ASSESSING DATA REQUIREMENTS FOR CALCULATING SUSTAINABLE MARINE MAMMAL BYCATCH LIMITS

by

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EXECUTIVE SUMMARY

The Marine Mammal Protection Act (MMPA) sits at the forefront of marine mammal conservation in the United States, focusing on management aspects such as population abundance, strandings and injuries, and fishery interactions and impacts. Within the Act, the recently implemented Fish and Fish Product Import Provisions extend several domestic marine mammal management tools to foreign fisheries wishing to export their products to the United States. Representing the most extensive effort by a single nation to influence environmental regulations of many other nations, these Provisions hold significant potential to alter global marine mammal conservation efforts. This study set out to further explore the Provisions, looking at one specific requirement they outline for foreign, exporting fisheries. This requirement is the calculation of bycatch limits for marine mammal populations impacted by said fishing operations. It sits amongst several other requirements, both regulatory and scientific in nature, that exporting fisheries will have to comply with to continue accessing lucrative US seafood markets. These requirements necessitate the distribution of a significant amount of information to the US government, and we hoped to reveal the extent of obligatory data collection for this specific requirement.

Fisheries bycatch, or the incidental injury and death during fishing efforts, of marine mammals represents the largest global threat to these species. In the United States, bycatch limits are calculated using the Potential Biological Removal (PBR) framework, a modeling formula created for low data scenarios that only requires a recent population abundance estimate. However, several methods exist for these calculations, and the Provisions call for the use of PBR *or* a "comparable scientific metric." This study explores all calculation methods available in current literature, along with their data requirements, and categorizes methods based on model structure, technical difficulty, and input data. Government documents, international and multilateral management organization and agreement reports and guidelines, and scientific literature were used to search for methods used to calculate bycatch and targeted removal limits for marine mammals. We specifically focused on models used for cetaceans (whales, dolphins, porpoises) and pinnipeds (seals, sea lions, walruses), as the Provisions' implementing agency – the National Marine Fisheries Service (NMFS) – manages these taxonomic groups in the US.

Our findings revealed that measures and concepts of population size are most crucial to creating bycatch limit models across existing methods. Five general categories of calculation methods were created*, all of which required information about marine mammal population size. Some methods require much more information than PBR, including catch history estimates, demographic parameters, and the impact of natural and anthropogenic stressors on populations. Other methods had similar or less intensive data requirements compared to PBR. The term 'comparable' is not defined in the text of the Provisions, creating difficulty in speculating which methods can be used in the context of this requirement. It is our recommendation that NMFS should not deem methods that are less robust than PBR as comparable, and the use of outdated population abundance estimates in any limit calculation method holds considerable conservation risks and should not be encouraged.

All but one currently implemented bycatch or targeted removal limit calculation method stem from Western management authorities. This finding may have implications for the preparedness of other nations – without limit calculation methods or marine mammal population data collection programs in place – in the context of this portion of the Provisions. Exporting fishery managers in low-data environments should focus on collecting population abundance data for this specific regulatory requirement.

Though this study focused on data, our findings indicate that other factors are also important to consider. In collecting population abundance and other data, fisheries managers should be mindful of aspects such as data uncertainties in limit calculation models, how robust data collection methods are, and how marine mammal conservation objectives may modify model parameters or results. The Provisions' outline of multiple requirements encourages the construction of more extensive marine mammal regulatory schemes in foreign contexts, which improves the effectiveness of limit calculation models and methods. Further, these models are most accurate and impactful when they are updated and grown as more data about marine mammal populations are collected, and several examples of this process were found in the literature. Data availability is the primary limiting factor in implementing bycatch limit methods,

* Potential Biological Removal; Limit Algorithms; Dynamic Population Models; Precautionary Objectives; and Alternative Low-Data Methods

and this work has important implications for comparability determinations for foreign fisheries under the new Import Provisions.

TABLE OF CONTENTS

I. INTRODUCTION

Since 1972, the Marine Mammal Protection Act (MMPA) has served as the primary legislation for the conservation of marine mammals in the United States. According to the National Oceanic and Atmospheric Administration (NOAA), the goals of the MMPA are twofold: 'i) prevent[ing] marine mammal species and stocks from diminishing [such that] they are no longer a significant functioning part of their ecosystems and ii) restoring [already] diminished species and stocks to their [O]ptimum [S]ustainable [P]opulations.'[1] The level at which a marine mammal stock sits may be impacted by a number of external factors, one of which is incidental takes – or bycatch – by fisheries and the number of individuals this process removes from the stock each year. Therefore, the MMPA must address impacts of fisheries bycatch in assessing and conserving the status of marine mammal stocks.

A biological reference point, the Potential Biological Removal (PBR), was introduced into US marine mammal management in 1994 as part of a series of amendments to the MMPA.[2] The primary purpose of these amendments was to better address the bycatch of marine mammals in US commercial fishing operations. The PBR approach was developed by Paul Wade and colleagues to determine 'acceptable' levels of marine mammal death and serious injury resulting from such activities, expressed as an annual limit across fisheries.[3] The suitability of these levels is, in line with MMPA goals, based on avoidance of population-level impacts that stem from captured and killed individuals, such that these impacts do not reduce stocks to below their Optimum Sustainable Population levels. PBR is specifically designed to ensure marine mammal stocks are able to either remain at or recover to these levels, despite losses due to fishery bycatch. Importantly, PBR is built into the legislation as part of a larger management scheme that includes a requirement for regular stock assessments, which must include periodic surveys and estimation of annual mortality levels.

[1] NOAA Fisheries. *What is the Marine Mammal Protection Act?* Retrieved from https://www.fisheries.noaa.gov/node/1211#:~:text=The%20primary%20objectives%20of%20the,to%20their%20optimum%20sustainable%20populations.

[2] Marine Mammal Protection Act Amendments of 1994, S. 1636, 103rd Cong. (1993-1994). https://www.congress.gov/bill/103rd-congress/senate-bill/1636/text.

[3] Wade, P. R. (1998). Calculating Limits to the Allowable Human-Caused Mortality of Cetaceans and Pinnipeds. *Marine Mammal Science, 14*(1), pp. 1-37. https://doi.org/10.1111/j.1748-7692.1998.tb00688.x.

One aspect of the 1994 amendments was not originally implemented along with the other changes. This portion of the amendments focuses on extending US-based protections to marine mammals impacted by foreign fisheries. Conversations between NOAA and environmental non-governmental organizations (NGOs) about this amendment increased throughout the mid-2000s, resulting in a lawsuit brought against NOAA in 2014 for its failure to enforce this MMPA requirement. In 2016, the lawsuit settlement resulted in the US government implementing these changes.[4] This new Import Provisions Rule (officially, the 'Fish and Fish Product Import Provisions of the Marine Mammal Protection Act,' hereafter referred to as 'the Rule'), levels the playing field for US fishermen by extending some important aspects of the MMPA to foreign fisheries that export seafood products to the US.

One important regulatory requirement of the Rule is the requirement for foreign fisheries to provide '[a] calculation of bycatch limit for marine mammal stocks in waters under [their flag's] jurisdiction that are [taken] in the export fishery.'[5] Further, the National Marine Fisheries Service (NMFS) defines the 'bycatch limit' in the regulatory text as the PBR or a 'comparable scientific metric established by the harvesting nation or applicable regional fisheries management organization or intergovernmental agreement.'[6] Thus, while foreign nations do not have to use the PBR approach, they must employ some *comparable* method to calculate acceptable levels of marine mammal bycatch for each stock that is impacted by exporting fisheries. This calculation is one of the conditions that must be met for an export fishery to receive a comparability finding, which allows the fishery to continue exporting its products to the US. However, the term 'comparable' is not defined in the legislation or elsewhere by NMFS, so specific methods – aside from PBR – that may be appropriate are not immediately obvious or provided by the US government.

[4] Uhlemann, S., Nasar, J., & Kimiko, M. (2016). *New Ruled Ban Seafood Imports That Don't Meet Strict U.S. Standards for Marine Mammal Protection*. Center for Biological Diversity. https://www.biologicaldiversity.org/news/press_releases/2016/marine-mammals-08-11-2016.html.
[5] National Oceanic and Atmospheric Administration. Fish and Fish Product Import Provisions of the Marine Mammal Protection Act, 81 F.R. 54389 (2016).
[6] *Id*.

II. OVERVIEW

Recognizing that multiple approaches toward these stipulated calculations exist, this report examines existing methods for calculating marine mammal removal limits in fisheries, including the US PBR approach. In reviewing these approaches, this paper takes a particular interest in the data that are needed both within and across methods. One concern that has been expressed about the Rule is how it will impact and be handled by exporting nations that lack the fishery and marine mammal research and management capacity found in the US and some other high income countries.[7] The intent is that the research herein will help shed light on what kind of data and research capacity are needed for this aspect of the Rule's outlined requirements.

In considering various calculation methods, algorithms on setting limits for bycatch and targeted removals (quotas) were both considered. The general idea behind both concepts is to assess the sustainability of fishery (whether targeted or incidental) removals on a particular marine mammal stock. Thus, the research approach herein involved a thorough literature review to locate and understand all potential [by]catch calculation methods – both in place and theoretical – to estimate the maximum number of sustainable marine mammal deaths and serious injuries in fishing operations. Details, such as the marine mammal species for which the method was developed, actual versus theoretical use, data collection methods, and, most importantly, data requirements, were noted for each method. Methods were then sorted into broader categories based on details of relevant analyses and data.

This report will first explore PBR and its modified versions, followed by each of the other categories created through this research process. For each category, the general approach will be explained, followed by data needs, data collection and proofing methods, and pros and cons of the overall approach. Uncertainties in different approaches are also discussed. Additional details, including all examples of each method located during the literature review, can be found in the supplementary materials. Additionally, this report looks beyond data, considering larger management schemes, data reliability and accuracy, and other questions that are important to

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[7] Williams, R., Burgess, M. W., Ashe, E., Gaines, S., & Reeves. R.R. (2016). U.S. Seafood Import Restriction Presents Opportunity and Risk. *Science, 354*(6318), pp. 1372-1374. DOI: 10.1126/science.aai8222
; Johnson, A. F., Caillat, M., Verutes, G. M., Peter, C., Junchompoo, C., Long, V., Ponnampalam, L. S., Lewison, R. L., & Hines, E. M. (2017). Poor Fisheries Struggle with U.S. Import Rule. *Science, 355*(6329), pp. 1031-1032. DOI: 10.1126/science.aam9153.

consider in the context of marine mammal protection. Finally, minimum data requirements found through this literature search are considered in the context of the Rule.

This project was embarked upon with several objectives in mind. First, this research can be used by NMFS as a tool for assessing the preparedness of foreign fisheries and governments for calculating marine mammal bycatch limits. Additionally, this research will help managers in exporting nations to prioritize research funding for marine mammals by outlining the data requirements for bycatch limit setting. Finally, general knowledge about data needs for marine mammal protection efforts can be a powerful advocacy tool, and the results in this report may be of use to environmental NGOs in their marine mammal advocacy and protection campaigns.

III. PBR AND MODIFIED PBR

Of all methods explored during the literature search, PBR was the most ubiquitous, but its use was not universal across management schemes, nations, and marine mammal species. This methodology originated in the US, but it has been adopted and adapted by fisheries managers in other high-income countries. Within this category are both classic PBR methods – those defined by Wade – and modified PBR methods. Typically, modifications to PBR are based on conservation objectives that differ from those in the US. PBR calculations require a specific conservation objective for each marine mammal stock, such as ensuring the stock will be at 50% of its carrying capacity 100 years into the future.[8] In the US, the PBR conservation objective is to allow each marine mammal stock to recover to (i.e. increase to) or remain at (i.e. stabilize) its maximum production level, or Optimum Sustainable Population level.[9] However, this target level can be modified for specific management schemes and conservation objectives, leading to adjustments in the PBR formula.

The PBR framework was specifically developed for low data scenarios: at minimum, its formula requires a single population abundance estimate. The PBR formula consists of three input

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[8] Sala, A., Konrad, C., & Doerner, H. (2019). *Review of the Implementation of the EU Regulation on the Incidental Catches of Cetaceans* (STECF-19-07). European Commission Scientific, Technical, and Economic Committee for Fisheries (STECF). https://stecf.jrc.ec.europa.eu/documents/43805/2489016/STECF+19-07+-+Incid+catches+cetaceans.pdf/3485bafd-4350-40af-8d72-0226a68cb86e.

[9] Punt, A. E., Siple, M., Sigurasson, G. M., Vikingsson, G., Francis, T. B., Granquist, S. M., Hammon, P. S., Heinemann, D., Long, K. J., Moore, J. E., Sepúlveda, M., Reeves, R. R., Wade, P. R., Williams, R., & Zerbini, A. N. (2020c). Evaluating Management Strategies for Marine Mammal Populations: An Example for Multiple Species and Multiple Fishing Sectors in Iceland. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(8), pp. 1316-1331. https://doi.org/10.1139/cjfas-2019-0386.

variables – an abundance estimate, a population recovery factor, and the population's maximum intrinsic growth rate – but the latter two variables can be input as default values based on species type and population status. This allows managers to set bycatch limits with a minimum of data parameters. Recovery factors are set between 0.1 and 1.0, with higher numbers indicating a better ability to withstand mortality (*i.e.* better conservation status).[10] Knowledge of the conservation status of a population helps set this number, but if this is unknown, a default value is used. If stock-specific maximum growth rates are unavailable, this parameter can be set at default values of 0.04 for cetaceans or 0.12 for pinnipeds.[11] These factors, alongside the population abundance estimate, are used to calculate an annual bycatch limit, although the abundance estimate for each population does not need to be updated on an annual basis.

PBR was designed for broad use with marine mammal species, and it is used for all marine mammals in US waters. It has been applied to pinnipeds and cetaceans in other nations and under other management schemes. Further, PBR use ranges across both targeted and accidental catches: some managers use it to limit bycatch of marine mammals, while others use it to set directed catch quotas. This broader use is perhaps not unexpected, as the ability to alter the formula's three input variables based on specific populations and taxa makes PBR an attractive option for use across cetaceans and pinniped species. Examples include its use for Greenland harp seals, common dolphins in the Northeast Atlantic Ocean, harbor seals in Norway, and harbor porpoises in the Belt Sea (see Supplementary Materials for more details). In these and other scenarios, PBR has been calculated and set by advisory groups, intergovernmental agreements, and government management authorities.

In performing the PBR calculation, some scientific research is required, and can be performed directly by competent authorities or by independent scientists. Within the PBR formula, only the estimate of population abundance definitively requires research and data collection. In the original, US-based PBR process, this estimate stems from recurring surveys of marine mammal populations. In this approach, these surveys are performed for each population management unit,

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[10] LeBoeuf, N. & Wieting, D. (2016). *Guidelines for Preparing Stock Assessment Reports Pursuant to the 1994 Amendments to the MMPA – February 2016 Revisions* (NMFS Instruction 02-204-01). National Marine Fisheries Service. https://media.fisheries.noaa.gov/dam-migration/guidelines_for_preparing_stock_assessment_reports_2016_revision_gamms_iii_opr2.pdf.
[11] *Id.*

or stock, as defined by the MMPA and NMFS guidelines.[12] For each stock, a minimum population abundance estimate is typically calculated as the "20th percentile of the lognormal distribution" of the estimate of the size of the population unit, with this estimate stemming from aerial surveys.[13] US managers may average estimates from several surveys, although this is not explicitly required for PBR.[14]

While some fisheries outside of the US that use PBR employ similar aerial survey methods, others take different approaches toward population abundance estimates. These include methods such as the use of pup production and pup modeling for pinnipeds, more complex models incorporating population monitoring data, and the use of expert elicitation. Regardless of method, what is important in determining abundance estimates is i) the *minimum* estimate is used, ii) the estimate is not an outdated representation of the population/stock size, and iii) the estimate is an absolute estimate. These considerations help to ensure that the data used for PBR calculations are accurate. Uncertainty is decreased by using a more conservative (i.e. the minimum) population abundance estimate, and ensuring data are up to date also decreases risks associated with the use of incorrect values in the PBR formula. In the US, abundance estimates are considered outdated if more than eight years have passed since the survey was conducted.[15] Using outdated abundance estimates can lead to incorrect assumptions about a population's health and ability to respond to certain levels of removals, making this an important part of the process's uncertainty minimization checks.

In the US, data undergo further vetting for uncertainty minimization through expert review. Under the MMPA structure used by NMFS, marine mammal stock assessments, which include PBR, undergo a rigorous, external peer review process, followed by public comment period, before they are finalized. This process helps address uncertainties, ensure the use of the best

[12] Sparling, C. E., Thompson, D., & Booth, C. G. (2017). *Guide to Population Models Used in Marine Mammal Impact Assessment* (JNCC Report No. 607). Joint Nature Conservation Committee. https://data.jncc.gov.uk/data/e47f17ec-30b0-4606-a774-cdcd90097e28/JNCC-Report-607-FINAL-WEB.pdf.
[13] Punt, A., Siple, M., Francis, T. B., Hammond, P. S., Heinemann, D., Long, K. J., Moore, J. E., Sepúlveda, M., Reeves, R. R., Sigurosson, G. M., Vikingsoon, G., Wade, P. R., Williams, R., & Zerbini, A. N. (2020). Robustness of Potential Biological Removal to Monitoring, Environmental, and Management Uncertainties. *ICES Journal of Marine Science, 77*(7-8), pp. 2491-2507. https://doi.org/10.1093/icesjms/fsaa096.
[14] Brandon, J. R., Punt, A. E., Morena, P., & Reeves, R. (2016). Toward a Tier System Approach for Calculating Limits on Human-Caused Mortality of Marine Mammals. *ICES Journal of Marine Science, 74*(3), pp. 877-887. https://doi.org/10.1093/icesjms/fsw202.
[15] LeBoeuf & Wieting (2016).

available science, and confirm the accuracy of the data. These reviews are carried out by one of three groups, each consisting of experts in marine mammal ecology, resource management, fishing operations, and other relevant fields.[16] Reviews are performed annually as part of the stock assessment report (SAR) process. These reviews, while part of the US management structure, are not inherently part of the PBR approach, thus are not required for non-US fisheries that use PBR.

It is perhaps not surprising that PBR is the most used tool for calculating bycatch limits, as its low data requirements make it easier to use than most, if not all, other methods. PBR accounts for some uncertainties in its formula, *e.g.* by using the minimum population abundance estimate and allowing for flexibility in setting the recovery factor. However, in cases where a large amount of data is available, it can be more advantageous to use a modeling approach that incorporates more in-depth information than PBR – this allows for increased accuracy in calculated bycatch limits.[17] Nevertheless, PBR is an extremely strong approach for low-data scenarios due to its estimable parameters and consideration of uncertainties by using more conservative estimates in its formula.[18]

IV. LIMIT ALGORITHMS

The International Whaling Commission (IWC) is the primary intergovernmental entity involved in cetacean management. The IWC was established in 1946 to regulate commercial harvests of the great whales, but has since pulled back on much of this work, following its 1986 moratorium on whaling.[19] Since the moratorium was put in place, the Commission developed several iterations of its Revised Management Procedure (RMP), a management scheme meant to estimate sustainable commercial harvests should the moratorium be lifted.[20] As part of these

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[16] NMFS (n.d.). *Scientific Review Group Terms of Reference*. https://media.fisheries.noaa.gov/dam-migration/srg_tor-508.pdf; NMFS. (2022). *Marine Mammal Stock Assessments*. Retrieved from https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessments; NMFS. (2022). *Scientific Review Groups*. Retrieved from https://www.fisheries.noaa.gov/national/marine-mammal-protection/scientific-review-groups.

[17] Hammill, M. O. & Stenson, G. B. (2007). Application of the Precautionary Approach and Conservation Reference Points to Management of Atlantic Seals. *ICES Journal of Marine Science, 64*(4), pp. 702-706. https://doi.org/10.1093/icesjms/fsm037.

[18] Robards, M. D., Burns, J. J., Meek, C. L., & Watson, A. (2009). Limitations of an Optimum Sustainable Population or Potential Biological Removal Approach for Conserving Marine Mammals: Pacific Walrus Case Study. *Journal of Environmental Management, 91*(1), pp. 57-66. DOI: 10.1016/j.jenvman.2009.08.016.

[19] IWC (2022). *The Revised Management Procedure*. Retrieved from https://iwc.int/rmp.

[20] Hammond, P. S., Paradinas, I., & Smout, S. C. (2019). *Development of a Removals Limit Algorithm (RLA) to Set Limits to Anthropogenic Mortality of Small Cetaceans to Meet Specific Conservation Objectives, With an Example Implementation for*

efforts, scientists at the IWC developed an algorithm to setting baleen whale 'take' limits: the Catch Limit Algorithm (CLA). Like PBR, CLA was created with specific conservation objectives in mind, with respect to population size and catch thresholds. This is perhaps not surprising as some of the same scientists were involved in the development of PBR and the CLA. In developing the CLA, the IWC agreed to prohibit removals from any cetacean stock with an estimated abundance under 54% of carrying capacity and implemented a tuning level of 72%.[21] This tuning level sets catches at a level that will allow the populations to stabilize at 72% of their original (pre-catch) size. While originally fielded as an approach (that has not been officially adopted by the IWC) to determine sustainable levels of targeted catch, CLA has also since been applied to fishery bycatch of cetaceans.

Since the creation of CLA, researchers at the Joint Nature Conservation Committee (JNCC) have developed a similar model for limiting human-induced mortality of small cetaceans: the Removals Limit Algorithm (RLA). Both CLA and RLA use a population model with similar input data and built-in robustness tests.[22] The RLA has not been officially adopted by any governing body, but has been used by managers. Both the CLA and RLA have the potential to be adopted on a larger scale, as part of more comprehensive management schemes for cetacean catches and bycatch.

Unlike the PBR formula, both CLA and RLA require data beyond a single population abundance estimate. These models require population abundance estimate(s) and a time series of removals (harvests or bycatch, depending on the application of the algorithm), which the subsequent population model is fitted to. The CLA model requires at least one recent population abundance estimate, while the RLA model requires a time series of abundance estimates and a current abundance estimate.[23] Additionally, for RLA, demographic information about the marine mammal population, such as age structure and population dynamics, is also fed into the algorithm.

Bycatch of Harbor Porpoise in the North Sea. (JNCC Report No. 628). Joint Nature Conservation Committee. https://data.jncc.gov.uk/data/8ac9a424-eda5-4062-957e-63d82d3e39cc/JNCC-Report-628-FINAL-WEB.pdf.

[21] IWC (2022b). *The Revised Management Procedure – a Detailed Account*. Retrieved from https://iwc.int/rmp2.

[22] Hammond et al. (2019); IWC (2022).

[23] Hammond et al. (2019).

CLA was originally developed to manage harvests of large cetaceans, and today is mostly applied to catches of large baleen whales by whaling managers in Iceland, Norway, and Greenland.[24] In practice, the CLA has been modified from its original form to fit different management scenarios. The North Atlantic Marine Mammal Commission (NAMMCO) has created management simulations with CLA using the original tuning level of 0.72 and a lower tuning level of 0.60 to create advice for whale harvesting nations.[25] The RLA has been adopted by the Convention for the Protection of the Marine Environment of the North-East Atlantic's (OSPAR's) Biodiversity Committee with respect to one population of harbor porpoises and was calculated by the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) as a theoretical approach to develop bycatch limits for harbor porpoises.[26]

CLA and RLA – like PBR – also require current abundance estimates, but estimates are considered outdated after six, not eight, years.[27] In the RLA model, abundance estimates stem from population surveys, which are also used in estimating depletion levels, thus giving information about current population size and status.[28] For CLA, abundance estimates can stem from abundance surveys, similar to those used in the US PBR structure, but the model does not stipulate that abundance estimates have to be generated from these surveys. Notably, CLA does not use population data to glean further information about a population's status or descriptive parameters – these data are only used for direct calculations of population size.[29] Removals data in both algorithms can stem from direct records of catches or from estimated catch based on fishing effort and bycatch data.

Recognizing that the impacts of large whale management schemes often cannot be seen in a timely manner in real life, the IWC built its algorithm around complex computer modeling and

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[24] NAMMCO Scientific Committee Working Group on Assessment. (2017). *Report of the NAMMCO Scientific Committee Working Group on Assessment – Greenland Representation, Copenhagen, Denmark, 25-27 January 2017*. (SC/24/AS/Report). NAMMCO. http://nammco.wpengine.com/wp-content/uploads/2017/02/large-whale-assessment-wg-report-january-2017.pdf.
[25] *Id*.
[26] Sala et al. (2019); Genu, M., Gilles, A., Hammond, P. S., Macleod, K., Paillé, J., Paradinas, I., Smout, S., Winship, A. J., & Authier, M. (2021). Evaluating Strategies for Managing Anthropogenic Mortality on Marine Mammals: An R Implementation With the Package RLA. *Frontiers in Marine Science 24*. https://doi.org/10.3389/fmars.2021.795953.
[27] IWC (2022b); Hammond et al. (2019).
[28] Hammond et al. (2019).
[29] Cooke, J., Leaper, R., Wade, P., Lavigne, D., & Taylor, B. (2012). Management Rules for Marine Mammal Populations: A Response to Lonergan. *Marine Policy, 36*(2), pp. 389-392. https://doi.org/10.1016/j.marpol.2011.06.009.

simulations.[30] RLA is similarly based on modeling scenarios. Throughout this computer modeling process for CLA and RLA, assumptions and data are checked for robustness against uncertainties. Population modeling is used in CLA and RLA to test the algorithms' performances in different ecological scenarios. CLA behavior is tested using simulated conditions that allow input data to fail model assumptions, and the algorithm itself tests for uncertainties related to demographic shifts, estimation bias, and carrying capacity changes.[31] Bayesian methods used in the RLA modeling process help reduce uncertainties, and RLA undergoes a similar robustness test via scenario testing.[32]

CLA and RLA can be adjusted to adopt a more or less conservation-minded, precautionary approach by changing their tuning levels. A higher tuning level in the algorithm corresponds to more focus on conservation objectives (and less on commercial catch objectives) – setting a higher tuning level simply directs the algorithm to adjust catch levels to achieve a larger resulting population size, which can be useful if uncertainties about the population size exist.[33]

These approaches are more data hungry than PBR – and were designed specifically with cetaceans in mind. CLA and RLA hold up well against uncertainties, as their models are built to test many of the data inaccuracies and errors that can arise in marine mammal management. Still, the incorporation of removals estimates can introduce new uncertainties, especially if removals are from bycatch rather than targeted efforts. Estimates of total bycatch are typically based on observer data or vessel-reported data, fitted to total fishing effort, and this process can create biases if the initial data are not thorough enough.[34] CLA includes a bias parameter to decrease the variance found in other parameters in the algorithm, which can help address this issue.[35] Still, CLA and RLA remain strong approaches, if existing knowledge of population size and removals is thorough and has been consistently collected in the past. These approaches are data demanding and species-specific, so they are used less frequently than PBR.

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[30] IWC (2022b).
[31] IWC (2022b); Hammill & Stenson (2007).
[32] Hammond et al. (2019).
[33] IWC (2022b).
[34] *Id.*
[35] *Id.*

V. DYNAMIC POPULATION MODELS

The third category used here for describing calculation methods consists of a broad range of approaches, combined under the catch-all 'dynamic population models.' These approaches are also used less frequently than the above methods, but include an even finer level of detail about demographics and life history. Dynamic population models use data to model population estimates and to project future scenarios for marine mammal populations. The use of extensive life history and population behavioral data creates more accuracy in these models, allowing scientists to set more precise management limits.

Several different models exist under this general method. These models can be used to predict population trajectories based on bycatch or harvest levels. In some approaches, Bayesian methods are used in conjunction with both marine mammal population data and fishery data.[36] While fishery catch data are also used in the CLA and RLA algorithms, dynamic population models go beyond just catch numbers, sometimes including data describing the effectiveness of bycatch mitigation methods, age-structured catch data, and longer time series of catch history.[37] Population abundance data in these models are often age and/or sex-structured, allowing for more realistic projections of population responses to and risks from external stressors like bycatch. Finally, environmental parameters are often added into these models, as environmental conditions can have limiting effects on population size and can exacerbate population stressors.[38]

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[36] Chilvers, B. L. (2008). New Zealand Sea Lions *Phocarctos hookeri* and Squid Trawl Fisheries: Bycatch Problems and Management Options. *Endangered Species Research,* 5(2-3), pp. 193-204. DOI:10.3354/esr00086; Ministry for Primary Industries. (2014). *Squid (SQU6T) – Final Advice Paper*. (B11-630). New Zealand Ministry for Primary Industries. https://web.archive.org/web/20141025165154/http:/www.fish.govt.nz/NR/rdonlyres/E920BB49-CFA7-4448-BDE5-F708E0F5ACD2/0/FinalAdvicePaperSQU6T2012.pdf.

[37] Ministry for Primary Industries (2014); Green, P. A., Fru, D., & Gilbert, D. J. (2016). *Sea Lion Population Modelling and Management Procedure Evaluations*. (New Zealand Aquatic Environment and Biodiversity Report No. 175). New Zealand Ministry for Primary Industries. https://fs.fish.govt.nz/Doc/24211/AEBR-175-Sealion-population-modelling.pdf.ashx; Chilvers, B. L. (2012). Population Viability Analysis of New Zealand Sea Lions, Auckland Islands, New Zealand's Sub-Antarctics: Assessing Relative Impacts and Uncertainty. *Polar Biology, 35*(10), pp. 1607-1615. DOI:10.1007/s00300-011-1143-6; Robertson, B. C. (2015). Is Management Limiting the Recovery of the New Zealand Sea Lion Phocarctos Hookeri? *Polar Biology, 38*(4), pp. 539-546. DOI:10.1007/s00300-014-1619-2; Heide-Jørgensen, M. P., Hansen, R. G., Fossette, S., Nielsen, N. H., Borchers, D. L., Stern, H., & Witting, L. (2016). *Animal Conservation, 20*(3), pp. 282-293. https://doi.org/10.1111/acv.12315; Biuw, M., Frie, A. K., Haug, T., Nilssen, K. T., Rosing-Asvid, A., Stenson, G. B., Smout, S., Zabavnikov, V., Grecian, J., Wickson, F., & Hansen, S. (2019). *ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP).* (ICES Scientific Reports 1(72)). WGHARP. https://nammco.no/wp-content/uploads/2019/11/final-report_wgharp-2019.pdf.

[38] Australian Fisheries Management Authority. (2010). *Australian Sea Lion Management Strategy: Southern and Eastern Scalefish and Shark Fishery (SESSF)*. Australian Government. https://www.fish.gov.au/Archived-Reports/2012/reports/Documents/AFMA_2010b.pdf; Department of Fisheries and Oceans Canada (DFO). (2020). *2019 Status of Northwest Atlantic Harp Seals, Pagophilus groenlandicus*. (Canadian Science Advisory Secretariat Science Advisory Report 2020/020). Fisheries and Oceans Canada. https://waves-vagues.dfo-mpo.gc.ca/Library/40878478.pdf.

These data-intensive population models are applied to a wider range of marine mammal species than RLA and CLA. Examples of these methods were found for both cetaceans and pinnipeds. Pinniped models tended to incorporate more detailed demographic data, drawing from surveys of pup production, observed survival rates, and models of density dependence. Cetacean models drew from surveys with modeled bias corrections, population trends, age and sex structure, and histories of catch and abundance data. While most models in this category were species-specific – and sometimes fishery-specific – in their development, the general concepts of their approaches can be applied to other data-rich species populations.

Data availability is crucial for these models. Often, data have been collected over long periods of time, requiring consistent, recurring monitoring of populations to learn about their dynamics and structures. Fishery data in these models stems from vessel and observer reports, which can be extrapolated across full fleets. In pinniped colonies, direct data collection via tagging or marking allows researchers to follow individual animals, incorporating supplementary data to typical aerial surveys.

While more data can increase model accuracy, it can also increase uncertainties around parameters that are estimated from these data. Models that are Bayesian in nature inherently work toward addressing uncertainties through the incorporation of more data, as Bayesian models use existing knowledge to make predictions based on probabilities.[39] Many dynamic population approaches incorporate Bayesian methods for this reason. The models in this category are also run under multiple management/bycatch scenarios, and the comparison of these results helps determine the best estimated catch limits. One example approach in this category compared modeling results of population responses and changes to existing empirical data – by running this model on predictions in the past and the future, researchers were able to make a direct comparison to actual population data, thus testing the accuracy of their results.[40] Corrections to some data uncertainties are available for use in these models as well.

[39] Van de Schoot, R., Depaoli, S., King, R., Kramer, B., Märtens, K., Tadesse, M. G., Vannucci, M., Gelman, A., Veen, D., Willemsen, J., & Yau, C. (2021). Bayesian Statistics and Modelling. *Nature Reviews Methods Primers, 1*(1). https://doi.org/10.1038/s43586-020-00001-2.
[40] Chilvers (2012).

Some dynamic modeling approaches, such as population viability analysis, have been critiqued for the amount of data they require – these data are not available for many marine mammal populations, decreasing the accessibility of this approach.[41] However, for intensively studied populations, such models can incorporate virtually everything that is known about how the populations behave, making the models more realistic. Inputting multiple catch limit scenarios into these models allows managers to view a range of potential population impacts, versus being presented with a single number that is then applied to fisheries. While the level of detail required for input parameters does make these approaches less generally accessible, less data-intensive methods can gradually evolve into in-depth population models as additional research and monitoring is performed on a marine mammal population. For example, New Zealand's sea lion population was previously managed through a PBR-derived method but is now managed through a Fishing-Related Mortality Limit method that incorporates the wealth of data that has been collected by managers since initial bycatch limits were put in place.[42]

VI. PRECAUTIONARY OBJECTIVES

The fourth category of approaches is, like PBR, centered around low-data scenarios. Precautionary objective approaches are based on the premise that a lack of data about a marine mammal population should not provide an excuse for a lack of management plan.[43] Further, in scenarios in which little is known about a marine mammal population, precautionary objectives can be used, as their name suggests, to develop management techniques based in precaution.

Precautionary objectives are typically set when additional data for modeling or more exact demographic estimates are not available. These limits – typically a fixed percentage of abundance - or a 'rule of thumb' – are often used as temporary placeholders, set as safeguards against population declines until more exact bycatch limits can be determined.[44] Reference level 'caps' on bycatch set through precautionary objectives work best as placeholders while additional data are collected, as more robust modeling is a stronger long-term approach.[45] While

[41] Chilvers (2012).
[42] Chilvers (2008); Ministry for Primary Industries (2014); Robertson (2015).
[43] Hammill & Stenson (2007).
[44] Sala et al. (2019).
[45] *Id.*

there are no exact time limits set on the use of precautionary objectives, their use should not prevent further research being done on the marine mammal populations to which they are applied. Ultimately, such approaches should only be used until enough data have been collected to allow managers to pivot to a more data-rich formula.

This category contained the second-smallest number of examples, but precautionary objectives still represent an important management approach for multiple cetaceans and a potential management approach for two pinniped species. Precautionary objectives have only been officially set for small cetaceans – dolphins and porpoises.[46] Some work has been done to create potential precautionary objective approaches for data-poor seal populations, but these methods have not been officially adopted.[47]

In precautionary objectives, the minimum data requirements are typically population abundance. There are fewer guidelines, such as a cutoff age for surveys, for this approach than for others that are centered around models with firm parameter inputs. Language in precautionary objective setting such as "best available" population abundance estimate allows for flexibility, inviting managers to use what they have, so that some management form can be put in place. Direct estimates of population abundance are used in fixed percentage approaches. However, other approaches do not base limits solely on direct estimates of population size. These precautionary objectives set numerical limits per vessel or per unit of fishing gear, with considerations such as population status and abundance, trends in fishing interactions with the population, and population response to removals and previous thresholds playing a role in setting these limits.[48]

Precautionary objectives are a viable way to protect populations from harm as better models are being developed, but these objectives should not be used for too long. A precautionary objective can increase its longevity by creating layers within its structure: it may set annual percentage

[46] Sala et al. (2019); Australian Fisheries Management Authority. (2019).*Gillnet Dolphin Mitigation Strategy*. Australian Government. https://www.afma.gov.au/sites/default/files/gillnet_dolphin_mitigation_strategy_updated_aug_2019_accessible.pdf; IATTC. (1992). *La Jolla Agreement for the Reduction of Dolphin Mortality in the Eastern Pacific Ocean*. https://www.ecolex.org/details/treaty/la-jolla-agreement-for-the-reduction-of-dolphin-mortality-in-the-eastern-pacific-ocean-tre-154445/; IATTC. (2009). *Agreement on the International Dolphin Conservation Program – Amended). https://media.fisheries.noaa.gov/dam-migration/aidcp-amended-oct-2009.pdf*.

[47] Hammill & Stenson (2007).

[48] Australian Fisheries Management Authority (2019); IATTC (2009); Hammill & Stenson (2007).

limits based on population size, with a broader rule to decrease these percentages each year, so that bycatch is not creating excess population harm in a single fishing season and approaching zero as time goes on.[49] Reviews and updates to data are crucial for the effectiveness of these approaches. Ultimately, though, researchers caution managers from using precautionary objective caps as methods more long-term than a steppingstone to more robust, data-intensive models.[50]

VII. ALTERNATIVE LOW-DATA METHODS

The final category described in this report comes from research that the Lenfest Ocean Program's Marine Mammal Bycatch Working Group has recently undertaken to develop alternatives to PBR when little is known about a population. PBR is meant for low-data scenarios, but the three methods in this category – slope, replacement yield, and depletion-corrected average catch – are aimed at scenarios in which data are still limited, but different than what is required for PBR. The rules for required data are also more flexible for these models than for PBR.

Across the three methods, the minimum data requirements are a time series of bycatch mortality estimates and at least two population abundance indices.[51] These are the only model-based approaches across this report that do not call for estimates of absolute abundance and do not provide an age cutoff for abundance estimates. Input time series with more (e.g., 20) data points and with consistent data points (e.g., per year) are more effective in the modeling processes, but as few as two data points can be used.[52] Bycatch estimates, like with other models, typically come from observer reports or other onboard methods but need to be extrapolated to estimate bycatch for full fishing fleets. Abundance indices can come from a range of methods, but surveys occurring at least every four years (twice as frequent as those for PBR) are noted as ideal, though not required.[53]

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[49] IATTC (1992); IATTC (2009).
[50] Hammill & Stenson (2007); Sala et al. (2019).
[51] Punt, A. E., Siple, M. C., Francis, T. B., Hammond, P. S., Heinemann, D., Long, K. J., Moore, J., Sepúlveda, M., Reeves, R. R., Sigurosson, G. M., Vikingsson, G., Wade, P. R., Williams, R., & Zerbini, A. N. (2020b). Can we Manage Marine Mammal Bycatch Effectively in Low-Data Environments? *Journal of Applied Ecology, 58,* pp. 596-607. DOI: 10.1111/1365-2664.13816.
[52] Punt et al. (2020b).
[53] *Id*.

These methods are, of course, better than no bycatch limit at all, but the uncertainty in them is quite high, and ensuring accuracy and a lack of bias in bycatch mortality estimates can be difficult. Indices of abundance can also be hard to generate as frequently as every four years, especially in low research capacity scenarios. Room for error increases in these models if bycatch estimates and abundance indices are less frequent and if the total number of data points is small.[54] These methods have not been implemented in any real management scenarios, but they have been tested on pinniped and cetacean populations in modeling scenarios. They present an option for fisheries managers who lack absolute marine mammal population information, but their lack of application to real-world scenarios presents some risks in implementing them.

The Working Group notes that bycatch mortality estimates can stem from observer programs, stranding drift models, or remote electronic monitoring systems on vessels.[55] However, because these models are not built into larger management schemes, there are not set rules associated with them on ensuring the accuracy of bycatch mortality data or how to avoid estimation bias. In presenting these models, the Group also notes that one identified method should 'not be used at all' and express caution about the use of the other two methods, especially if bycatch mortality estimates are not fully reliable.[56] Additionally, if abundance indices are absolute estimates of population size, it is recommended that PBR is used rather than these low data models.

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[54] *Id.*
[55] *Id.*
[56] *Id.*

	PBR and Modified PBR	Limit Algorithms	Dynamic Population Models	Precautionary Objectives	Alternative Low Data Methods
Minimum Data Requirements	One population abundance estimate, no older than eight years	At least one abundance estimate, no older than six years, and multiple bycatch estimates	Multiple abundance and bycatch estimates, demographic data, sometimes environmental data	Abundance estimates and general population status information	At least two abundance and bycatch estimates
Species Applied To (In Practice)	All cetacean and pinniped species	Fin whale, minke whale; harbor porpoise	Sea lion, beluga whale, harp seal, harbor seal, narwhal	Small cetacean species, dolphin species	None
Species Applied To (In Theory)	All cetacean and pinniped species	Large baleen whales and small cetaceans, respectively	All marine mammal species	Harp and harbor seals, all other marine mammal species	All cetacean and pinniped species

Figure 1. Table of methods categories and their details.

VIII. UNCERTAINTIES IN MODELING

As estimation is necessary throughout the above approaches, varying levels of uncertainty are inherent in this work. Many models have methods built in to address uncertainties, but they cannot be fully discounted or removed. Knowledge about population dynamics and predictions of future behavior cannot be exact, which inserts a certain level of risk in applying each of these approaches. Historically, the use of fishery management methods that did not fully account for uncertainties and were not sufficiently conservative has led to management failures, such as in the case of Atlantic cod stocks and large whales.[57] All of the approaches here consider uncertainties, with varying levels of robustness in resolving them.

Uncertainties can be addressed by running robustness tests on models, incorporating additional demographic data into models, and vetting data through review processes. Enough uncertainty in a model risks a population collapsing under resulting bycatch management schemes or feeling a larger, negative impact from chosen bycatch limits, so building in pathways to address this is crucial. The IWC factored uncertainties into CLA by requiring the inclusion of statistical uncertainty of abundance estimates in modeling procedures and multiple simulation runs for more accurate population response predictions.[58] The PBR method includes variation in the abundance estimate in its equation, which allows for the final limit to be adjusted as a reflection of variation in the abundance estimate.[59] Managers may also choose to set a low recovery factor in the PBR formula as a failsafe against uncertainties in population status.[60] As previously noted, population dynamic models incorporate more information about populations, but also must account for the uncertainties in estimations and predictions. For more data sparse approaches, adjustments such as lowering fixed percentages for removals can be considered if uncertainties are acknowledged.[61]

Any viable method needs to account for uncertainties to some extent, as assumptions and estimations are used in all models. The most comprehensive way to address uncertainties is likely via a combination of scenario modeling, precautionary approaches in estimates and threshold setting, and third-party review of estimates. Additionally, having more data about a population and its behavior allows for increased confidence in models of that population. For

[57] Hamill & Stenson (2007).
[58] IWC (2022); IWC (2022b).
[59] Mackay, A., Goldsworthy, S. D., & Harrison, P. L. (2016). *Critical Knowledge Gaps: Estimating Potential Maximum Cumulative Anthropogenic Mortality Limits of Key Marine Mammal Species to Inform Management – Technical Report*. (FRDC Project No. 2015/035). Fisheries Research and Development Corporation and South Australian Research and Development Institute. https://www.frdc.com.au/final-report-2015-035-critical-knowledge-gaps-estimating-potential-maximum-cumulative-anthropogenic; Punt et al. (2020b).
[60] Sparling et al. (2017).
[61] Sala et al. (2019); IWC-ASCOBANS Working Group on Harbor Porpoises. (2000). Annex O – Report of the IWC-ASCOBANS Working Group on Harbor Porpoises. *Journal of Cetacean Research and Management 2(Supp.)*. https://www.ascobans.org/sites/default/files/document/Inf32_JointWorkshopReportSupplement%202.pdf-2Supp297_305AnnexO.pdf.

example, increasing the frequency of population surveys increases confidence in the abundance estimates calculated from them.[62] Uncertainties are more difficult to address and minimize in low-data scenarios, but the initial step of simply identifying the kinds of variability and unpredictability in model data should still be used as a starting point to find solutions to these issues.

Uncertainties are not only different across models, but across species as well. Generally, there may be more uncertainty involved in estimating the population size of cetaceans as compared to pinnipeds, largely because pinnipeds can be more easily observed out of the water. Thorough research and knowledge intake takes time, and increased familiarity with marine mammal populations can increase confidence in predicting their responses and patterns.

IX. BEST PRACTICES

The primary purpose of this research was to investigate data requirements for this aspect of the Rule, but it is important to keep in mind the broader contexts of best practices to consider when collecting and using data, understanding marine mammal population health, and how these approaches are developed and applied. In this section, these best practices, derived from details within scientific reports and considerations of how models compare to one another, are discussed for further considerations beyond data requirements.

Capacity requirements and reliability vary across data collection methods. Generally, it is better to have more data about a population, but details such as productivity rate and shifts in carrying capacity are often difficult to obtain. As a general rule, the best available – and feasible – scientific methods should be used to study and collect data on marine mammal populations, their environments, and the fisheries that impact them. The expert elicitation (EE) process provides a potential alternative when no published data are available. However, EE has been used only once in this way, and even in this case, some invited experts were not comfortable providing estimates of population size for the target marine mammal species.[63] Some participants noted that they felt EE should not be used to generate abundance estimates that are used to develop bycatch limits

[62] DFO (2020).
[63] Mackay et al. (2016).

within management schemes, especially those that call for absolute abundance estimates.[64] However, the use of expert opinion can create usable estimates for population data, in data scarce situations or for understudied species.[65]

In considering the reliability of data collection processes, managers should weigh the question of whether using a less robust method is preferable to the absence of any method. While less thorough data gathering methods may introduce more uncertainty, they also may allow for the temporary implementation of bycatch limits until more data can be procured, similar to the use of precautionary objectives. This same line of thought may be applied to considerations of data validity over time. Models like PBR and CLA have rules stating when data is too outdated to accurately reflect a population's current details, but these kinds of considerations are not built into every available method. In situations in which research capacity and funds are severely limited, managers may have to ask themselves whether using a 15-year-old population abundance estimates is preferable to the absence of information on population size. PBR, CLA, and RLA set limits to zero or leave them undefined if abundance estimates are too old, and it may be wise to introduce this kind of cutoff in methods without timeline instructions for input parameters. However, managers will also need to consider impacts on affected fisheries if bycatch limits are set to zero because of a lack of data.

The PBR peer review process presents a potential solution to data uncertainties and risks in these methods. The review process is well developed in the US, and a similar approach of external review could be undertaken as a precautionary measure in cases where outdated, less reliable data is the only option for use in calculating bycatch limits. Algorithms and modeling can also be used, such as in the case of CLA, to 'review' results by testing their robustness technologically. A combination of external, human review and computer tests may be the best way to avoid the use of 'bad' science and poor-quality data, but this requires a significant amount of effort, and the reviewed methods in this report tended to select one review process over the other rather than combining them.

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[64] *Id.*
[65] Sala et al. (2019).

Each of the approaches in this report considers marine mammal population status through the lens of lethal interactions with fisheries. In truth, however, many other stressors impact these populations, which can affect their ability to respond to and overcome the loss of individuals to bycatch and targeted catch. Impacts from environmental conditions, non-lethal interactions with ships and fishing vessels, climate change, and more can diminish the fitness of the population and individuals within it. Several of the above methods do not include sub-lethal and larger environmental impacts on populations in their models, but these aspects of marine mammal population studies may be increasingly important.

Some approaches discussed in this report are already considering impacts outside of bycatch, such as Canada's incorporation of sea ice decline in its management models for harp seals.[66] Changes in ice cover are expected to impact seal pup mortality rates, and may impact carrying capacity, creating a new uncertainty in this model that the government has decided to address in the model's next iteration. Robards (2009) points to shifting PBR toward more of an ecosystem-based approach, suggesting the incorporation of indices such as sea ice conditions, prey abundance, and population distribution into bycatch limit setting.[67] Similarly, other researchers have suggested the use of additional natural history and environmental parameters into precautionary management approaches for marine mammals and other species.[68] Across environmental factors, climate shifts will play an increasing role in the conversation around general marine conservation. However, out of all methods that were reviewed for this report, only two models considered climate impacts on population dynamics.[69]

Other than environmental factors, it is also important to note that removals from marine mammal populations are not solely derived from natural deaths and fishery removals. Some models

[66] DFO (2020).
[67] Robards et al. (2009).
[68] Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J., & Sainsbury, K. J. (2004). Ecosystem-Based Fishery Management. *Science, 305*(5682), pp. 346-347. DOI: 10.1126/science.1098222; Punt et al. (2020); Chilvers (2012); Brandon, J. R. & Punt, A. E. (2013). Testing the Gray Whale Strike Limit Algorithm (SLA): Allowing Environmental Variability to Influence Population Dynamics. *Journal of Cetacean Research and Management, 13*(1). https://www.researchgate.net/profile/Andre-Punt/publication/228974604_Testing_the_Gray_Whale_Strike_Limit_Algorithm_SLA_Allowing_environmental_variability_to_influence_population_dynamics/links/00b7d518a82f673616000000/Testing-the-Gray-Whale-Strike-Limit-Algorithm-SLA-Allowing-environmental-variability-to-influence-population-dynamics.pdf.
[69] DFO (2020); IWC (2022b).

incorporate additional lethal and sub-lethal interactions into their calculations, though this was not common across the methods herein. NAMMCO's joint working group on narwhals and belugas included struck and lost whales in its most recent model for targeted whale removals.[70] New Zealand's bycatch modeling for sea lions is specifically targeted at the squid fisheries but includes bycatch data from other fisheries to increase accuracy.[71] Managers should incorporate these kinds of data if they exist, in order to ensure their bycatch limits are not set too high given other sources of removals from marine mammal populations.

In addition to the above optional considerations, there are other factors that managers must take account of when developing and applying bycatch limit algorithms. The first consideration by managers should be what data are available for use. Data availability is the primary limiting factor for these methods, hence this report's focus on data requirements. Ideally, all available, relevant data will be incorporated into the chosen bycatch limitation model. Not only is it important to know what data are available, but the details of such data – confidence in accuracy, ability to create robust estimations from data, *etc*. – should also be considered.

Consider estimations of total removals that are required for models such as RLA: if observer data are driving these estimations, managers must consider their potential for bias and uncertainty. EU legislation, for example, recommends a minimum of five percent coverage of fishing effort by observers.[72] The US recommends 20-30 percent coverage in fisheries with the highest bycatch rates, although US fleets average only one to five percent coverage in practice.[73] Low observer coverage can potentially bias our estimates of total bycatch, though this outcome is not guaranteed.[74] This is relevant not only for setting limits in models that require catch history timelines, but also in ensuring limits are adhered to after they are put in place. An alternative data source to observer coverage is the use of fisher logbooks, but these may not reflect true

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[70] NAMMCO-JCNB Joint Working Group. (2020). *Report of the Joint Working Group Meeting of the NAMMCO Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Working Group*. https://nammco.no/wp-content/uploads/2021/05/final_report_jwg-2020.pdf.
[71] Ministry for Primary Industries (2014).
[72] Bjørge, A., Skern-Mauritzen, M., & Rossman, M. C. (2013). Estimated Bycatch of Harbor Porpoise (*Phocoena phocoena*) in two Coastal Gillnet Fisheries in Norway, 2006-2008. Mitigation and Implications for Conservation. *Biological Conservation, 161*, pp. 164-173. https://doi.org/10.1016/j.biocon.2013.03.009.
[73] *Id*.
[74] Sala et al. (2019).

bycatch rates. NMFS notes that data from logbooks can only be used to obtain minimum estimates of bycatch mortality, rather than total estimates.[75] Managers should consider how to improve bycatch data collection techniques to avoid these issues. Other researchers note that the use of model-based estimates can help diminish uncertainties in data but should not prevent managers from improving survey designs to increase data accuracy.[76]

Data collection should also be considered through the lens of longevity. Most methods outlined above require current data inputs, especially for abundance estimates. In choosing which approach to take, managers should weigh their capacity to continue collecting data in the future. Not only are longevity considerations important for data collection, but also for the fluidity of and relationship between different approaches. While a low-data scenario may call for the use of a precautionary objective, as more data are collected, this approach can shift to PBR and, given time and resource additions, more detailed models that include more information about marine mammal populations. This process can and has occurred within existing models as well. Canada's harp seal management plan and New Zealand's sea lion management plan both use models that are routinely updated with new data, not only to replace existing, older data but also to fill data gaps.[77]

The approaches discussed in this report can both build off each other and be individually strengthened with a focus on scientific research and knowledge accumulation. To prioritize these objectives, it is critical that bycatch limitation approaches are built into larger management plans. In marine resource management and conservation, individual research methods are often not standalone approaches, but rather are one portion of a larger regulatory and management scheme. Obtaining data on a recurring basis can be easier when outlined under a larger, mandatory plan that sets aside resources for population surveys and catch monitoring.

Additionally, the existence of more holistic management schemes helps to create solutions when issues arise around compliance with calculated limits. For example, the critically endangered

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[75] LeBoeuf & Wieting (2016).

[76] Authier, M., Rouby, E., & Macleod, K. (2021). Estimating Cetacean Bycatch From Non-Representative Samples (I): A Simulation Study with Regularized Multilevel Regression and Post-Stratification. *Frontiers in Marine Science, 8*. https://doi.org/10.3389/fmars.2021.719956.

[77] DFO (2020); Ministry for Primary Industries (2014).

Baltic Sea harbor porpoise's annual PBR is less than one individual, which is unattainable if any gillnet fishing occurs in the area.[78] Management plans built around the use of PBR here help stakeholders come together to create solutions to this conservation issue. Management schemes also help ensure resources are allocated to more general compliance monitoring. A calculated bycatch limit is, arguably, only as strong as its enforcement. US PBR sits within the SAR approach, CLA sits within the IWC's proposed RMP, and individual population response models are built into overall fishery management plans and guidelines. Even within the Rule's text, the regulatory requirement for bycatch limit calculations sits amongst several other regulatory and reporting requirements, thus encouraging the creation of marine mammal regulatory schemes within foreign fishery management organizations.

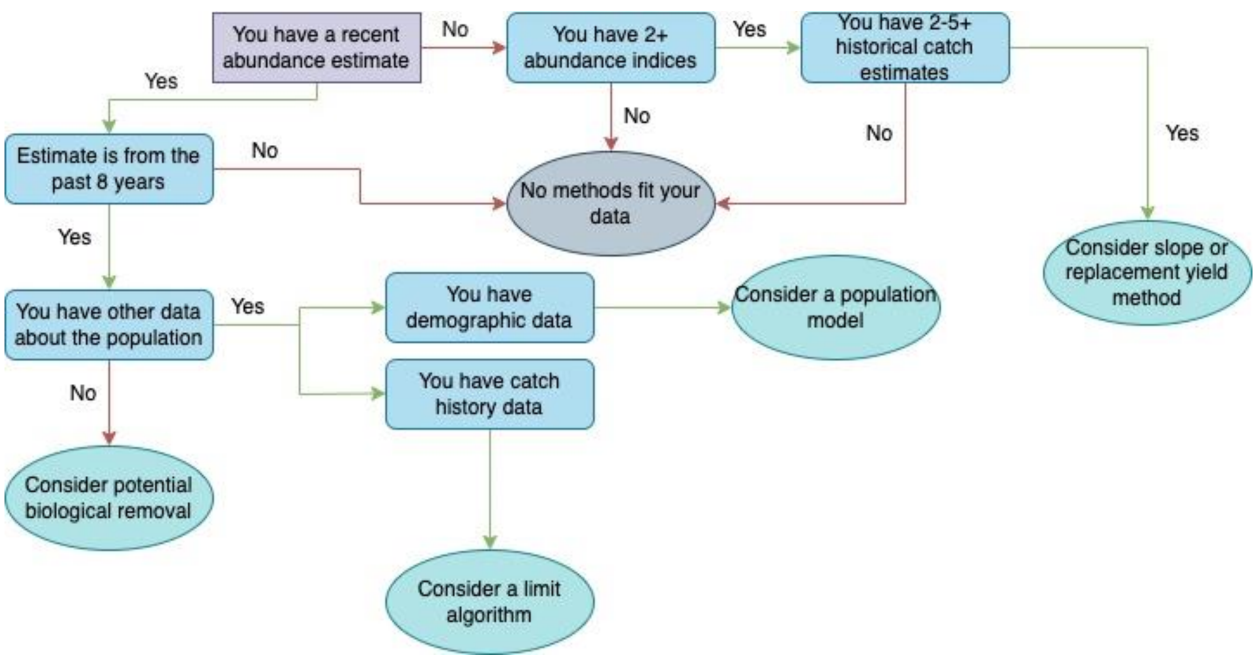

Figure II. Flowchart of data needs for different approaches.

[78] ASCOBANS Advisory Committee. (2021). *Action Points From the 17th Meeting of the Jastarnia Group*. (ASCOBANS/AC26/Doc.3.1b). https://www.ascobans.org/sites/default/files/document/ascobans_ac26_doc3.1b_action-points-jg17.pdf.

X. APPROACHES IN THE CONTEXT OF THE IMPORT PROVISIONS RULE

As previously discussed, the Rule outlines what is required of foreign fisheries who wish to continue exporting fish and fish products to the US. Fisheries must use PBR or a 'comparable' approach to determine bycatch limits for all marine mammals that interact with each fishery. While it is ultimately up to NMFS to define 'comparable' in a legal context, we can speculate about comparability in the context of data. NMFS noted in a Federal Register comment that 'CLA using the conservation objective of ASCOBANS' is an example of a comparable bycatch limit.[79] As CLA requires more data than PBR, this determination was expected. However, it is unclear if NMFS will accept methods using less data than required by the PBR approach, such as the low data methods developed by the Lenfest group that use abundance indices rather than absolute abundance estimates. Additionally, because PBR can be modified to fit different conservation objectives, it is not clear if a heavily modified PBR framework with weak conservation objectives (i.e. low abundance goals relative to Optimum Sustainable Population levels) will be deemed comparable.

Despite this uncertainty, it is possible to conclude what the minimum data requirements are for implementing any existing bycatch limit method. Across all existing methods, minimum data requirements are either an absolute population abundance estimate or abundance indices and bycatch estimates. It seems fair to say that any fishery that lacks these data cannot accurately determine whether bycatch levels are sustainable and thus should not be provided with a comparability determination. Further, many models have data requirements beyond the above minimums, making them less attainable for managers in nations with low capacity for fishery management and marine mammal research.

Additionally, the approaches in this report require additional knowledge before they can be implemented. One critical aspect is the definition and structure of a distinct population or stock.[80] In the US, managers define 'distinct population segments' for SARs, and abundance estimates are performed for each segment.[81] An improper understanding of the structure of populations impacted by a fishery risks setting a single bycatch estimate for multiple populations, which may

[79] National Oceanic and Atmospheric Administration (2016). [Comment 32].
[80] Sala et al. (2019).
[81] Mackay et al (2016); NMFS (2022).

have negative conservation consequences. Thus, an understanding of population structure is needed before any bycatch limit calculation can be made. Further, calculating and applying bycatch limits also requires some understanding of conservation objectives and desired size/health of each marine mammal population. Most methods described in this report are built around an understanding of managers' ultimate conservation goals for each marine mammal population, e.g., as discussed above for PBR and CLA. Finally, as discussed in section IX, data collection is not only important for calculating limits, but also for ensuring they are followed, and monitoring is needed to determine bycatch levels and their comparability to sustainable thresholds. The Rule itself, in fact, also requires exporting fisheries to provide an estimate of total bycatch for marine mammal populations.

The results presented here may also have implications for the preparedness of foreign fisheries in non-Western nations to implement this rule requirement. Nineteen methods for calculating bycatch or targeted catch limits were found. Of these, sixty-three percent were based in European waters/nations (including Greenland). Ten percent were based in North America, with the remainder based in Australia, New Zealand, and one approach from an RFMO, the Inter-American Tropical Tuna Commission (IATTC). Within these 19 methods, 13 were implemented to reduce bycatch, while the remainder were focused on harvests of seals and whales. The geographic breakdown of these methods suggests that it may be difficult for low-income nations to develop bycatch limits in place, as they have little experience doing so. Further, the breakdown of bycatch versus quota limit calculations exhibits the novelty of the Rule. Only a few nations outside of the US (Australia, New Zealand, three European intergovernmental groups, and the IATTC[*]) have implemented a calculated limit-based approach to reducing bycatch occurrences and impacts on marine mammal populations. This Rule has the potential to create a unique approach to multilateral marine mammal protections and to spread this conservation approach to new parts of the world.

XI. CONCLUSION

This report outlines data needs for existing bycatch limit calculation models and discusses how these data requirements are built into broader management and conservation considerations. The

[*] Note, though, that the US is a member of the IATTC.

conclusions contained herein are applicable to multiple stakeholder groups in the world of fisheries and bycatch management. As NMFS makes its comparability findings for exporting fisheries, it should consider what data have been collected by foreign fishery managers. If these data do not meet the minimum requirements outlined here, it will be difficult, if not impossible, for a fishery to meet this regulatory requirement. Environmental NGOs that pushed for the implementation of the Rule will continue to monitor its progress, efficiency, and results, and knowledge about data requirements may help in their advocacy efforts in this context. Finally, foreign fisheries managers can use the conclusions of this report to target and direct funds toward specific research projects that will ensure they have the necessary data in hand to compute proper bycatch limits.

Many researchers consider knowledge of population size and status as essential for proper management of marine mammals.[82] This report underlines the conclusion that effective management approaches require estimates of population size. Data needs are at the heart of creating and implementing conservation actions for marine mammals, and the methods described here highlight this significance and present important conclusions for US and foreign fishery managers and marine mammal conservationists.

[82] Robards et al. (2009); Garner, G. W., Amstrup, S. C., Laake, J. L., Manly, B. F. J., McDonald, L. L., & Robertson, D. G. (1999). Marine Mammal Survey and Assessment Methods. *Proceedings of the Symposium on Surveys, Status, & Trends of Marine Mammal Populations, Balkema, Rotterdam*; Small, R. J., Pendleton, G. W., & Pitcher, K. W. (2003). Trends in Abundance of Alaska Harbor Seals 1983-2001. *Marine Mammal Science, 19*(2), pp. 344-362. **https://doi.org/10.1111/j.1748-7692.2003.tb01113.x**; Taylor, B. L., Wade, P. R., DeMaster, D. P., & Barlow, J. (2000). Incorporating Uncertainty into Management Models for Marine Mammals. *Conservation Biology, 14*(5), pp. 1243-1252. DOI: 10.1046/j.1523-1739.2000.99409.x.

SUPPLEMENTARY MATERIALS

Below are details of each individual method investigated for this report. These are organized by the five categories in the above body text.

I. PBR

Outside of the US, fifteen examples were found of classic and modified PBR methods (both in place and in research journals). Of these, nine targeted pinnipeds, and six targeted cetaceans. Several PBR examples come from intergovernmental organizations and agreements.

The joint Working Group on Harp and Hooded Seals (WGHARP) is a collaborative effort between the International Council for the Exploration of the Sea (ICES), the Northwest Atlantic Fisheries Organization (NAFO), and NAMMCO. This group has historically used PBR to set total allowable catches (TACs) of harp and hooded seals in the Greenland Sea and Northwest Atlantic. The Northwest Atlantic Population of hooded seals is data poor, so the working group uses PBR to assess how many of its individuals can be caught in targeted efforts each year.[83] In this case, pup surveys are used for estimations of population abundance. The Greenland Sea population of harp seals is more data-rich, so the working group uses a more involved abundance estimation process for the PBR formula. In this case, a population dynamics model with population age structure, fecundity rates, and gender breakdown for age sectors is used to obtain a population abundance estimate, which is then inserted into the PBR equation. A second harp seal group uses a simplified population abundance estimate, as it is data poor, and a low recovery factor to set a PBR limit.[84]

ASCOBANS has calculated a PBR limit for the critically endangered population of harbor porpoises in the Baltic Sea as part of its ongoing Jastarnia Plan. This plan focuses on recovery efforts for the Baltic population. With the conservation objective of "restoring the population to 80% [or more of] its carrying capacity", the Jastarnia Group calculated PBR for this population as 0.7 individuals per year.[85] This case shows an interesting, rare example of PBR that is

[83] Zabavnikov et al. (2019).
[84] *Id.*
[85] ASCOABANS Advisory Committee. (2009). *Recovery Plan for Baltic Harbor Porpoises – Jastarnia Plan (Revision).* ASCOBANS/MOP/Doc.7-01 (AC). https://www.ascobans.org/sites/default/files/document/MOP6_7-01_RevisionJastarniaPlan_1.pdf. Jastarnia Group. (2021). *Action Points from the 17th Meeting of the Jastarnia Group*.

essentially unattainable while fishing continues, even with thorough bycatch mitigation plans in place. Another group, the Baltic Marine Environment Protection Commission (HELCOM), assesses marine mammal populations as part of its work in the Baltic Sea and surrounding areas. HELCOM's current plan for assessing the status of the Belt Sea harbor porpoise population includes a modified PBR derived from the US PBR formula and OSPAR's Marine Mammal Expert Group's bycatch work.[86] ASCOBANS noted that though PBR has been calculated and can be put in place, this population requires historical estimates of bycatch data for a comprehensive assessment of its status.[87] This and the case of the Baltic harbor porpoise both exhibit the need for larger management schemes that these bycatch limits are built into.

In 2021, OSPAR's Biodiversity Committee also adopted a similar modified PBR approach for the Northeast Atlantic population of common dolphins.[88] Finally, a combination of PBR and CLA methods were used by two international agreement groups to derive a bycatch limit for harbor porpoises in the European Atlantic. ASCOBANS and the IWC came together at a workshop to create a population dynamics model that drew from PBR and CLA. This model included multiple sources of population abundance data and resulted in a final limit of 1.7% of each harbor porpoise population.[89] This percentage was chosen based on its predicted ability to allow the population to remain at 80% of its carrying capacity in the future.[90] While percentages of populations usually fall under the precautionary objectives category, this percentage derivation required more modeling and math than is used for most precautionary objective setting. There has been some discussion amongst researchers of rethinking this limit, as it was created in 1999, but it is currently still used by managers.[91]

Individual governments also make use of PBR outside of the US. In Scotland, PBR is used to set limits on takes of Scottish populations of gray and harbor seals. This PBR application, however,

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ASCOBANS/AC26/Doc.3.1b. https://www.ascobans.org/sites/default/files/document/ascobans_ac26_doc3.1b_action-points-jg17.pdf.

[86] Coalition Clean Baltic. (2021). *Progress Report on the Conservation Plan for the Harbour Porpoise Population in the Western Baltic, the Belt Sea and the Kattegat 2021.* ASCOBANS/AC26/Inf.3.2. https://www.ascobans.org/sites/default/files/document/ascobans_ac26_inf3.2_progress-report-wbbk-plan_0.pdf.

[87] *Id*.

[88] Authier et al. (2021).

[89] IWC-ASCOBANS Working Group on Harbor Porpoises. (2000).

[90] *Id*.

[91] Hammond et al. (2019).

is primarily for targeted takes during seal control processes in fisheries, rather than incidental bycatch.[92] In Australia, PBR was derived for three low-data species – the short-beaked common dolphin, fur seal, and long-nosed fur seal – in a technical workshop funded through government bycatch research efforts.[93] In this scenario, expert elicitation was used to derive estimates of population abundance for the three species. These estimates were then used in modified PBR formulas. This was the only case of expert elicitation-based data found in this literature review. Managers resorted to this process because of a lack of published abundance estimates, but some invited experts expressed concerns at the workshop and chose not to provide abundance estimates.[94] Finally, the Norwegian Ministry of Fisheries and Coastal Affairs has created two potential approaches for determining TACs of harbor seals, which are hunted in Norway. One of these methods is a modified PBR approach, and the other is the use of a more complex, age-structured model. Because the Ministry must account for both hunting TACs and bycatch removals in its overall number of individuals that can be killed, it currently uses the age-structured model, as this is less conservative so allows for hunting quotas in addition to bycatch removals and because the population is well-studied enough to have the necessary data for this model.[95] For both the modified PBR and age-structured model, the government plans nationwide seal counts every five years (aligning with TACs that are set for five years at a time) and uses land-based seal counts to obtain a minimum population abundance estimate.[96]

Other PBR examples can be found in journal articles and other literature, though they are not implemented by official management groups. Researchers have calculated PBR for the Northeast Atlantic population of common dolphins through the Cetacean Offshore Distribution and Abundance in the European Atlantic (CODA) Project. This PBR was calculated with the conservation objective of having the population remain at 80% of its carrying capacity over 200 years.[97] Australian scientists recently used PBR to calculate bycatch limits for common dolphins

[92] Morris, C., Thompson, D., & Duck, C. (2021). *Provisional Regional PBR Values for Scottish Seals in 2021*. SCOS-BP 20/07. https://www.gov.scot/binaries/content/documents/govscot/publications/map/2018/10/marine-licensing-map-of-seal-management-areas-and-provisional-pbr/documents/seal-licensing-provisional-regional-pbr/seal-licensing-provisional-regional-pbr/govscot%3Adocument/SCOS_BP%2B20_08%2B%2BPBR%2BScotland.pdf.
[93] Mackay et al. (2016).
[94] *Id*.
[95] Ministry of Fisheries and Coastal Affairs. (2010). *Management Plan for Harbor Seals*. https://www.tffk.no/_f/p1/i5199830b-9dbe-444f-a284-b381c5022049/forvaltningsplan-steinkobbe-2.pdf.
[96] *Id*.
[97] Sala et al. (2019).

in Southern Australian fisheries. Due to a lack of abundance estimates for this population, researchers performed aerial transects and mark recapture surveys in this work, in addition to more conservative parameters in the PBR formula.[98] Finally, other researchers have published PBR estimates for common dolphins, harbor porpoises, and bottlenose dolphins in Black Sea waters.[99] Brandon et al. (2016) proposed a tiered PBR system that allows managers to adjust the PBR approach to the amount of data they have access to. In this approach, three tiers are used, with the third and final tier incorporating the most data.[100] Importantly, a tiered approach has managers use more than one population abundance estimate, via the use of weighted averages.

II. Limit Algorithms

As discussed in section IV above, CLA was created for large baleen whales, and the primary users of this approach are whaling nations. In Iceland, NAMMCO's large whale working group provides advice based on CLA for harvests of fin and minke whales. NAMMCO's recent (2017) advice for these species was used to replace its previous interim advice – noted as so because of the use of outdated abundance estimates for these populations (eight and six years old, respectively).[101] For its minke whale calculations, four baseline models were used to project population impacts based on different demographic characteristics and catch scenarios.[102] NAMMCO has also given advice to Norway for its minke whale harvests, using similar CLA simulations and tuning levels as are used for its Iceland advice.[103]

Outside of whaling applications, as noted in the above PBR section, CLA was also used in creating a management model for harbor porpoises. The working group carried out robustness trials using multiple algorithms to find which had the strongest performance.[104] CLA has also been applied to harbor porpoises (though only in theoretical scientific materials and not legitimate management frameworks) in several European water bodies. The EU's Scientific, Technical and Economic Committee for Fisheries (STECF) performed bycatch limit calculations

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[98] Parra, G. J., Bilgmann, K., Peters, K. J., & Möller, L. M. (2021). Abundance and Potential Biological Removal of Common Dolphins Subject to Fishery Impacts in South Australian Waters. *Frontiers in Marine Science 8*. https://doi.org/10.3389/fmars.2021.617075.
[99] Birkun, A., Northridge, S. P., Willsteed, E. A., James, F. A., Kilgour, C., Lander, M., & Fitzgerald, G. D. (2014). Studies for Carrying Out the Common Fisheries Policy: Adverse Fisheries Impacts on Cetacean Populations in the Black Sea. *Final Report to the European Commission, Brussels*.
[100] Brandon et al. (2016).
[101] NAMMCO Scientific Committee Working Group on Assessment. (2017).
[102] *Id*.
[103] *Id*.
[104] IWC-ASCOBANS Working Group on Harbor Porpoises. (2000).

using CLA for harbor porpoise populations in inner Danish waters, the North Sea (multiple populations), the Western Black Sea, in waters west of Britain and Ireland, and in waters in the southwest of France, Portugal, and Spain.[105] These models were created using abundance data from the Small Cetaceans in the North Sea and Adjacent Waters (SCANS II) program. The aforementioned-CODA project data was also used to calculate CLA for common dolphins in the Northeast Atlantic.[106]

RLA, as a more recently created approach, has not been explored or applied to the same extent as other approaches. One group of researchers applied the algorithm to the North Sea population of harbor porpoises, using population abundance data from the most recent SCANS program (SCANS-III).[107] OSPAR's Biodiversity Committee additionally officially adopted the use of RLA for this same harbor porpoise population in 2021.[108] During its original development, RLA included an example case study of this North Sea population.[109] RLA has not been applied to other harbor porpoise or other cetacean populations.

III. Dynamic Population Models

Several governments have implemented more complex population models than those involved in PBR calculations. In New Zealand, the evolution of the models used by the government highlights an important example of how bycatch limit calculation models can change and grow as more data are collected about a population. Currently, a Fishing-Related Mortality Limit (FRML) model is used for setting a threshold for squid fishery kills of Hooker's (also known as New Zealand) sea lions.[110] This model is both species and fishery-specific, requiring data about the sea lion population and the fishery operation. It incorporates population demographic data such as carrying capacity and other age and sex-specific parameters, fishing effort parameters, bycatch estimates, and pup estimates.[111] These parameters are incorporated into a Bayesian

[105] Sala et al. (2019).
[106] *Id*.
[107] Birkun et al. (2014).
[108] Genu et al. (2021).
[109] Hammond et al. (2019).
[110] Ministry for Primary Industries. (2014).
[111] *Id*; Green et al. (2016); Robertson. (2015).

model to determine population size, with further modeling used to test different management scenarios.[112]

However, earlier iterations of the management strategy for sea lion bycatch in squid fisheries were not as data intensive. Prior to FRML, a Maximum Allowable Level of Fishing Related Mortality (MALFIRM) model was used by the New Zealand government. The MALFIRM model was rooted in PBR methodology, using a simpler population model than FRML. This early management decision was based on the data-poor nature of the sea lion population at the time, and the transition to the FRML model was made later on as more population data were collected.[113] Since implementing the FRML model for sea lions, the government has also considered implementing a FRML model for endangered Hector's and Maui dolphins. This proposal is still in its early stages, though, as these dolphin populations are still relatively data-poor compared to the more extensively studied sea lions.[114]

Population viability analysis (PVA) is another more complex modeling system that is used to set bycatch limits. The Australian government uses PVA to set trigger levels for its Southern and Eastern Scalefish and Shark Fishery's (SESSF) bycatch of sea lions. This modeling process includes the use of observer bycatch data and sea lion life history and abundance data.[115] Though this process makes use of available data from both the sea lion population and the fishery, government researchers have noted its limitations, namely that it does not include density dependence (due to a small sample size) and that it includes assumptions about sea lion mortality that introduce new uncertainties into the model.[116]

PVA has also been used in a research context, though not an official management context, on New Zealand sea lion populations. In this work, PVA was used to model past and future population responses to squid fishery bycatch. Results for modeled years in the past were compared to existing real-life data to determine model accuracy.[117] The author of this study also

[112] Ministry for Primary Industries. (2014); Chilvers. (2008).
[113] Chilvers. (2008); Ministry for Primary Industries. (2014).
[114] Ministry for Primary Industries. (2020). *Hector's and Maui Dolphins Threat Management Plan Review*. https://www.mpi.govt.nz/consultations/hectors-and-maui-dolphins-threat-management-plan-review/.
[115] Mackay et al. (2016); Australian Fisheries Management Authority. (2010).
[116] Australian Fisheries Management Authority. (2010).
[117] Chilvers. (2012).

noted that PVA was a viable approach for this particular sea lion population because of its small, isolated nature, and that PVA may not reflect population dynamics as accurately for larger, more dispersed populations.[118] In this modeling process, numerous population indices and demographic parameters were used.

One of the simpler models in this category is a Bayesian model for West Greenland beluga stocks developed by researchers as a theoretical management approach. This model makes use of the available lengthy (30 and 40 years, respectively) time series of both abundance estimates and targeted catch estimates for these whales. The developed model was run under different catch level scenarios, corrected for uncertainties relative to population survey methods, incorporated historical population trends, and was age and sex structured.[119] Results from this approach have implications for beluga population recovery and how it may be impacted by set catch limits.

Total Allowable Catch (TAC) models found during this research project also fell under this category or approaches. TACs are set for targeted catches of marine mammal species, similar to fishery quotas. In the course of this project, three TAC models were found that made use of data-rich, dynamic population models. The first of these models comes from NAMMCO and is used to regulate catches of beluga whales and narwhals. Population models for each species include catch history, abundance estimates, and demographic information such as age of sexual maturation.[120] Specific conservation objectives are input into these models to calculate allowable TACs. Norway also implements TACs for its population of harbor seals. The Norwegian government has two methods for calculating these TACs: through a modified PBR approach (in low-data scenarios, as noted above) and through an age-structured population model.[121] This model requires seal birth rates for different age groups, survival rates, age-structured production rates, and parameter values that represent biological responses and fluctuations of the population

[118] *Id*.
[119] Heide-Jørgensen, M. P., Hansen, R. G., Fossette, S., Nielsen, N. H., Borchers, D. L., & Witting, S. L. (2016). Rebuilding Beluga Stocks in West Greenland. *Animal Conservation 20*(3), pp. 282-293. https://doi.org/10.1111/acv.12315.
[120] NAMMCO. (2021). *Beluga*. https://nammco.no/topics/beluga/; NAMMCO-JCNB Joint Working Group. (2020). *Report of the Joint Working Group Meeting of the NAMMCO Scientific Committee Working Group on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga Scientific Working Group.* https://nammco.no/wp-content/uploads/2021/05/final_report_jwg-2020.pdf.
[121] Norwegian Ministry of Fisheries and Coastal Affairs. (2010). *Management Plan for Harbor Seals*. https://www.tffk.no/_f/p1/i5199830b-9dbe-444f-a284-b381c5022049/forvaltningsplan-steinkobbe-2.pdf.

– many more data than the modified PBR method.[122] Differing TAC levels are then modeled to view population responses and set the final TAC.

The final TAC approach is, alongside New Zealand's sea lion FRML, the most data-intensive model found in this research. In Canada, TACs are set for targeted harvests of harp seals on a three-year (three hunting season) basis. A population model is created that includes catch data, birthing rates, multiple pup production estimates from recurring aerial surveys, and more demographic indicators/data to inform reproduction, survival, and death rates in the population.[123] The most recent model additionally incorporates climate impacts by including expected juvenile seal mortality rates based on shrinking sea ice cover. This population model is used to i) create population reference levels that inform managers of the general status of the population, which impacts how high TACs can be set, and ii) population responses to different harvest levels, which can be age-structured in modeling scenarios.[124] This approach is possible only because the Canadian government has gathered so much information about harp seal populations.

V. Precautionary Objectives

Four examples of precautionary objectives were found, though only one of them is a classic precautionary objective (i.e. set as a percentage of the population). This method is the bycatch limit put forward by ASCOBANS for small cetaceans. ASCOBANS suggests 1% of a population as a 'rule of thumb' limit for small cetacean populations impacted by fishery bycatch.[125] The group has chosen this as a limit to work toward reducing bycatch to or below in data-scarce situations. Though setting the limit as a percent does not require data, knowing what quantitative limit that percent translates to does require a 'best available' abundance estimate.[126] While ASCOBANS's 1.7% limit for harbor porpoise populations is also a fixed percentage limit, it was created, as noted above, through more intensive modeling, rather than a general rule that applies to multiple species, as seen here.

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[122] *Id*.
[123] Canadian Science Advisory Secretariat. (2020). *2019 Status of Northwest Atlantic Harp Seals, Pagophilus Groenlandicus*. Science Advisory Report 2020/020. https://waves-vagues.dfo-mpo.gc.ca/Library/40878478.pdf; NAMMCO (2021). *Harp Seal*. https://nammco.no/topics/harp-seal/#1475844586552-bbd974dc-67bc.
[124] *Id*.
[125] Sala et al. (2019).
[126] *Id*.

In Australia, dolphin species bycatch limits are sometimes set through a maximum interaction rate. This approach does not use percentages of population sizes, instead using a set number of dolphins that can be killed per unit of gear. Currently, this is only used for gillnet interactions with dolphins, and the rate is set as one dolphin per X meters of gillnet used, with X changing each time the management plan is reviewed.[127] Management authorities use information like population abundance data, dolphin interactions with fisheries, and mitigation measure impacts to help inform the maximum interaction rate. In its discussion of this method, the government notes that this is a data-poor population, which prevents the use of more thorough bycatch threshold approaches.

The IATTC also uses a precautionary objective to set bycatch limits for dolphin populations (spotted, spinner, common) interacting with its fisheries, in the form of dolphin mortality limits. These follow a long-term goal of reducing bycatch to zero, achieved by setting limits as a lower percentage of population sizes each year. Currently, the overall number of dolphins that can be killed in IATTC fisheries is set at 5000 individuals (~0.08% of each population) across species and populations.[128] The IATTC also sets per-stock per-year dolphin mortality caps as part of this management framework, which the dolphin mortality limits must be consistent with. These caps are set as a percentage of the population's minimum abundance estimate –between 0.1 and 0.2% of the minimum estimate, with this percentage staying fixed at 0.1% after 2001.[129] Parties to the agreement also decided that this minimum abundance estimate should come from Wade's abundance estimation method for PBR or from a comparable approach.[130]

Finally, a precautionary approach that has been explored in research but is not used in an official capacity comes from Hammill and Stenson, who suggest setting conservation and precautionary reference points for Atlantic seal populations to determine allowable harvest levels. In this

[127] Australian Fisheries Management Authority. (2019). *Gillnet Dolphin Mitigation Strategy: Minimising Dolphin Interactions with Gillnets in the Southern and Eastern Scalefish and Shark Fishery*. https://www.afma.gov.au/sites/default/files/gillnet_dolphin_mitigation_strategy_updated_aug_2019_accessible.pdf.
[128] IATTC. (2009). *Agreement on the International Dolphin Conservation Program (Amended).* https://media.fisheries.noaa.gov/dam-migration/aidcp-amended-oct-2009.pdf; IATTC. (1992). *La Jolla Agreement on the Reduction of Dolphin Mortality in the Eastern Pacific Ocean*. https://www.iattc.org/PDFFiles/AIDCP/_English/AIDCP_La%20Jolla%20Agreement.pdf.
[129] IATTC. (1992).
[130] *Id*.

approach, population data are used to determine reference points that help indicate population status when compared to abundance estimates.[131] Seal populations with an estimated size closer to the lower reference point should have their harvest numbers decreased, as they sit in a more at-risk category.[132]

VI. Alternative Low-Data Methods

The three methods examined by Punt et al. are Depletion-Corrected Average Catch (DCAC), Replacement Yield (RY), and Slope. The DCAC method requires multiple estimates of removals (bycatch mortality) and multiple abundance estimates. While this method suggests the use of at least 20 years of data, it can be tested with five or fewer data points for abundance and bycatch. The RY method requires an estimate of initial population size, an estimate of bycatch mortality, and data on changes in population size. Finally, the Slope method requires multiple bycatch mortality estimates and multiple abundance indices.[133] Across all three methods, Punt et al.'s team note the primary data requirements as bycatch mortality estimates and relative abundance indices. These three methods build on previous work by researchers in fisheries management, with adjustments made for a shift from fish populations to marine mammal populations. After testing these methods with marine mammal data, this research group concluded that DCAC is not a viable method, and that RY and Slope methods involve a heightened number of uncertainties if abundance indices are not updated at least every four years and if time series of bycatch and abundance data are short.[134]

[131] Hammill, M. O. & Stenson, G. B. (2007). Application of the Precautionary Approach and Conservation Reference Points to Management of Atlantic Seals. *ICES Journal of Marine Science, 64*(4), pp. 702-706. https://doi.org/10.1093/icesjms/fsm037.
[132] *Id*.
[133] Punt et al. (2020b).
[134] *Id*.