. 2012, Liu et al. 2015). Despite these anticipated changes in intensity, the natural variations of boundary currents might conceal the effects of climate change (Yang et al. 2016).

Eastern boundary currents and the associated upwelling ecosystems are characterized by high productivity, high nutrient levels, and cool water.

Mesoscale processes such as eddies and fronts will be impacted by any changes in boundary currents. These processes are more dynamic and less persistent than boundary current circulation and as such may be more susceptible to more dramatic changes. These processes occur on a spatial scale smaller than the global circulation models can currently resolve (Oey et al. 2005) and requires downscaled models to project. A weakened Loop Current in the Gulf of Mexico would shed weaker, shallower, and cooler eddies (Liu et al. 2012, Liu et al. 2015).

Finer scale and local processes such as estuarine and event-driven circulation may be subject to even greater changes, as the number of driving forces multiplies. Estuarine circulation is driven by both riverine and tidal forces. While astronomical tides are expected to undergo minimal change, other forces that affect tides such as sea surface height and prevailing winds may affect tides. Riverine discharge is expected to change in many areas as precipitation patterns change. In the Gulf of Mexico, an increase in Mississippi river discharge (Tao et al. 2014) may alter circulation patterns, which already exhibit complex interactions between river discharge and mesoscale circulation features (Walker et al. 2005, Luo et al. 2016, Barkan et al. 2017).

Changes in storms such as hurricanes are difficult to project (Knutson et al. 2010, Kirtman et al. 2013, Maloney et al. 2014, Walsh et al. 2015, Walsh et al. 2016) and, despite their importance for local and regional circulation, we do not consider it in our assessment.

In areas where multiple types of circulation overlap (e.g., tidal currents and estuarine circulation, or eddies and boundary currents), consider the predominant forcing and the type of circulation that the stock is most interacting with. For example, in estuaries, consider the relative importance of river flow and tidal signal. For stocks that interact with both eddies and boundary currents, consider which features they interact with more frequently and for what purposes.

Scoring:

Bin 1 (Low):	Stock distribution overlaps almost exclusively with large boundary currents or tidal currents
Bin 2 (Moderate):	Majority of stock distribution overlaps with large boundary currents or tidal currents. Stock may also interact with mesoscale features such as fronts or eddies.

Bin 3 (High):	Majority of stock distribution overlaps with currents that are expected to have a high magnitude of change such as estuarine circulation, nearshore density currents, and/or wind driven currents. Stock may also interact with mesoscale features such as fronts or eddies.
Bin 4 (Very High):	Stock distribution overlaps almost exclusively with currents that are expected to have a high magnitude of change such as estuarine circulation, nearshore density currents, and/or wind driven currents.

B.9 Sea Level Rise

Background: Sea level rise refers to the relative change in sea level and has both a local and a global component. Sea level rise comprises thermal expansion of sea water, addition of water volume from melting of land-based glaciers, and local changes in land elevation due to processes such as subsidence and isostatic rebound. Sea level rise can effectively eliminate some shoreline habitat over time and has the potential to exacerbate coastal flooding during storms and spring tides. While direct effects of sea level rise are more pronounced for inshore and intertidal areas, coastal stocks that utilize waters over the continental shelf may also experience impacts from sea level rise, particularly in shallower areas. Those stocks that are trophically linked to estuary, wetland, seagrass, or beach habitat may also experience indirect effects from sea level rise.

A hybrid quantitative-qualitative approach adopted from the Fish Stock Climate Vulnerability Assessment (Morrison et al. 2015, Hare et al. 2016) is used for this attribute to account for stocks that will experience sea level rise but not in a functionally relevant manner (e.g., open ocean stocks). We modify the approach of the Fish Stock Climate Vulnerability Assessment (Morrison et al. 2015, Hare et al. 2016) to include finer resolution for low and moderate exposure and convert the units to match available sea level rise projections (Sweet et al. 2017).

To score this exposure factor, first consider whether the stock will experience sea level rise in a relevant manner. Stocks that use wetlands, seagrass beds, beaches, and/or estuaries are expected to experience direct effects of sea level rise and should be scored in Bin 3 or Bin 4 based on the degree of projected sea level rise within their range. Stocks with coastal distributions and in waters over the continental shelf are expected to experience diluted direct effects of sea level rise that decrease with depth. However, these coastal stocks may be trophically linked to wetland, seagrass, or estuarine habitat and may experience shifts in available habitat from a changing coastline. Generally, coastal stocks will align with Bin 2. Offshore and open ocean stocks are not expected to directly experience the effects of sea level rise, though they may have trophic linkages to wetland, seagrass, or estuarine habitat. Generally, offshore stocks will align with Bin 1.

Scoring:

Bin 1 (Low):	Stock is found generally in deeper water beyond the continental shelf
Bin 2 (Moderate):	Stock is generally coastal or found in continental shelf waters
Bin 3 (High):	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and the change in regional sea level within their range is expected to increase less than 7 mm yr^{-1} by 2050
Bin 4 (Very High):	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and regional sea level within their range is expected to increase greater than or equal to 7 mm yr^{-1} by 2050

B.10 Appendix B References

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Appendix C Sample Scoring

We show sample exposure scores (Table C1) and sensitivity scores (Table C2) for a hypothetical stock. Here we highlight the process of calculating the weighted means, the component scores, the overall vulnerability score, and the response category scores.

Attribute and Factor Weighted Means (section 2.4.1)

Weighted means are calculated for each Sensitivity/Adaptive Capacity Attribute and each Exposure Factor. The weighted means are calculated by multiplying the number of tallies in each bin by the bin number (number of tallies in Bin 1 times 1, number of tallies in Bin 2 times 2, number of tallies in Bin 3 times 3, number of tallies in Bin 4 times 4) and then dividing by the total number of tallies for that attribute or factor. The value of these weighted means ranges from 1.0 to 4.0.

Component Scores (section 2.4.2)

Exposure and Sensitivity component scores are calculated using the Attribute and Factor Weighted Means from above and the component score logic model from Table 4 in section 2.4.2.

Sea Surface Temperature mean, Air Temperature mean, Precipitation mean, and Ocean pH weighted means are all above 3.5. The Exposure Component score is therefore Very High (4).

No Sensitivity/Adaptive Capacity attribute weighted means are greater than 3.5. Prey/Diet Specificity and Reproductive Plasticity both have weighted means greater than or equal to 3.0. The Sensitivity/Adaptive Capacity Component score is therefore High (3).

Component score logic model (see section 2.4.2 and Table 4)

Component Score	Criteria
Very High (4)	3 or more attribute or factor mean scores ≥ 3.5
High (3)	2 or more attribute or factor mean scores ≥ 3.0, but does not meet threshold for “Very High”
Moderate (2)	2 or more attribute or factor mean scores ≥ 2.5, but does not meet threshold for “High” or “Very High”
Low (1)	Less than 2 attribute or factor mean scores ≥ 2.5

Overall Vulnerability Score (section 2.4.3)

Using the vulnerability matrix (Figure 3 in section 2.4.3) and the component scores from above, a Very High Exposure Component and a High Sensitivity Component converge at a Very High Overall Vulnerability (12).

Vulnerability matrix (see section 2.4.3 and Figure 3)

Sensitivity	Very High (4)	Moderate (4)	High (8)	Very High (12)	Very High (16)
	High (3)	Low (3)	Moderate (6)	High (9)	Very High (12)
	Moderate (2)	Low (2)	Moderate (4)	Moderate (6)	High (8)
	Low (1)	Low (1)	Low (2)	Low (3)	Moderate (4)
		Low (1)	Moderate (2)	High (3)	Very High (4)
		Exposure			

Response Category Scores (section 2.4.4)

The distribution, abundance, and phenology response category scores are derived from the attribute weighted means calculated according to the relationships with each attribute described in Appendix A. The weighted means are used in the component score logic model (Table 4), similar to the calculation of component scores above.

The distribution response scores as High because Prey/Diet Specificity and Migration weighted means are greater than 3.0. The abundance response scores as High because Prey/Diet Specificity and Reproductive Plasticity weighted means are greater than 3.0. The phenology response scores as High because Prey/Diet Specificity and Migration weighted means are greater than 3.0.

Table C1. Sample exposure scores

Species/Population - Common Name	Reviewer Name
SAMPLE	SAMPLE

USER ENTERS 5 TALLIES PER ROW
Bin1 + Bin2 + Bin3 + Bin4 must equal 5

Exposure Factor		Bin 1	Bin 2	Bin 3	Bin 4	DATA QUALITY	FACTOR WEIGHTED MEAN
Sea Surface Temperature		Bin 1	Bin 2	Bin 3	Bin 4		**4**
Mean/Standard anomaly	Tallies				5	3	
Sea Surface Temperature		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Air Temperature		Bin 1	Bin 2	Bin 3	Bin 4		**3.8**
Mean/Standard anomaly	Tallies			1	4	3	
Air Temperature		Bin 1	Bin 2	Bin 3	Bin 4		1.4
Variability/Variance ratio	Tallies	3	2			3	
Precipitation		Bin 1	Bin 2	Bin 3	Bin 4		**3.6**
Mean/Standard anomaly	Tallies			2	3	3	
Precipitation		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Sea Surface Salinity		Bin 1	Bin 2	Bin 3	Bin 4		2.6
Mean/Standard anomaly	Tallies		2	3		3	
Sea Surface Salinity		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Ocean pH		Bin 1	Bin 2	Bin 3	Bin 4		**4**
Mean/Standard anomaly	Tallies				5	3	
Ocean pH		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Sea ice coverage		Bin 1	Bin 2	Bin 3	Bin 4		1
Mean/Standard anomaly	Tallies	5				3	
Sea ice coverage		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Dissolved oxygen		Bin 1	Bin 2	Bin 3	Bin 4		**3.4**
Mean/Standard anomaly	Tallies			3	2	3	
Dissolved oxygen		Bin 1	Bin 2	Bin 3	Bin 4		1
Variability/Variance ratio	Tallies	5				3	
Circulation		Bin 1	Bin 2	Bin 3	Bin 4		**1.4**
	Tallies	3	2			2	
Sea level rise		Bin 1	Bin 2	Bin 3	Bin 4		**1.8**
	Tallies	1	4			2	

Table C2. Sample sensitivity scores

Species/Population - Common Name	Reviewer Name
SAMPLE	SAMPLE

Sensitivity/Adaptive Capacity Attribute		USER ENTERS 5 TALLIES PER ROW Bin1 + Bin2 + Bin3 + Bin4 must equal 5				DATA QUALITY	ATTRIBUTE WEIGHTED MEAN	DISTRIBUTION RESPONSE	ABUNDANCE RESPONSE	PHENOLOGY RESPONSE
		Bin 1	Bin 2	Bin 3	Bin 4		3.2	3.2	3.2	3.2
Prey/Diet Specificity	Tallies			4	1	3				
		Bin 1	Bin 2	Bin 3	Bin 4		2.6	2.6	2.6	2.6
Habitat Specificity	Tallies		2	3		2				
		Bin 1	Bin 2	Bin 3	Bin 4		2.4	2.6	2.4	N/A
Site Fidelity	Tallies	1	2	1	1	1				
		Bin 1	Bin 2	Bin 3	Bin 4		1.2	N/A	1.2	N/A
Lifetime Reproductive Potential	Tallies	4	1			3				
		Bin 1	Bin 2	Bin 3	Bin 4		2.0	N/A	2.0	N/A
Generation Length	Tallies		5			3				
		Bin 1	Bin 2	Bin 3	Bin 4		3.0	2.0	3.0	2.0
Reproductive Plasticity	Tallies		1	3	1	2				
		Bin 1	Bin 2	Bin 3	Bin 4		1.0	4.0	N/A	4.0
Migration	Tallies	5				3				
		Bin 1	Bin 2	Bin 3	Bin 4		1.4	1.4	1.4	N/A
Home Range	Tallies	3	2			3				
		Bin 1	Bin 2	Bin 3	Bin 4		2.4	2.4	2.4	2.4
Stock Abundance	Tallies		3	2		2				
		Bin 1	Bin 2	Bin 3	Bin 4		2.0	2.0	2.0	2.0
Stock Abundance Trend	Tallies	1	3	1		2				
		Bin 1	Bin 2	Bin 3	Bin 4		2.2	2.2	2.2	2.2
Cumulative Stressors	Tallies		4	1		3				