INDEPENDENT ADVISORY TEAM FOR MARINE MAMMAL ASSESSMENT

Final Report – Phase II

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1. Introduction

1.1. IAT's Mission

Commercial fisheries interactions with marine mammals are managed primarily under the terms of the Marine Mammal Protection Act (MMPA, 1972). The Potential Biological Removal (PBR) scheme was introduced in the 1994 amendments of the MMPA as a way of ensuring that the incidental mortality and serious injury (M/SI) of marine mammals in commercial fisheries (bycatch) is sustainable. In practice, the scheme has been applied more broadly to encompass all human-caused removals from a marine mammal stock. Annual marine mammal stock assessment reports explain, for each stock, the basis for the PBR calculation and the estimate of M/SI. The PBR is compared with the M/SI estimate to evaluate whether the removal rate (by fisheries and other causes) is consistent with the management objectives of the MMPA. The PBR scheme is a precautionary approach to management (e.g. Taylor *et al.*, 2000) such that, for example, the greater the uncertainty about abundance and stock status, the lower the allowable bycatch (Wade, 1998).

Most marine mammals are highly mobile and range over large areas. This can lead to estimates of abundance that are imprecise or negatively biased. A coefficient of variation (CV) for abundance estimates of 0.30 or less is generally considered by NMFS to be a desirable level of precision for making management decisions (e.g. GAO, 2008) (lower CV's represent more precise estimates). However, the majority of stocks have abundance estimates with lesser precision[1]. Likewise, funding, logistical, and other constraints limit observer coverage for commercial fisheries, which often means that estimates of marine mammal bycatch are imprecise and may be highly variable year on year.

Uncertainty in marine mammal stock assessments can lead to either over-protection (triggering regulatory actions when they are not actually warranted) or under-protection (allowing unsustainable removals from marine mammal populations). Reducing uncertainty in marine mammal stock assessments, therefore, can benefit both conservation and resource exploitation. The main goal of the IAT is to develop scientific approaches that will aid in reducing uncertainty in the assessment of marine mammals.

1.2. Objectives

The main objectives of the IAT are to:

- Draw upon a broad range of quantitative techniques, including modeling approaches such as Management Strategy Evaluation, to better elucidate sources of uncertainty and evaluate their significance in marine mammal assessments and management plans.

[1]The median CV for abundance estimates across stocks in the 2014 U.S. marine mammal stock assessment reports was 0.41. CVs for abundance estimates are available from: http://www.nmfs.noaa.gov/pr/sars/region.htm

- Evaluate the effectiveness of approaches to fishery management related to marine mammal conservation (e.g. Take Reduction Plans and the List of Fisheries).
- Develop new approaches to stock assessment that improve the ability of agencies to meet their assessment and management responsibilities (in relation to marine mammal conservation and sustainable fisheries) given the limits on funding and other resources.
- Establish collaborations or partnerships with scientists and managers from federal, state and regional bodies concerned with protected species and fisheries, as well as other stakeholders, to leverage available human and financial resources.

In the course of pursuing those objectives, the IAT will continue to:

- Refine our understanding of the marine mammal stock assessment process, including, for example, requirements and protocols for conducting and reviewing assessments, primary data sources, survey methods, and methods used to estimate abundance and human-caused mortality and serious injury.
- Provide input to relevant meetings and workshops (e.g., Scientific Review Groups, agency technical workshops or program reviews, Marine Mammal Commission).
- Advise SCeMFiS members, when requested, on marine mammal assessment and science issues.
- Report to SCeMFiS on progress of the work and present final research recommendations.
- Disseminate the results of IAT research projects to other interested parties (i.e., scientific, management and stakeholder communities).

The IAT *modus operandi* is illustrated in Figure 1.

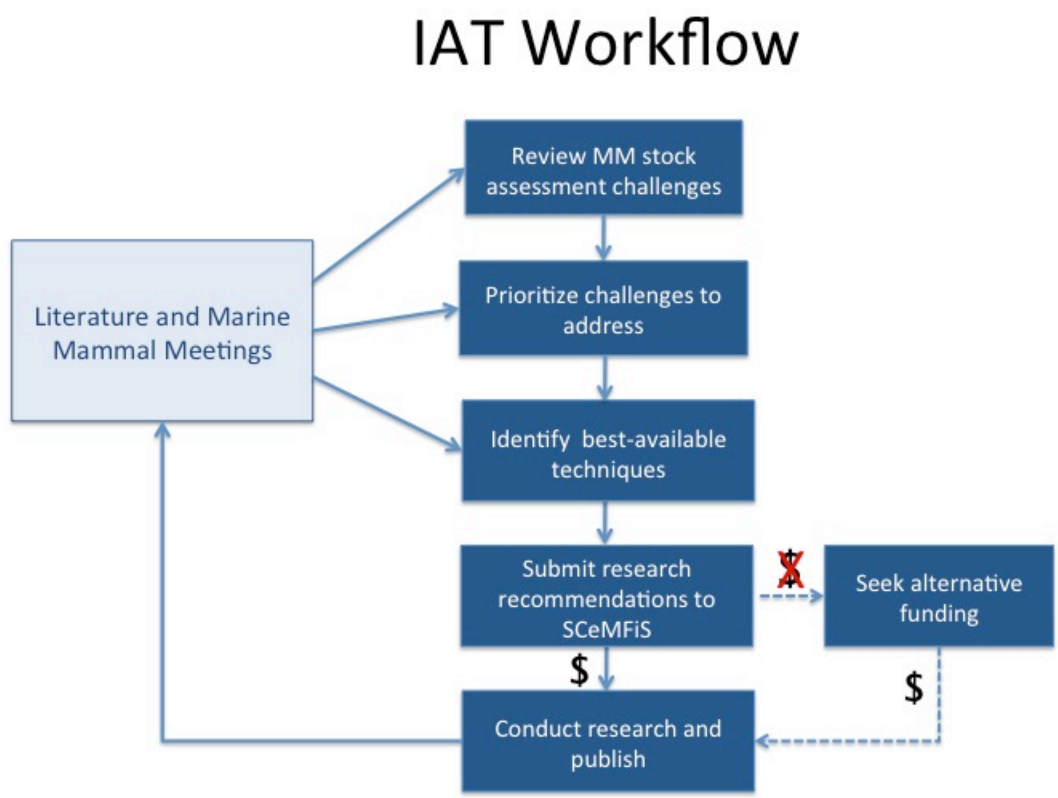

Figure 1 – Process followed by the IAT aimed at developing robust methodologies to reduce uncertainty in estimates of marine mammal population parameters.

2. Main Activities during Phase II

The IAT attended a number of meetings to inform its research and facilitate interactions with agency scientists and managers as well as non-governmental experts (Table I). The IAT members commented and posed questions at some of these meetings and provided formal responses to requests for input on several occasions. Following is a brief summary.

2.1. Comments Submitted by the IAT

2.1.1. NEFSC Review of Modeling Methods Applied to AMAPPS Data

The Atlantic Marine Assessment Program for Protected Species (AMAPPS) is an inter-agency, multi-year program led by the Northeast Fisheries Science Center. The program has been generating a wealth of marine mammal data, thereby creating new opportunities to address stock assessment issues. To take full advantage of such opportunities, it will be necessary to integrate multiple types of survey data (e.g. acoustic and visual) from different sources (e.g. towed and stationary hydrophones, aerial and shipboard survey platforms) and to apply a variety of modeling approaches. In response to a request from the NEFSC, the IAT provided comments on the latter (see Appendix A).

Table I – Meetings attended by the IAT during phase II.

Title	Date	Location	Attendees	Presentation
2014				
Bays and Bayous Symposium	December 2-3	Mobile, AL	Moreno	Yes
2015				
Atlantic Scientific Review Group	February 18-20	Jacksonville, FL	Brandon Moreno Reeves	No
BOEM Webinar	March 5		Moreno	No
Pacific Scientific Review Group	March 10-12	Seattle, WA	Punt Moreno	Yes
Gulf of Mexico MM Research and Monitoring Meeting, MMC	April 7-8	New Orleans, LA	Moreno	Yes
Northeast Region Coordinating Council	May 27-28		Russ Brown NEFSC	Yes
Marine Mammal Commission Annual Meeting (MMC)	May 5-7	Charleston, SC	Moreno	No
NMFS Protected Species Science Reviews		Webinar		Public Comment
• NEFSC	April 13-16		Brandon Moreno	
• NWFSC/SWFSC	July 27-31		Brandon Moreno Reeves	
• PIFSC	July 27-31		Brandon Moreno Punt	
• SEFSC	August 25-27		Moreno	

2.1.2. NMFS Protected Species Science Program Review

On a 5-year cycle NMFS conducts Protected Species Science Program reviews at each regional science center. The review panel, which consists of agency and non-agency scientists, is asked to address the following questions per the terms of reference:

"1. Do current and planned protected species scientific activities fulfill mandates and requirements under the ESA and MMPA, and meet the needs of the regulatory partners?

2. Are there opportunities to be pursued in conducting protected species science, including shared and collaborative approaches with partners?
3. Are the protected species scientific objectives adequate, and is the best suite of techniques and approaches to meet those objectives?
4. Are the protected species studies being conducted properly (survey design, statistical rigor, standardization, integrity, peer review, transparency, confidentiality, etc.)?
5. How are advances in protected species science and methodological approaches being communicated and applied in NMFS?"

The IAT provided comments, verbally or in writing, to several of these regional review meetings. For example, the team suggested initiatives for improving data accessibility and stimulating collaboration between NMFS scientists and the broader scientific community (see comments submitted to the NEFSC review, Appendix B). It was noted that such initiatives would be consistent with the recently announced policies of the federal government aimed at increasing transparency and utilization of data produced by government agencies (e.g. NOAA Research Council 2015, US Open Data Policy, 2013a and 2013b). However, as was expressed at several of the regional meetings, implementation of those policies is a major challenge given the limited resources available to NMFS's Protected Species programs. Initial actions that could be taken by NMFS using existing resources would be to make raw (but quality-checked) monitoring data (e.g. observations and effort from surveys) and products already compiled (e.g. tables and maps published in Stock Assessment Reports) available online in machine-readable format. It would be preferable, in our view, if actions such as those were taken *before* the agency invests major resources in developing new software products aimed at visualization of survey data or model outputs (e.g. using the OBIS-SEAMAP interface).

2.1.3. BOEM Request for Information on the Development of a Long-term Monitoring Plan for Marine Mammals in the Gulf of Mexico

BOEM is planning a large-scale, long-term monitoring program for the Gulf of Mexico similar to AMAPPS. The IAT submitted comments concerning the types of data and studies that would improve knowledge about marine mammal populations and the threats from human activities in the Gulf (see Appendix C). Such large-scale, long-term (at least multiyear) monitoring is important not just because it provides regionally important information but also because it can improve basic understanding of marine mammal biology and of marine ecology more generally.

2.2. IAT Meeting

In January 2015, the IAT convened a two-day work meeting at the Gulf Coast Research Laboratory in Ocean Springs, MS to discuss and refine proposals. Debi Palka (NEFSC) and Greg DiDomenico (SCeMFiS Liaison) also participated via webinar. This meeting resulted in the development of the first two research recommendations that are described in detail under Section 3 below.

2.3. Education

In the summer of 2015, two interns participated in the IAT project to learn about techniques used to monitor marine mammal populations, the information requirements of stock assessments (PBR, trends, status, etc.) and assist in data preparation. Rice was funded by a grant from the GCRL Research Internship Program (PI: Samuel Clardy), while Screptock volunteered her time. Engaging interns in this type of work has the dual benefit of supporting project tasks at little cost while providing valuable training to future scientists. Amanda Screptock (B.Sc. in Biology, Bowling Green State University, May 2015) and Carley Rice (B.Sc. in Biology, Western Michigan University, May 2015) were supervised by Paula Moreno (University of Southern Mississippi). The internship also involved discussion of scientific articles led by the interns. Moreno counseled the interns on matters such as continuing their education and pursuing advanced degrees. Both Screptock and Rice applied to graduate school. Rice has been accepted to the James Madison University International Master's Program in Environmental Management & Sustainability.

2.4. Dissemination of Results

Presentations were given at various meetings (Table I) to disseminate the results of our efforts and to foster collaborations. In addition, the previous IAT report (Phase I) was circulated to various agencies (e.g. NMFS Science Centers, Marine Mammal Commission) and groups (e.g. regional Scientific Review Groups for marine mammal Stock Assessments).

3. Key Outcomes and Achievements

3.1. Research Recommendations to Address Stock Assessment Challenges

The IAT identified two fundamental and overarching needs for marine mammal stock assessment that we feel we can help address, namely: (a) improved understanding of the factors responsible for uncertainty surrounding abundance and M/SI estimates and for the large variability in these estimates through time, and (b) better evaluation of the performance of methods used (and potentially used) to monitor marine mammal stock abundance and levels of human-caused mortality and serious injury. The following four proposals were conceived and designed to make progress on fulfilling those needs.

3.1.1. Examination of Fishing Methods, Targeted Species, and Marine Mammal By-catch: Northeast (New England) sink gillnet fisheries as a case study

Motivation and Relevance

Related fishing methods may be assigned to general classes of commercial fisheries under the National Marine Fisheries Service's List of Fisheries (LOF) as required by the Marine Mammal Protection Act. For instance, both drift gillnets and anchored sink gillnets are included under the "Mid-Atlantic Gillnet Fishery" (MAG fishery). However, the equipment and methods used for drift and sink gillnets may differ in terms of, among other things, mesh size and soak duration. Such differences may be related to which species is targeted (e.g. sink nets for monkfish and drift nets for bluefish). The same applies to the “NE sink gillnet fishery” (NESG fishery). Both fisheries are listed as Category I under the LOF. Category I fisheries are defined as having frequent M/SI (e.g. bycatch) of marine mammals and trigger development of a Take Reduction Plan (TRP) for strategic stocks.

All else being equal (e.g. area, season), the marine mammal M/SI rate in gillnets increases with longer soak durations and larger mesh sizes (e.g. IWC 1994; Orphanides 2009; Palka et al. 2008; Hatch and Orphanides 2014). If M/SI rate varies substantially among the fishing practices used in the NESG fishery, then M/SI should be estimated based on a stratified approach which reflects this.

Currently, following the Harbor Porpoise TRP, NESG fishery data are stratified by season, port group or management area, whether pingers were used, and the presence or absence of groundfish landings (Hatch and Orphanides 2014). This approach accounts for the distribution of marine mammals and commercial gillnet fisheries (Rossman and Merrick, 1999), aims to ensure M/SI rates are representative of the NESG fishery (Orphanides 2013), and enables evaluation of mitigation effectiveness. However, it is not designed to discriminate among fishing practices associated with high and low M/SI rates. Generalized Additive Models have been used previously to examine the effects of fishing gear and practices along with spatio-temporal and environmental factors (Palka et al., 2009; Palka, 2012). However, those analyses included variables such as management area, as dictated by the Harbor Porpoise TRP. The spatial descriptors selected in all models could mask the effects of fishing gear and practices if such factors are correlated. Another consequence of using management area is that it requires data to be sub-setted.

Previous analyses also examined the effect of target species, which could, in principle, serve as proxies for characterizing “sub-fisheries.” A caveat in the case of gillnet fisheries is that target species are identified at the start of a trip based on information provided by the captain. However, the target species by haul (within a trip) is subject to change. Vessels are permitted to use different types of gillnets during a trip, and the type is often selected for a given within-trip haul based on conditions encountered (or regulations in force). Thus, using targeted fish species (including caught species) along with fishing methods and practices in the two-step approach described below may provide stronger inferences on the factors that influence M/SI.

We propose a quantitative method of selecting a data stratification scheme and estimating M/SI. The goal is to test whether such an approach could lead to more precise estimates of M/SI overall and improve the ability to discriminate among fishing practices associated with high and low M/SI rates. The precision with which estimates of M/SI are obtained directly determines the regulatory actions implemented to recovery marine mammal populations. This project aims to increase that precision. Regulatory actions are ideally targeted at those sub-fisheries with the highest M/SI rates. This project also aims to develop a method to rank sub-fisheries in terms of rates of M/SI.

Goals

The goal is to test whether such an approach could lead to more precise estimates of M/SI overall and improve the ability to discriminate among fishing practices associated with high and low M/SI rates. This could enhance the ability of management measures to achieve the objectives of the MMPA, with lesser impacts on sub-fisheries with low M/SI rates.

The method will be applied to the NE sink gillnet fishery which is included in the NMFS's List of Fisheries as a Category I fishery (frequent M/SI), and for which there exists a relatively large data set related to marine mammal bycatch. If shown to be successful, this approach should be applicable to other fisheries such as the Mid-Atlantic Gillnet fishery.

Approach and Deliverables

The proposed approach involves two steps. The first is to define métiers. A métier is a group of fishing methods and practices, including gear types used in specific areas and times of year, associated with particular targeted fish species (e.g. Deporte et al. 2012). Observer data from the NESG fishery include mesh size, soak duration, trip ID, targeted fish species, fish species caught, observed marine mammal M/SI, etc.

Rather than relying on the recorded targeted species alone to define métiers, a multivariate statistical approach (such as canonical correspondence analysis) will be used. This would involve treating the vector of species caught (instead of targeted species) as a multivariate response variable, and factors such as vessel, fishing location, time of day and of year, and gear specifications such as mesh size and soak duration as explanatory variables. Spatial explanatory variables would include fishery statistical zones (or coordinates of the cell centroid) instead of port or management area. The designation of métiers using multivariate statistical methods is common in fishery assessments (e.g. Deporte et al. 2012).

The second step uses the results of this analysis to define métiers that catch particular groups of fish species. The métier definition analysis would then be used to (a) estimate rates of M/SI for harbor porpoises and by métier, (b) estimate total harbor porpoise M/SI by métier by raising the rate of observed M/SI to fleet total by métier, and (c) assessing whether the data suggest that M/SI rates differ significantly among métiers and if they do, by how much. The results from (b) would be compared with existing estimates of harbor porpoise M/SI derived from other stratification schemes and estimation methods. Research results would be reported in the form of a manuscript to be submitted for publication in a scientific journal.

3.1.2. Characterization and Analysis of Uncertainty in Abundance Estimation for U.S. Marine Mammal Stock Assessment

Motivation and Relevance

Conservation management of marine mammal stocks in U.S. waters requires calculation of the Potential Biological Removal (PBR) for each stock. PBR is obtained through a formula set forth in the Marine Mammal Protection Act (MMPA, as amended in 1994) and includes three parameters: minimum abundance (N_{min}), maximum population growth rate (R_{max}) and a recovery factor (F_r) related to the status of the stock. In calculating PBR, default values can be used for the recovery factor and maximum population growth rate, and such values are used for most U.S. stocks. The only parameter that must be estimated to allow PBR to be calculated is stock abundance.

Concern has been raised frequently about the uncertainty associated with abundance estimates (e.g. NMFS 2004, GAO 2008, Moore and Merrick 2011). The Atlantic Scientific Review Group (2014) expressed "general frustration with the assessment of marine mammal stocks, including *inter alia* the inconsistency of data collected, affecting the ability to estimate abundance and trends therein" and emphasized the need for "systematic" changes in the way data are generated and analyzed for the Stock Assessment Reports (SARs).

Understanding the causes of uncertainty in abundance estimates is important because uncertainty can impede development of effective conservation measures (e.g. by making it difficult or impossible to estimate trends in abundance) and adversely affect fisheries (e.g. by leading to frequent changes in fishery regulations or making PBR lower than warranted).

There are several potential causes of low precision and bias of estimates of stock abundance. For example, (a) the actual range or distribution of a stock may change in response to altered environmental conditions, (b) a stock's range may extend outside U.S. waters (e.g. the Western North Atlantic right whale stock, the Western Atlantic long-finned pilot whale stock, and the Hawaiian pelagic false killer whale stock) where comparable survey data are unavailable, or (c) group size may be highly variable and estimation prone to observer errors. Moreover, at-sea detection and species determination is difficult for some species due to cryptic behavior (e.g. beaked whales) or morphological similarity with other species (e.g. long-finned and short-finned pilot whales). In addition, logistical factors (e.g. inclement weather, vessel/aircraft availability) may increase the uncertainty associated with abundance estimates.

The IAT's analysis (Moreno et al. 2015) of abundance estimates in the 2012 and 2013 Atlantic SARs (Waring et al. 2013; Waring et al. 2014) showed that precision as quantified by the sampling CVs for the abundance estimates was lower, on average, than the NMFS recommendation of CV ≤ 0.3 (Figure 2). It also revealed substantial inter-annual differences in the estimates of abundance for some stocks (Figure 3). Large inter-annual changes in true abundance are not expected for marine mammal populations that are fully protected from deliberate removals, unless extreme conditions occur (e.g.

mass die-offs, shifts in distribution) or incidental mortality has been exceptionally high due to a major change in fisheries. In the absence of such circumstances, much of the variation would likely be due to sampling error and other sources of variation.

As indicated, our previous analysis was limited to only two years and only one of the three NMFS management regions. Moreover, we did not attempt to identify the factors that may have contributed to the low precision of estimates or the large inter-annual differences in the estimates of abundance. Likewise, previous studies by other authors have not included a formal quantitative analysis of factors that may result in varying levels of precision or temporal variability in abundance estimates (Read and Wade 2000; Taylor *et. al.* 2007; Roman *et. al.* 2013).

Therefore, we propose to conduct a more inclusive, in-depth examination of SARs since 1995 for the two management regions with the most survey information (Atlantic and Pacific) to gain insights into: 1) the prevalence of low precision and large inter-annual differences in estimates and 2) the main factors responsible for uncertainty and variability.

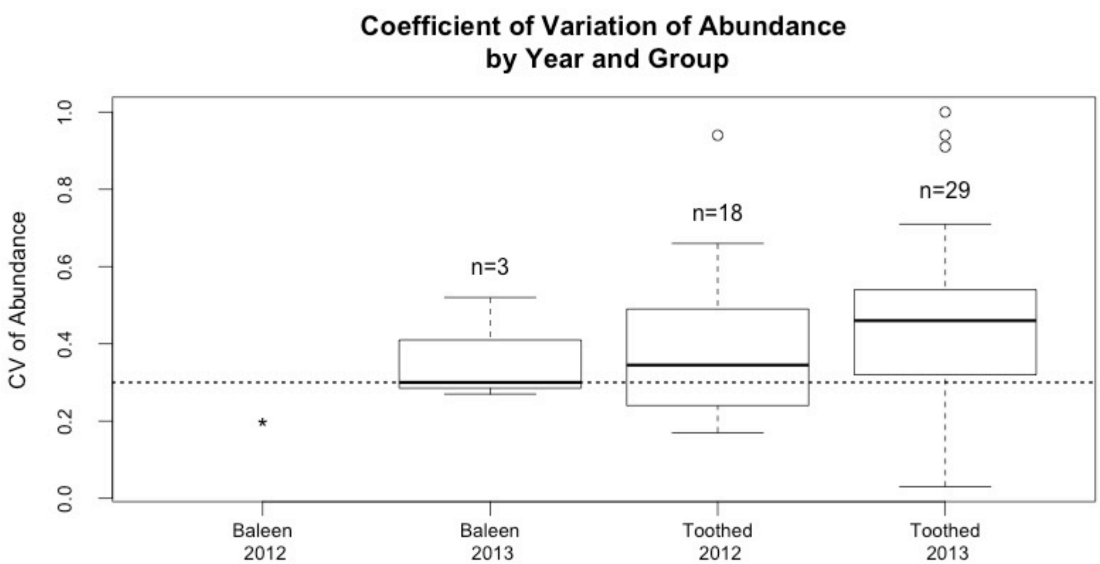

Figure 2 – Coefficients of variation of abundance estimates in 2012 SAR and 2013 SAR for two taxonomic groups in the Atlantic region: Baleen whales and Toothed cetaceans (odontocetes). Number of stocks (n) shown above boxplot. Asterisk (*) indicates no CV available for comparison because only minimum counts of animals seen alive (instead of estimates of population abundance) were reported. Dashed horizontal line indicates level of precision considered desirable by NMFS (CV=0.3). Boxplot elements: 1st and 3rd quartiles (box), median (band), range (whiskers) and outliers (open circles). (Source: Moreno et al. 2015)

This project will compile information on the available abundance estimates for marine mammal stocks in two regions, their sampling CVs, and other factors that could lead to inter-annual variation in estimates of abundance. This information will be used to assess the extent to which sampling error can explain inter-annual variation in abundance estimates and hence the extent to which more intense sampling can lead to lesser such inter-annual variation. It will explore whether particular groups of stocks are more susceptible to low precision or large fluctuations in estimates, unrelated to sampling error. Ultimately, a better understanding of the scale and causes of uncertainty associated with abundance estimates will assist with the design of future monitoring programs. In addition, this analysis will identify information gaps or inconsistencies in reporting estimates and methods in the SARs across regions.

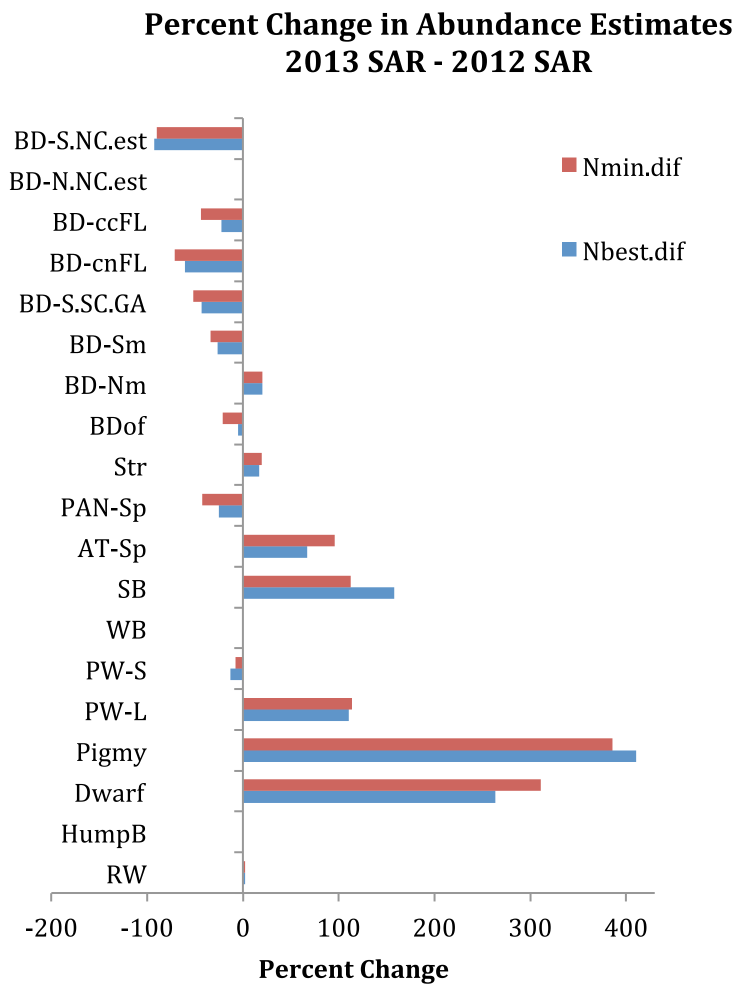

Figure 3 – Comparison of minimum abundance (N_{min}) (red) and point abundance (blue) estimates for Atlantic stocks from the 2012 SAR and 2013 SAR. Positive and negative values refer to a percentage increase and a decrease, respectively, in the 2013 SAR relative to 2012 SAR. Minimum abundance is calculated as $N_{min} = N/\exp(0.842 * (\ln(1+CV(N_{best})^2))^{1/2})$, where: N_{best} is the point estimate, and. $CV(N_{best})$ is the coefficient of variation of the abundance estimate. (Source: Moreno et al. 2015)

Goals

- Characterize variability[2] in abundance estimates for U.S. Atlantic and Pacific stocks.
- Identify factors that most strongly influence variability in estimates by investigating whether the magnitude of the coefficient of variation of additional variation by stock is associated with certain stock features (e.g. transboundary) or estimation methods.
- Identify instances where the data provided in SARs were insufficient to allow these types of analyses to be carried out across regions and for long time series.

Approach and Deliverables

Precision of abundance estimates depends on factors that are inherent to the stock and to the survey design or estimation methods. We will extract data on abundance estimates and their respective coefficients of variation (CVs) from the SARs published annually since 1995 for two regions: Atlantic and Pacific. We will focus on cetacean stocks, excluding bay/estuarine stocks. For each stock, we will estimate variability in abundance estimates during this 20-year period. We will then estimate 'additional variation' (the extent to which the variation in point estimates of abundance exceeds that expected from sampling error along). To identify factors associated with additional variation, we will compare additional CVs between geographic areas (Pacific and Atlantic), taxonomic groups (e.g. odontocetes and mysticetes), status classifications (strategic vs non-strategic, depleted, ESA-listed as threatened or endangered, none of those), geographic range of the stock (transboundary vs non-transboundary), survey methods, and estimation methods. Factors to be examined regarding survey methods include the type of survey (e.g. aerial vs vessel platform) and coverage (e.g., total effort, stock range, season).

A multivariate statistical analysis (e.g. Generalized Additive or General Linear Models) will be used as the basis of the quantitative analysis of the data, where the square of the additional CV by stock is the response variable and the factors above are the explanatory variables. This analysis will be used to assess the extent to which elimination of particular sources of error will lead to lower inter-annual variation in abundance estimates. A power analysis will be conducted to assess how well currently available data can estimate the extent of additional variation and detect the factors that determine the extent of additional CV.

The information from the synthesis will be made available to NOAA and stakeholder groups. A final report in manuscript format will be submitted to a peer-reviewed journal.

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[2] Measured by precision of annual estimates and magnitude of inter-annual differences.

3.1.3. Case-specific MSE for Hawaiian Islands False Killer Whales

Motivation and Relevance

The project funded by the Western Pacific Fishery Management Council on the development of a tier system for calculating Potential Biological Removal (PBR) values was generic. Its primary objective was to evaluate alternative PBR tier structures across a wide range of scenarios. However, it is well known that case-specific management strategies are more efficient (i.e. more likely to achieve the management goals) because they can be tailored to the uncertainties most relevant to the case in question. The International Whaling Commission has adopted a case-specific approach by developing *Strike Limit Algorithms* (*SLA*s) for aboriginal subsistence whaling, including for bowhead whales off Alaska, humpback whales off West Greenland, and the eastern North Pacific stock of gray whales. The *SLA*s selected for bowhead whales and humpback whales off West Greenland outperformed the standard PBR equation because they were selected taking into account the key uncertainties for these situations rather than being developed for a generic situation (IWC, 2015, in press). Although the management objectives for aboriginal subsistence whaling differ from those of the Marine Mammal Protection Act (MMPA), these examples illustrate that adopting a case-specific approach management strategy evaluation (MSE) can lead to insights that cannot be obtained from generic approaches.

Case-specific MSE can also be used to obtain a better understanding of the implications of specific uncertainties in cases where the management strategy has already been selected (as is true for false killer whales (*Pseudorca crassidens*) off the Hawaiian Islands). A MSE will be used to (a) identify the uncertainties that are most pertinent to this situation and (b) evaluate the benefits (in terms of the ability to achieve the goals of the MMPA) if each uncertainty could be reduced (or eliminated) through research. The need for this project was identified during the review of the Pacific Islands Fisheries Science Center marine mammal program which members of the IAT observed remotely during August 2015.

Goals

The project goals are:

- Identify the most important uncertainties pertinent to the management of fisheries and conservation of false killer whales off the Hawaiian Islands.
- Develop an MSE framework to represent these uncertainties, along with the monitoring and management system in place.
- Conduct projections of the system to enable prioritization of the uncertainties based on their relative influence on (i) achieving the goals of the Marine Mammal Protection Act and (ii) constraints needed to be imposed on fisheries to ensure that removals do not exceed PBR.

Approach and Deliverables

Punt *et al*. (in press) highlight the steps needed to conduct an MSE: (a) identification of the management objectives and representation of these using quantitative performance statistics; (b) identification of a broad range of uncertainties for the case in question; (c) development of a set of models (often referred to as 'operating models') that provide mathematical representations of the system to be managed; (d) selection of the values of the parameters of the operating model(s) and quantification of parameter uncertainty (ideally by fitting or 'conditioning' the operating model(s) to data from the actual system under consideration); (e) identification of candidate management strategies that could realistically be implemented for the system; (f) simulation of the application of each management strategy for each operating model; and (g) summary and interpretation of the results from the MSE. This project will build on the population model and projection software developed by the WPFMC-funded project on the performance of tier systems for applying PBR, although that software will need to be modified to fit the operating model to the available data.

In the case of false killer whales off the Hawaiian Islands, the management objectives (step a) arise from the MMPA, and Wade (1998) translated those objectives into quantitative performance statistics (albeit in a single-stock scenario). The tasks to be undertaken to address the remaining steps are:

(1) Hold a workshop with broad involvement of researchers (governmental and academic) as well as stakeholder groups, including industry and non-governmental organizations to identify hypotheses regarding the status, population dynamics, distributions and threats faced by the false killer whale stocks off the Hawaiian Islands (step b). This workshop will also aim to identify research projects that have the potential to reduce (or even resolve) some of the uncertainties.
(2) Develop a population dynamics model that can represent the hypotheses identified during the workshop (the population dynamics model developed and coded as part of the WPFMC-funded PBR project could form the basis for this population dynamics model) (step c).
(3) Fit the population dynamics model to existing data on abundance, distribution and removals (e.g. serious injuries and deaths from fishery interactions) of false killer whales off the Hawaiian Islands (note that the values for parameters such as carrying capacity will be model-estimated). Where data are not available to estimate parameters (e.g. reproductive rates and the extent of density-dependence in biological parameters), the values for the parameters concerned will be set based on the literature (and if necessary by analogy). (step d).
(4) Conduct projections of the population dynamics model in which PBR (and hence the allowable removals from the modeled population) for each future year is set based on the way the PBR approach has been applied to false killer whales off the Hawaiian Islands (steps e and f). Scenarios will consider cases in which the catch is distributed about the PBR or some fraction of the PBR. Scenarios will also consider cases in which research is undertaken to reduce one or more of the uncertainties.
(5) Conduct tasks (3) and (4), eliminating one uncertainty at a time to facilitate an evaluation of the role of each type of uncertainty in determining whether or not the management goals can be achieved.

Deliverables are:

- Workshop report outlining the discussions and conclusions and identifying the key sources of uncertainty pertinent to false killer whales off the Hawaiian Islands.
- MSE framework that can be extended for other case-specific MSEs for marine mammal-fishery interactions.
- Manuscripts submitted to peer-reviewed journals highlighting the results of the analyses and which uncertainties, once resolved, would have the greatest chance to increase the probability of meeting the management goals.

3.1.4. North Pacific Humpback Model

Motivation and Relevance

Population model-based assessments that consider alternative hypotheses regarding the population dynamics of the modelled population and integrate information from a variety of data sources are considered state of the art to provide scientific advice for fishery management. There are, however, limited examples of this approach being applied for cetaceans, mostly under the auspices of the International Whaling Commission (IWC). Within the US, such assessments have been conducted for bowhead whales in the Bering-Chukchi-Beaufort Seas (Brandon and Wade, 2006), gray whales in the eastern North Pacific (Punt and Wade, 2012; International Whaling Commission, 2013), right whales off the US east coast (Caswell *et al*., 1999; Fujiwara and Caswell, 2001), and blue whales in the eastern North Pacific (Monnahan *et al*., 2015). In relation to the Marine Mammal Protection Act (MMPA), these types of assessment can provide estimates of stock status relative to Optimum Sustainable Population (OSP), i.e. whether the stock is "depleted" under the MMPA (Punt and Wade, 2012; Punt and Moore, 2013).

One reason for the limited number of population model-based assessments is that these require information about stock structure, current population abundance, trends in abundance, and human-caused removals. Unfortunately such information, particularly regarding stock structure, is often lacking for marine mammals. In cases where stock structure is uncertain, but there is information on abundance and removals (e.g. gray whales and sei whales in the North Pacific), it is possible to conduct analyses to explore the sensitivity of inferences to assumptions regarding stock structure (and other uncertainties) (International Whaling Commission, 2015, in press).

North Pacific humpback whales are a case in which a rangewide assessment based on fitting a population dynamics model has yet to be conducted. There are several reasons why this population is likely an excellent candidate for such an assessment: (a) considerable work has been undertaken to identify breeding and feeding groups, and to understand genetic population structure basinwide (e.g. Baker et al., 2013), (b) life history parameter estimates based on photo-identification data are available (e.g. Mizroch *et al*., 2004), and (c) there are time-series of indices of absolute abundance for specific feeding grounds (e.g. Calambokidis and Barlow, 2004; Calambokidis *et al*. 2004; Mobley *et al*. 2001; Hendrix *et al.,* 2012), along with rangewide population estimates based on the SPLASH program (Calambokidis *et al*., 1997; Barlow *et al*., 2011). The results from an assessment could help in the conservation of North Pacific humpback whales in US waters by informing on stock status relative to OSP and on the risk of extinction for Distinct Population Segments (recognized under the Endangered Species Act, ESA).

The project could lead to reinterpretation or reformulation of current perceptions of North Pacific humpback whales in terms of their stock structure and depletion/recovery status relative to the pre-exploitation (or later historical) state. This is particularly relevant given the currently ongoing evaluation of whether North Pacific humpback whales, or at least some stocks (or Distinct Population Segments), should be delisted. NMFS has proposed the delisting of the Hawaii and Mexico breeding stocks, which would result in an increase to the recovery factor coefficient in the calculation of Potential Biological Removal (PBR). The values assigned for recovery factors include consideration of, among other things, a stock's status relative to OSP, and the approach proposed here represents one way of evaluating this.

Goals

The project goal is:

- Conduct a population model-based stock assessment of North Pacific humpback whales using an age- and sex-structured model.

Approach and Deliverables

This project involves two main steps. The first step is to conduct a catch reconstruction to provide a set of scenarios on which the assessment could be based. It is possible to reconstruct the historical catches, as has been accomplished for bowhead whales (Bockstoce and Botkin, 1983, Higdon, 2010), gray whales (Allison *et al*., 2011), and North Atlantic humpback whales (Smith and Reeves, 2003). A member of the IAT (Randall Reeves) has been a lead analyst in the development of catch histories for eastern North Pacific gray whales (Reeves *et al.,* 2010; Reeves and Smith, 2010) and North Atlantic humpback whales (Reeves and Smith, 2002; Smith and Reeves, 2002, 2003). A similar approach will be taken to develop a catch history for North Pacific humpback whales. In the case of North Pacific humpback whales, it will be necessary to coordinate with a number of colleagues who have been working to revise statistics on the ex-Soviet Union illegal catches of whales in the North Pacific (e.g. Ivashchenko *et al*., 2013).

The second step is to develop a multi-stock age- and sex-structured population dynamics model for humpback whales based on knowledge of the identified breeding and feeding groups in the North Pacific (Figure 4). The model will be based on those developed for North Atlantic humpback whales (Punt *et al*., 2006) and gray whales (Punt, 2015). The model will include four breeding grounds (Western North Pacific, Hawaii, Mexico and Central America) and six feeding grounds (northwards from Kamchatka in the west and California in the east). It will be structured under the assumption that calves tend to be associated with both the feeding and the breeding grounds of their mothers, i.e. there is strong natal philopatry. A variety of assumptions regarding how density-dependence affects the population dynamics will be explored, including that density-dependence is a function of density on either the breeding ground or the feeding ground.

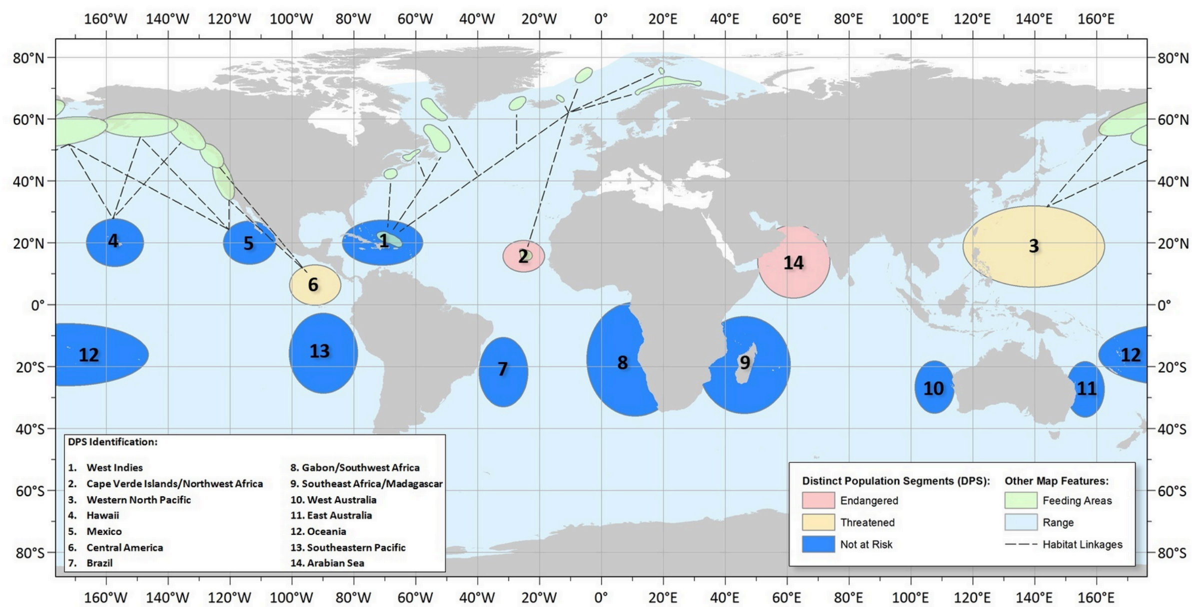

Figure 4 – Map showing the 14 proposed Distinct Population Segments, including those in the North Pacific (numbers 3-6), which have been identified by NMFS for humpback whales. (Source: http://www.nmfs.noaa.gov/pr/species/mammals/whales/humpback-whale.html)

The parameters of the model are the carrying capacities for each feeding ground and breeding ground, the movement rates, the age-specific rates of natural mortality and fecundity, the age-at-maturity, and the parameters that determine how density-dependence operates. It will be necessary to estimate the ratio of stock size to carrying capacity for the first year of the model if the model does not start in a pre-exploitation state. The values for the biological parameters will be taken from existing demographic analyses (and sensitivity to alternative values for these parameters will be explored) while the values of the other parameters will be estimated by fitting the model to the data on trends and mixing rates (the proportion of each feeding stock in each breeding ground, for example).

A key initial step in the modelling will be to assess whether it is possible to construct a model that initializes the population trajectory in the year catches were first recorded (as was the case for humpback whales in the southern hemisphere, e.g.. Johnston *et al*., 2011) or the model should instead be initialized using a more recent year (as was the case for humpback whales in the North Atlantic and gray whales).

Deliverables are:

- Manuscript for submission to a peer-reviewed journal documenting the catch reconstruction of North Pacific humpback whales.
- Manuscript for submission to a peer-reviewed journal documenting the stock assessment.

3.2. IAT Research Initiated in Phase I: Development and Testing of a PBR Tier System

During Phase II, the IAT conducted a management strategy evaluation (MSE) for a PBR Tier System. An assumption underlying the current PBR scheme, as originally evaluated, is that only the single most recent estimate of abundance is used to calculate the PBR (Wade, 1998). Our MSE extended the original PBR MSE by introducing a tiered hierarchy of data availability, from data-rich to data-poor. Alternative approaches for deriving values used to calculate PBR in each tier (e.g. incorporating multiple abundance estimates for data-rich stocks) were evaluated relative to the management objectives of the U.S. Marine Mammal Protection Act.

The underlying population dynamics model included age and sex structure. This differed from the age- and sex- aggregated model used in the original PBR MSE. Results were shown to be equivalent between modeling approaches, but the inclusion of age and sex structure allowed us to evaluate the performance of PBR under different patterns of vulnerability to human-caused mortality for different sex and age classes. It was shown that if selectivity is skewed with respect to age or sex, the performance of the standard PBR limit may over- or under-protect stocks, depending on the nature of the skew in selectivity. If human-caused mortality consists predominately of young animals and/or of males, the standard approach will likely be overly conservative, i.e., the PBR will be biased low. Conversely, the standard approach may not be sufficiently precautionary (i.e., the PBR will be biased high) if human-caused mortality consists predominately of mature females.

It was also shown that an alternative value for the N_{MIN} percentile could be adopted when survey estimates are imprecise and multiple abundance estimates are available. Additionally, incorporating multiple abundance estimates for data-rich stocks can lead to increased stability of calculated values for PBR through time. The reduction in variability need not come at the expense of increasing the conservation risk for data-rich stocks, but it could reduce the economic uncertainty associated with human activities that are regulated according to PBR (e.g. commercial fishing in the U.S. which involves the risk of marine mammal bycatch). Therefore, including multiple abundance estimates, when possible, into the calculation of PBR may prove desirable. A PBR tier system would allow the best available information to be used for each stock, recognizing the different types and levels of uncertainty surrounding data from the different stocks.

The FORTRAN computer code for the operating model and calculating PBR for the data tiers is free, open-source, and available from: https://github.com/John-

Brandon/PBR-Tier-System. R code to analyze and visualize MSE output is available in the same repository.

The Western Pacific Fisheries Management Council funded this research. A manuscript was submitted to the *ICES Journal of Marine Science*, and has been provisionally accepted for publication with revisions.

4. Next Steps

Several topics could be considered in the next phase of the project.

- The scenarios investigated in the PBR Tier System MSE considered only a single stock. This was done to be comparable with the original PBR MSE. However, the underlying population dynamics model that was developed allows for two spatially overlapping stocks, with one stock's range extending outside the surveyed area (e.g. beyond the U.S. EEZ). Therefore, the model could be used in future MSEs to take examine two-stock scenarios. These could include uncertainties in allocating bycatch to overlapping stocks of the same species, and in estimates of abundance for stocks that have been only partially surveyed.
- The PBR MSE project undertaken by the IAT assumed, in common with the analyses used to develop the PBR formula, that bycatch is normally distributed about the PBR. However, in reality, the PBR approach is embedded in larger management system, including a decision whether a stock is 'strategic', assignment of fisheries to Categories, and establishment of Take Reduction Teams and hence development of Take Reduction Plans. Thus, the risks to marine mammal recovery estimated using analyses based on the approaches taken in the PBR (and similar) projects will not correctly reflect the risk to the stock and the fisheries. This problem could be addressed by extending the current MSE to include these additional factors.
- At the NEFSC Protected Species Review Meeting, April 13, 2015, NMFS underscored the need to evaluate the efficacy of measures implemented by the Atlantic Large Whale (ALW) Take Reduction Team. A MSE framework that includes whether stocks are assessed to be strategic and fishery classification applied to ALWs would allow a formal investigation of the robustness of the management measures implemented over time under various sources of uncertainty (e.g. incomplete reporting of entanglements and/or incomplete compliance with fishing restrictions). Accounting for uncertainty is especially relevant given that efficacy of these time-area measures is very dependent on the distribution of the protected resource, which in the case of North Atlantic Right whales is poorly known. This modeling approach allows testing the efficacy of measures under different ALW distribution scenarios. More importantly, this approach could be extended to incorporate other ALW management measures currently in effect, namely those designed to limit ship strikes, to fully account for the combined effects of fishing and shipping measures on the recovery of ALWs.

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APPENDIX

Comments on the AMAPPS (Atlantic Marine Assessment Program for Protected Species) documents

André E. Punt

The aim of the AMAPPS is to synthesize data for multiple species collected from several platforms within a Bayesian framework. The estimation framework will integrate both availability and detection bias (i.e. including estimating $g(0)$ and the shape of the detection function). In general, the proposed approach should be a major step forward to provide precise estimates of abundance, and trends in abundance for the more data-rich / abundant species. The project is a work in progress and the comments listed below should be taken in that context. The documentation wasn't as complete as I might have liked, but this review process was to give the community a first look at the project so that is understandable.

1. The proposed approach is Bayesian. Until recently, conducting analyses such as those proposed would be computational infeasible within a classical framework. The development of Template Model Builder (TMB; https://github.com/kaskr/adcomp) is allowing models with hundreds or thousands of random effects to be fitted. Given the known difficulties associated with fitting Bayesian methods, consideration should be given to exploring whether TMB may be a more robust estimation approach. TMB is already being used by NOAA scientists to explore spatial (and other) problems.
2. It was unclear how the various analyses were to be integrated as the outcomes of some of them feed into other analyses (and ultimately the estimation of abundance). In principle, the posteriors for some of the analyses could be used as priors for subsequent analyses.
3. There are quite substantial discrepancies between some of the in-situ measurements and other predictions of the environmental variables (satellite- and model-based) (paper 2). Error in predictor variables will lead to bias when fitting regression-type models. I suggest that a project be implemented to examine the consequences of this bias. Paper 4 indicates that missing covariates were interpolated and sometimes the process for interpolation was insufficient. The consequences of this could be explored using simulations. In general, proposed methods should be evaluated using simulation.
4. The various surveys collect different covariates. While the factors influencing detection bias would be expected to differ between shipboard and aerial surveys, it is unfortunate that the NEFSC and SEFSC do not have the same data collection protocols for shipboard and aerial surveys respectively.
5. The approach is hierarchical (paper 4), but what is shared among species, seasons and years and how is not specified – for example, the parameters of the detection function could be assumed to be drawn from a hyper-prior that also allows for between-species differences in parameters. Similarly, this approach could be used to allow for between-season (or between-year) variation in the parameters of the spatial model.

6. The approach for modelling habitat includes constant terms, linear terms for covariates, and quadratic terms for covariates. Consideration should be given to using spline functions for these relationships (although it appears that this has been done for humpback whales; Paper 5a), as is common in spatial distribution modelling. I was surprised that the spatial random effect is not spatially correlated.
7. Are covariates included in the model for group size (paper 4 suggests not)?
8. The documentation should outline how geostatistical methods will be used to construct measures of uncertainty for the model outputs.
9. Given the known issues with fitting Bayesian models (not to mention Bayesian spatial hierarchical models), there needs to be a focus on diagnostics. For example, I was hoping in Paper 5a to see posterior predictive intervals and also summaries of the posteriors for the variance parameters and the parameters of the hyper-distributions.
10. Figures 4 and 5 of paper 5a appear to be indicative of model mis-specification.

Documents Reviewed

1. Palka, D. Overview of the data analyses: for review of 26Feb2015 (paper 1)
2. Palka, D., Chavez, S. Warden, M., Murray, K., Josephson, E., Garrison, L., Hatch, J., Orphanides, C., Ortega-Ortez, J. Data used in the AMAPPS models (paper 2)
3. Chavez, S. and D. Palka. Initial investigations into large whale data (paper 3)
4. Sigourney, D. Description of a Bayesian Hierarchical Species Distribution Model for Protected Species off the East Coast of the United States (paper 4)
5. Anon. Humpback whales (paper 5a)

From: Independent Advisory Team for Marine Mammal Assessment

Subject: NEFSC Protected Species Science Review (2015)

Date: April 15, 2015

To: Review Panel of the NEFSC Protected Species Science

We appreciate the opportunity to share with the Review Panel a recent report from our group, the Independent Advisory Team (IAT) for Marine Mammal Assessment. The IAT was formed through the Science Center for Marine Fisheries (SCeMFiS) which includes the NEFSC in its membership. SCeMFiS is a National Science Foundation Industry-University Cooperative Research Center. Our report is primarily based on the 2013 U. S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments Report (SAR) and is focused on stocks managed by the NEFSC. The main goal of this preliminary analysis was to help our team gain a better understanding of areas of research that might lead to the reduction of uncertainty in the key estimates of MM assessments, which are required under the Marine Mammal Protection Act (MMPA). The review of the 2013 SAR and other MM assessment reports, along with insightful meetings with the NEFSC scientists and other MM assessment scientists, led to the research recommendations found in our report. The NEFSC's Protected Species Branch kindly reviewed the report, which contributed to its improvement.

For your convenience the table of contents of the report is included below. The full report can be found at:
http://scemfis.org/2015_reports/IAT_report_final_2015.pdf

The complexity of the issues associated with monitoring and managing marine mammals is enormous despite the many advances in survey technologies and analytical approaches. Despite limitations and fluctuations in their budget, the Protected Species Branch has established a strong marine mammal science program with promising monitoring and management capabilities.

We offer a few brief suggestions with the goal of: 1) Stimulating collaborations and promoting scientific studies based on data collected by the NEFSC, and 2) Identifying some emerging research needs that might be considered as part of the NEFSC Strategic Plan that is under development.

1) Increase data accessibility and stimulate interdisciplinary collaborations between NEFSC scientists and the broader scientific community by:

- Providing public access to the ORACLE database that stores raw survey data, which can be used by students and other researchers.
- Providing the tables listing survey and stock information in the electronic Stock Assessment Reports compiled by the NEFSC in text-delimited (or spreadsheet) format. Likewise, provide GIS data files of the maps with

sighting locations and of figures included in the Fishery Descriptions (Appendix III) characterizing fishing effort and bycatch events. The SARs produced since 1995 are available online but in pdf format only.

2) Emerging research needs:

- Explore methodologies to incorporate mortality from Unusual Mortality Events (UMEs) in the marine mammal stock assessments. A bottlenose dolphin UME encompassing waters managed by the NEFSC was declared in 2013 and is only recently subsiding. Over 1,500 dolphin fatalities were recoded from New Jersey to Florida.
- Use Management Strategy Evaluation, including aggregate and individual-based modeling approaches, to understand and predict effects of climate change, as well as to develop and test bycatch mitigation measures. The recent appointment of a dedicated MSE expert in each NMFS Science Center creates unique opportunities in this area.

Thank you very much for your time and consideration.
Sincerely,

Paula Moreno
Independent Advisory Team for Marine Mammal Assessment

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- A National Science Foundation Industry/University Cooperative Research Center (I/UCRC)

SUBJECT: Response to BOEM Request for Information on the Development of a Long Term Monitoring Plan for Marine Mammals in the Gulf of Mexico; MMAA 104000

FROM: Independent Advisory Team on Marine Mammal Assessment (Paula Moreno, André Punt, John Brandon, Randall Reeves), Science Center for Marine Fisheries (SCeMFiS), Gulf Coast Research Laboratory, University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, MS 39564

DATE: 8 December 2015

The Independent Advisory Team (IAT) was established in early 2014 to add to efforts by others (notably NOAA scientists) to address uncertainties in marine mammal stock assessments, focusing initially on the Atlantic region. The IAT has initiated a project that will use a Management Strategy Evaluation framework to test a tiered approach to setting Potential Biological Removal (PBR) values for marine mammal stocks. The team is also considering conducting a meta-analysis of Gulf of Mexico stock assessment reports to characterize uncertainties and evaluate the strengths and weaknesses of the methods that have been used to assess marine mammal stocks in the region.

We offer the following thoughts on various aspects of long-term monitoring that should be considered for incorporation into BOEM's planning process for long-term monitoring of marine mammals in the Gulf of Mexico.

Baseline Information:

The importance of having reliable baseline (reference) data has been underscored by recent events in the Gulf (notably the Deepwater Horizon oil spill) and this is now widely recognized. Data obtained through NOAA stock assessment surveys and BOEM-sponsored programs such as GulfCet during the 1990s and the Sperm Whale Seismic Study during the early 2000s provided a valuable foundation. Any support BOEM can provide to enable additional surveys that complement, supplement, and extend those foundational data would be welcome. Particular attention should be given to (a) times or areas not previously well surveyed (historically, offshore survey coverage has been greater than coverage of inner shelf and coastal waters, bays, and estuaries) or not surveyed for a long time, (b) species or stocks that are defined as at risk (listed as threatened or endangered under the ESA, classified as strategic under the MMPA, etc.), (c) populations that are known or suspected to be discrete and small even if the data in support may be limited (e.g. Gulf Bryde's whales), and (d) offshore cetaceans that are known or suspected to be especially vulnerable to noise exposure (e.g. ziphiids, Risso's dolphins).

Bottlenose Dolphins:

The bottlenose dolphins is the Gulf's most conspicuous, frequently observed, and iconic cetacean. It is also, in some ways, the most vulnerable because some stocks inhabit near-shore and inshore waters where human activities are most varied and intense. It is not surprising that bottlenose dolphins are the cetaceans most frequently involved in unusual mortality events, one of which was declared in the Gulf starting in February 2010. Stock delineation is fundamental for all species but it is especially challenging in the case of bottlenose dolphins, because there are numerous stocks with complex connectivity patterns within the Gulf. Any long-term monitoring program should include a strong component focused on bottlenose dolphins, and this should include photo-identification (for abundance estimation, movement analysis, social connectivity) and biopsy sampling (for genetic, contaminant, and diet analyses), health assessment, and habitat use studies. Surveys and studies should cover the entire range of stocks to ensure that valid inferences regarding changes over time are not confounded with possible changes in distribution. Existing efforts of these kinds should be continued or, where necessary, initiated. Results should make it possible for BOEM to determine which stocks occur in or near areas of active Oil and Gas (O&G) exploration or extraction activities, and are therefore most at risk from the effects of such activities.

As suggested above, baseline information is key to understanding the impacts of human activities on wildlife populations. The occurrence of bottlenose dolphins in near-shore and inshore waters has spurred numerous research efforts over the last few decades. We believe that BOEM should take advantage of this situation by: (a) identifying existing long-term baseline studies, (b) ensuring that archived data are prepared and processed following current technological standards (e.g., high-resolution scanning of pre-digital imagery), and (c) ensuring that appropriate analyses of these data sets are carried out.

Cumulative Impacts:

The oil and gas industry, as well as its regulators (BOEM), may regard monitoring of cetaceans (and other wildlife) in areas other than those where specific O&G activities are taking place to be outside their sphere of responsibility. Although cumulative (or aggregate) impacts are routinely acknowledged to be a valid concern, the development of methods to characterize, quantify, and assess such impacts is in its infancy. BOEM would be well advised to invest in cumulative impact assessment in two ways: (a) by ensuring that relevant data are collected as part of long-term monitoring (including geo-referenced data on human activities as well as marine mammal distribution and abundance) and (b) by supporting developmental work on ways to use those data in cumulative impact analyses.

Stranding Networks:
Multiple lines and levels of evidence are often needed to establish links between cases of serious injury or mortality of marine mammals and specific causal factors, including O&G activities such as seismic surveys. Networks that help ensure detection, necropsy, and sampling of stranded marine mammals are valuable elements of long-term monitoring. Oceanographic modeling may enhance the value of information obtained from strandings by allowing estimation of the location where death occurred and therefore aiding in the determination of the probable cause(s) of the mortality.

Risk Analysis:
Risk analysis should be used to rank relative vulnerability of different areas, species, and stocks to the effects of seismic surveys. Such ranking can then be employed to help ensure appropriate sampling strategies, survey design, survey techniques, etc.

Improved understanding of marine mammal distribution and habitat use: a step toward accurate forecasting models:
To better understand the dynamics of marine mammal distribution and habitat-use patterns (including relative abundance), a suite of environmental attributes that include “drivers” (e.g., prey) as well as “stressors” (e.g. seismic surveys, naval exercises), should be monitored long-term. In the Gulf of Mexico, for example, foraging may be especially intensive in certain areas (e.g., associated with Loop Current eddies, Mississippi River plume) and seasons (e.g., in relation to prey migrations). The techniques used to acquire such data and their spatio-temporal resolution will vary. Ideally, environmental attributes will be monitored coincident with abundance surveys, as well as via tagging devices, fixed stations, remote sensing, and unmanned vehicles such as gliders and drones, depending in part on the scale of coverage one seeks to achieve.