A Shift Towards Quantitative Cumulative Impact Assessments for Data Poor Marine Mammal Species: A Novel Approach for the Australian Context

Capri D. Jolliffe, Craig R. McPherson, and Brandon Southall

Contents

OPEN ACCESS with major support from JASCO APPLIED SCIENCES

C. D. Jolliffe (✉) · C. R. McPherson
JASCO Applied Sciences, Perth, Australia
e-mail: Capri.jolliffe@jasco.com; Craig.mcpherson@jasco.com

B. Southall
Southall Environmental Associates, Aptos, CA, USA
e-mail: Brandon.southall@sea-inc.net

A. N. Popper et al. (eds.), *The Effects of Noise on Aquatic Life IV*,
https://doi.org/10.1007/978-3-031-94229-7_70-1

Abstract

Marine fauna are vulnerable to a variety of acute and chronic stressors that act across varying spatial and temporal scales. The evaluation of the effect of these stressors requires consideration of the key threats and impact pathways, and the cumulative effect of anthropogenic pressures from all aspects of a project in concert with projects and long-term environmental change. Migratory species, particularly those that migrate across jurisdictional boundaries, may be exposed to pressures that compromise the recovery or health of the population that are not manageable under any one country's legislation. Thus, the evaluation of cumulative impacts in a meaningful manner requires careful consideration of pressures at biologically meaningful spatial and temporal scales. Complex models predicting the population consequence of disturbance are increasingly being used to understand the potential significance of anthropogenic pressures on populations. While incredibly valuable, information to parametrize these models are not available for many species and populations. This chapter presents a semi-quantitative framework for the prediction of cumulative impacts on migratory marine mammal populations, with examples of how this may be applied using the Australian legislative and environmental context.

Keywords

Cumulative impacts · Environmental impact assessment · Cumulative effects · Environmental regulation · Marine species · Species management · Environmental management

Introduction

Marine fauna may be vulnerable to a variety of acute and chronic stressors acting across varying spatial and temporal scales. Effective management of the cumulative effect of stressors on protected species requires an understanding of key threats and impact pathways and robust cumulative impact assessment at a biologically meaningful spatial and temporal scale. The range over which impacts should be considered is contingent on species and environmental context. Migratory fauna, particularly those that cross jurisdictional boundaries, may be exposed to pressures that compromise the recovery or health of the population that are not manageable under any one country's legislation. However, understanding the inherent stress on a population across its full migratory range within and beyond jurisdictional boundaries is a key consideration in the meaningful evaluation of cumulative impacts.

In the context of marine environmental impact assessment, anthropogenic noise is one of the most pervasive and widespread pressures resulting from industrial activities. Marine species experience acoustic stimuli not in isolation but in combination with other environmental stressors (e.g., climate change, chemical ocean pollution, habitat modification, food depletion) with potentially detrimental effects

(Kappel 2005, Halpern et al. 2008). These stressors can directly interact with each other in complex ways, i.e., they can be potentiating (additive or multiplicative), counteracting (subtractive or divisive), or non-interactive (see: National Academies of Sciences 2016). Many pressures affecting marine animals are themselves affected by larger-scale ecological drivers. For example, global climate change is an ecological driver changing the marine environment and exposing marine life to the stressors of warming, ocean acidification, and shifting human activities. Similarly, the distribution of predators, prey, and competitors of marine mammals are being affected by ecological interactions of these stressors (National Academies of Sciences 2016). With regard to marine animals, cumulative and additive effects from multiple sound sources as well as other stressors have been identified as important parameters for the assessment of human impacts (NRC 2005, Williams et al. 2015, Ellison et al. 2016b, Southall et al. 2019, Tyack et al. 2022, Southall et al. 2023).

Predicting Population Level Effects

Potential noise-induced effects critically depend on the spatial, temporal, spectral, and contextual nature of the noise in relation to auditory and behavioral sensitivity and the spatio-temporal distribution of species in question (Southall 2021). Developing a framework for population level effects of noise-induced disturbance requires integrative assessments informed by empirical measures of response and how responses manifest in the context of differing vital rates such as foraging, reproduction, and survival. Population consequence of disturbance (PCOD) and associated models (e.g., PCAD) provide valuable and realistic insights into the possible effects and significance of disturbance to populations of marine mammal species, by combining physiological and behavioral information to predict the population level effect of disturbances. However, their application is limited to populations for which physiological, biological and ecological information is known. This information is lacking for many species and populations leaving too many unknowns for models to be run. Thus, there is the need for a cumulative impact assessment approach that is general enough to be applied to populations and species for which little data exist.

Risk Assessment Framework

To provide a practical balance and an approach which can be readily implemented using currently available information, the Risk Assessment Framework (RAF; Southall et al. 2023) was developed in the United States of America (USA) and incorporates the complexity of relevant parameters to assess the consequences of acute and aggregate noise exposure to marine mammals on a population level. In this context, acute can be defined as the sound associated with one discrete activity while aggregate is the combined sound of multiple activities. The approach is scalable and can be quantified independently for selected species, period (e.g., months, years), and geographical areas based on the interaction of noise-generating activities, and species distribution patterns. The RAF presumes that the magnitude of adverse impacts from disturbance are directly related to the spectral, spatial and temporal interaction of noise and species characteristics. Consequently, it can be applied to assess the risk and potential consequences of behavioral and physical effects of noise exposure to marine mammals. The relative magnitude and risk of potential impacts is evaluated within a biological significance framework that incorporates key species-specific parameters such as population status, distribution patterns, adaptability and variability, and uncertainty in these and other parameters.

Applicability to Legislative Frameworks

The cumulative impact framework presented here is adapted for the Australian context from the Southall et al. (2023) approach to make it more appropriate for use on wide ranging, data deficient species, and simplified to improve integration into EIA processes. This has the benefit of addressing site and seasonal specific scenarios, other stressors and spatial-temporal-spectral intersections of animals and anthropogenic activities. The assessment of cumulative effects will vary between jurisdictions and while it is not possible to develop a cumulative effects framework to directly inform every legislative context, this framework provides a generalized approach that can be adapted for different regulatory contexts.

Within Australia, threatened species are listed under the Environmental Protection and Biodiversity Conservation Act 2001 (EPBC Act). Species can be listed as migratory, marine, cetacean, and/or threatened. Some marine mammal species, typically those listed as endangered that have known and predictable occurrences in Australian waters, have species specific Recovery Plans, also called Conservation Management Plans. These Recovery Plans are legislative instruments that apply under the EPBC Act and set out specific actions and management objectives that apply to the species.

For species with Recovery Plans, Biologically Important Areas (BIAs) have been defined that provide important information to species managers, environmental regulators and environmental impact assessment practitioners to inform the evaluation of risks of impact to the species. Australia also has defined areas referred to as Key Ecological Features (KEFs), which are elements of the Commonwealth marine environment that are of regional importance for either a region’s biodiversity or its ecosystem function and integrity.

The cumulative impact assessment approach detailed in this chapter focuses on marine mammals, but could also be extended to marine reptiles and marine avifauna. Fish, avifauna and marine invertebrates were not considered during its development as the focus for cumulative effects assessments in the Australian marine context is typically endangered marine mammals. Further, there remain considerable scientific uncertainties in the prediction and management of impacts to fish, avifauna and marine invertebrates that would further limit the ability of the framework, in its current form, to be readily applied at present.

Terminology

In the context of this risk assessment framework, the following terms are used:

Acute Assessment: An acute assessment is the assessment of a single activity or operation.

Aggregate Assessment: Multiple acute activities for either a single operation, sequentially or concurrently, or multiple acute activities across different operations/ proponents in a localized area occurring concurrently.

Cumulative Assessment: Combination of aggregate activities within a zone and also within the entire migratory region for migratory marine mammals.

Environment Which May Be Affected (EMBA): The EMBA encompasses not only the development envelope but the surrounding environment that may be impacted during construction or operation.

Assessment Zone (Zone): A square zone which is suitably large that it captures both the potential effects of the activity, but also considers the influences of other regional activities via the pressure index.

Methods

Cumulative Impact Assessment Framework

The framework is an iterative process that considers species context through an assessment of vulnerability and exposure to baseline stressors (Fig. 1). The potential cumulative impact of the new pressure or activity is then calculated by evaluating the acute impact of the individual activity/pressure in aggregate with concurrent and reasonably foreseeable activities in a spatially limited zone.

The first stage of the process is an assessment of the species vulnerability to impacts (Vulnerability Index) considering exposure to baseline pressures across a species/population's full migratory range, as well as the spatial overlap of offshore industries with key areas for critical behaviors. The second stage is assessing activity impacts (Exposure Index), which requires an evaluation of the impact of the proposed activity, as well as the aggregate of concurrent activities/pressures in the region of the activity (Fig. 1).

Both a "standard" and a "simplified" approach are provided for the evaluation of cumulative impacts to enable application to all environmental impact assessments irrespective of whether complex underwater noise modelling has been undertaken. For activities that are of a very small nature and scale, it may be appropriate to utilize the simplified approach. The principles of both approaches are the same, the only difference is that in the simplified approach surrogate ranges for different activity types are provided to enable cumulative impact assessment even in the absence of modelled effect ranges. These surrogate ranges may also be utilized during the standard approach for the evaluation of concurrent and sequential activities for which information regarding effect ranges is not available.

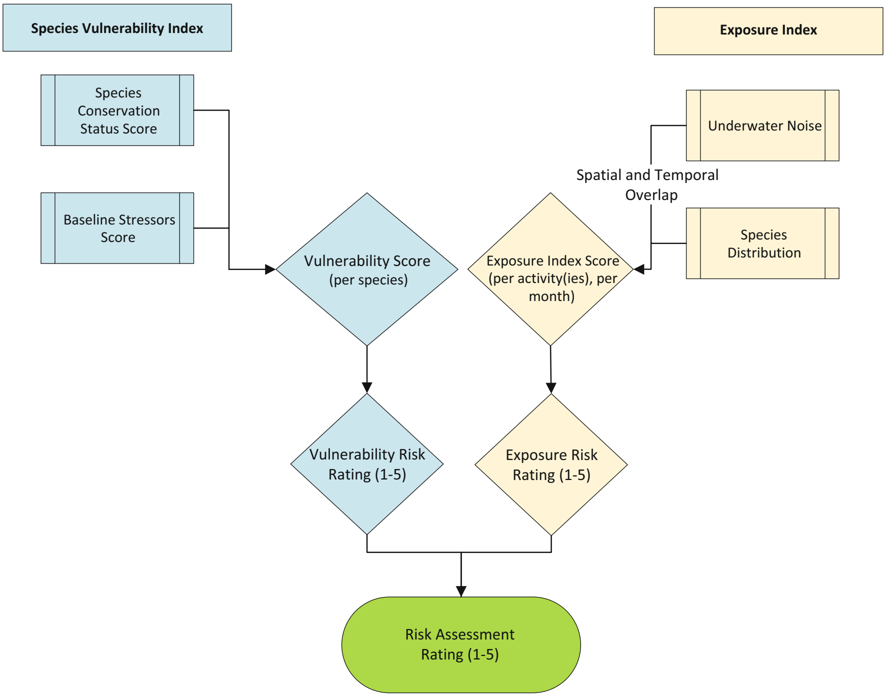

Fig. 1 Cumulative impact assessment framework

Spatial Scales

When considering a species or population's vulnerability to cumulative impacts one should consider the range of threats they are exposed to throughout their migratory range, as the migratory range of a species is generally correlated to their ecology and biological cycles. Spatially defined areas within which species are known to undertake critical behaviors are important context for informing cumulative effects assessments. In this framework, the calculation of species baseline stressors should be undertaken across the full migratory range of the species aligned with any identified habitat(s).

The consideration of impacts (thus the *Exposure Index* calculation) from multiple aspects of a single activity, as well as the aggregate impacts from multiple concurrent activities within a region requires a separate meaningful spatial scale for assessment to be applied. Dependent on the approach taken for the calculation (e.g., standard or simplified approach) the scale of this assessment is intended to be relevant for the potential extent of noise induced impacts and risks that may overlap for activities within a particular area.

For the standard approach, a square zone should be defined that is suitably large that it captures both the potential effects of the activity but also considers the influences of other regional activities via the pressure index. This zone could range from 10's to 1000's of square kilometers, depending upon the activity and the species which occur within the region. It is recommended that the extent of the EMBA, based on the larger of the ranges/areas for either the species-specific behavioral response threshold or the TTS extents, be at least doubled and then translated onto a square grid. The resulting area, which is used for the cumulative effects assessment, is referred to as the *Assessment Zone* (or just Zone). For the simplified approach a square assessment zone of a minimum of 100 km × 100 km (defined as a 50 km range from the center of the activity) should be utilized. A 10 km grid based upon the Geocentric Datum of Australia 2020 (GDA2020) is then overlaid onto this Assessment Zone. Aligning the grid with the GDA020 allows for consistent application across adjacent and overlapping *Assessment Zones* to assist in regional assessments. If in future, ambient noise and masking is included in the vulnerability assessment, this also may be able to be conducted on the smaller grid cell basis to account for the spatial variation in ambient noise.

Species Vulnerability Rating

A total species-specific vulnerability rating is determined for the Australian context based on two scoring categories:

- Species conservation status/listing status score (*listing score*)
- Existing environmental and anthropogenic stressors throughout migratory range (*baseline stressors score*)

Total index scores resulting from a structured assessment of a factor's sub-elements are combined to determine an overall vulnerability risk rating score for each species-area-time disturbance scenario. The maximum total species-specific vulnerability score is 23, with a five-point vulnerability rating determined as a proportion of this maximum score.

Species Statutory Conservation Status Score

In Australia information about population status, trends and size is not consistently available, and therefore the population status for each species is determined using the single highest EPBC Act Listing Status category as detailed in the Species Profile and Threats (SPRAT) database (Table 1). In other jurisdictions, the IUCN Red list may provide a valuable source of information as to a species listing status.

Table 1 Species listing score

Species listing status	Score (max 5)
Cetacean and/or marine spp. (i.e., not listed threatened/migratory), OR IUCN least concern	1
Listed threatened (vulnerable, migratory, conservation dependent), OR IUCN near threatened	3
Listed threatened (critically endangered or endangered)	5

Table 2 Baseline stressors score

Baseline stressors elements	Score (max 18)
Chronic anthropogenic sound: Species subject to variable levels of current or known future chronic anthropogenic sound within the full migratory range (i.e., dense or overlapping concentrations of industrial activity):	Maximum possible of 5
Shipping lanes/port operation	1
Areas of regular seismic surveys (once every 3 years)	1
Sonar testing ranges	1
Offshore windfarm areas	1
Oil and gas infrastructure	1
Migratory range overlap: Estimated overlap with anthropogenic activities in all critical areas (e.g., HCTS, BIAs, key habitat, and KEFs) on species across entire migratory range:	Maximum possible of 3
High probability (>85%)	3
Medium probability (25–75%)	2
Low probability (<25%)	1
Population pressures within full migratory range:	Maximum possible of 10
Climate change/sea level rise	1
Direct take	3
Overharvesting of prey	2
Marine debris/entanglement risk	1
Intensive marine aquaculture	1
Vessel strike	1
Habitat loss (including declines in the quality of habitat)	1

Existing Environmental and Anthropogenic Stressors

The consideration of existing environmental and/or human stressors already placing pressure on a species prior to the specified potential disturbance is essential, and this has been a key element of risk assessment frameworks since their early stages (Ellison et al. 2016a).

The stressors listed in Table 2 consider the relative levels of all types of ongoing human activity, which consider existing current and likely future uses, the existence and severity of biological (non-anthropogenic) risk factors such as disease, climate change or nutritional stress, and migratory range. The assessment of these stressors is referred to as the "*baseline stressors score*."

Consideration of the spatial overlap with sources of potential disturbance to determine vulnerability is considered on a whole of migratory range basis, which allows this factor within the risk framework to stay general and not conflict with detailed environmental assessments for specific activities.

The *baseline stressors score* factor is applied on an annual basis given the nature of the associated stressors and typical reporting of data for each, and includes a maximum possible score of 18.

Total Vulnerability Score Rating Method

A *Vulnerability Score* is the percentage of the aggregate of the three scores relative to the maximum possible score (32). Vulnerability scores are assigned a relative risk probability and a vulnerability rating using quintiles (Table 3; as in Southall et al. 2023). It is important to note that these ratings are intended to represent relative and realistic values for distinct species, time periods, and areas considered within the same context. Consequently, relative terms (e.g., lowest, highest) are used rather than absolute terms that might become misused to compare risks between very different combinations of species, time, area, and context, which is not the intention here.

The *Vulnerability Score* is presented spatially by 10 km grid cells based upon an understanding of the distribution of a species. The *Vulnerability Score* is calculated per species per year per grid cell per Zone.

Exposure Severity

As with the vulnerability score, exposure severity calculations here were adapted from approaches presented in Southall et al. (2023) for the Australian context. The exposure severity index should be calculated within the *Assessment Zone*. All aspects of the project being assessed should be calculated along with all current and reasonably foreseeable activities that may occur within that range. The exposure severity is calculated monthly to enable consideration of shorter duration acute stressors such as seismic surveys and construction activities. It also enables

Table 3 Vulnerability score: Normalized species-, time-, area-, and context-specific vulnerability score and associated risk probability and vulnerability rating

Total vulnerability score (from all factors)	Total risk probability (% of total possible)	Relative vulnerability risk rating
>25	80–100	Highest (5)
19–24	60–79	High (4)
13–18	40–59	Moderate (3)
7–12	20–39	Low (2)
0–6	0–19	Lowest (1)

consideration of temporal periods of presence of marine mammals. Monthly categorization or presence or absence is binary, thus even 1 day of presence of either a stressor or marine mammal species within a month means presence in that month is counted. It is possible that the temporal scale over which this is calculated could be altered to reflect cumulative impact risk over an entire migratory leg, or for an entire year where species are resident and stressors are consistent, for example, long term operations as opposed to acute activities such as petroleum exploration and construction.

The *Exposure Index* (EI) includes an *Activity Index* normalized by habitat availability and characterizing the temporal and spatial extent of potential impact in relation to species-specific distribution and relevant effect thresholds.

The species-specific *Exposure Index* is calculated across all BIAs, KEFs, or defined area of high ecological value and is applicable to all such features within a Zone monthly.

Activity Index

The *Activity Index* used here is composed of two discrete terms, $\mathrm{AI}_{\mathrm{spatial}}$ and $\mathrm{AI}_{\mathrm{temporal}}$, that quantify the spatial and temporal activity. The spatial activity index ($\mathrm{AI}_{\mathrm{spatial}}$) component (units: km^2) is derived from the spatial area within which the received level from a known activity is thought or known to be high enough to elicit a species-specific behavioral response OR to induce TTS, the larger of the two ranges/areas must be used.

The spatial activity index is only calculated for the area of overlap between critical life stage BIAs (calving, resting, reproduction, foraging, and migration) or the relevant KEFs for a species within the Zone(s) the activity is in.

For static sources:

$$\mathrm{AI}_{\mathrm{spatial}} = A_{\mathrm{Ensonfied}} \times N_{\mathrm{t}} \ \left(\mathrm{km}^2\right)$$

where:

- $A_{\mathrm{Ensonfied}}$ is the area ensonified per day within the BIA/KEFs within the Zone(s) ensonified by the activities over the behavioral response threshold or TTS (based upon the maximum range to isopleth (R_{max})).
- N_{t} is a daily binary metric of activity defined for different activities, where 1 is "activity present," and 0 is absent.

For mobile sources:

$\mathrm{AI}_{\mathrm{spatial}}$ is calculated for the activity occurring within the BIA/KEFs within the Zone(s) and period, by looking at the area ensonified by the translocation of the source along the actual or nominal vessel path over a specific period of time (hour, day, or month) which will be scaled to a month. If the source is approximately stationary, or operating within a restricted area, the static source approach should be applied.

If the distance to behavioral threshold is greater than that to TTS, a simplistic calculation could be:

$$AI_{spatial} = 2 \times R_{max} \times S_V \times T_V$$

where:

- R_{max} is the maximum range to threshold (km).
- S_V is the average speed of a vessel (km/hr) within the defined area.
- T_V is the average length of time of a vessel trip (hours).

Temporal activity index ($AI_{temporal}$) represents the percentage of days that disturbance will occur within a specific time period, calculated for each type of activity for each period within which the activity occurs.

Static sources/operations:

$$AI_{temporal} = N_{td}/N_d$$

where:

- N_{td} is the total number of days of activity per month.
- N_d is the total number of days in the month being evaluated.

For mobile sources:

$$AI_{temporal} = N_V/N_d$$

where:

- N_V is the number of days of the month in which a vessel trip occurs.
- N_d is the total number of days in the month being evaluated.

Exposure Index

The *Exposure Index* considers the *Activity Index* in association with the likely area of habitat use for the species. This is determined based upon known areas within which animals undertake certain behaviors or the suitability of habitat as defined by spatial layers available in databases such as the Species Profile and Threats Database (SPRAT) or other reliable sources. Within the Australian context, BIAs are an appropriate layer to use; however, where these are not available, other spatial layers such as important marine mammal areas (IMMAs) or similar may be used. The

Table 4 Exposure index scale

EI or $EI_{aggregate}$ value	EI relative risk rating
>24	Highest (5)
20–24	High (4)
14–19	Moderate (3)
9–13	Low (2)
0–8	Lowest (1)

scaling factor is determined by the overlap between $AI_{spatial}$ and the spatially defined area of habitat use, or the relevant KEFs for a species within the Zone(s), normalized by the area of that same feature within the Zone.

$$EI = \frac{AI_{spatiol}}{OverlappedFeature} \times AI_{temporal} \times 100$$

The *Aggregate Exposure Index* ($EI_{aggregate}$) is the assessment of the combined *Exposure Indices* for a single proponent/activity along with the estimated *Exposure Indices* for multiple proponents/activities for each defined period (a month).

$$EI_{aggregate} = \Sigma \text{Sources EI}$$

The *standard* assessment approach for the *Aggregate Exposure Index* is to use project specific (modelled) footprints to calculate the acute *Exposure Index*, and 10 km grid cells (as described in the Spatial Scales, Page 6) to represent the spatial extent of effects from other activities within the Zone. The *simplistic* approach is to use 10 km grid cells for both project specific and other proponent activities.

The *Exposure Index* (Table 4) is a non-dimensional value related to the potential exposure for species within a specific BIA or KEF within a Zone, during which activities occur for a specified period based upon spatial distributions and habitat use.

Integrated, Species-Specific Risk Assessment Rating

The final stage in the process is to combine the risk assessments from the vulnerability assessment with that from the exposure severity. The *Vulnerability Score* is calculated per species per month per grid cell per Zone, and the *Exposure Index* is calculated per month for the section of a BIA or KEF within the Zone. The two scores can be combined spatially for each individual grid cell within each Zone. If a grid cell is partially overlapped by a BIA or KEF, then the entire grid cell is within the feature for the intent of this assessment.

The Aggregate Exposure Index from all activities within the Zone for the time period of interest is then calculated using information available in public submissions such as referrals, EIAs, EES's, Environment Plans or Offshore Project Proposals. Where information on predicted effect ranges from concurrent and sequential activities is not available, the surrogate ranges presented in Table 5 should be utilized.

Table 5 Surrogate impact ranges for common offshore activities for low-frequency cetaceans on the north-west shelf

Activity type	Impact range (km)	
	TTS (based on 24 hours sound exposure level)	Behavioral response
Seismic	**80**	15 km
Drilling (including resupply)	3	**15 km**
Geophysical/geotechnical survey	**1**	0.5 km
Pipelay	4	**15 km**
Rock dumping	0.25	**4 km**
Dredging	1	**5 km**
Shipping lane	2	**5 km**
Oil and gas platform	5	**5 km**

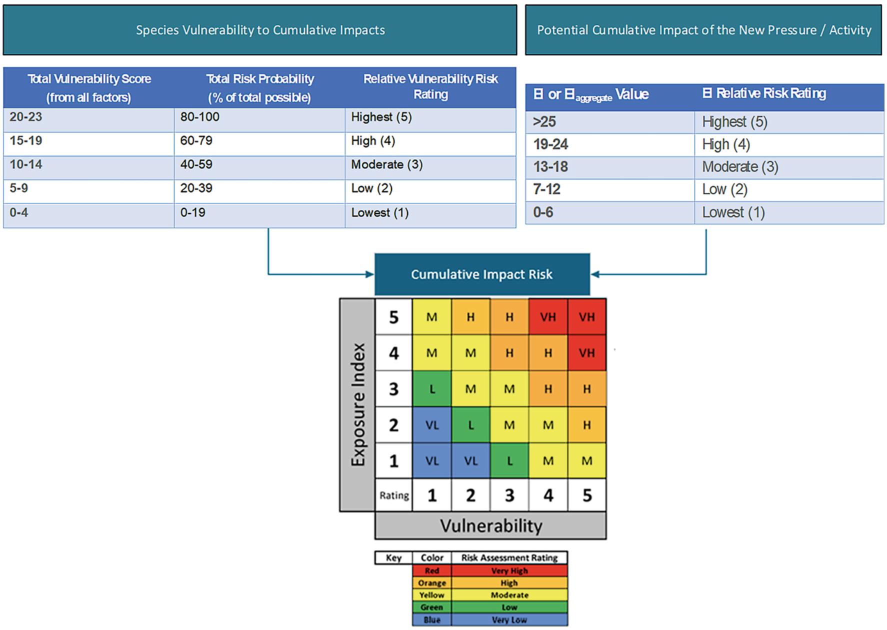

Fig. 2 Risk assessment rating matrix based upon species-specific and scenario-specific vulnerability and exposure index rating scores, similar to Southall et al. (2023)

A summary of the proposed Risk Assessment Process is provided in Fig. 2. The cumulative risk rating for the activity is determined by inputting the Exposure Index and the Species Vulnerability Index into the Cumulative Risk Matrix (Fig. 2). This rating applies to the time period for which the exposure Index was calculated (e.g., monthly, annually, migratory period).

Discussion

As anthropogenic pressures continue to increase, so too does the importance of cumulative environmental impact assessments. This is particularly the case in the marine environment, where many species, particularly marine mammals are wide ranging. While many studies into the effects of anthropogenic pressures on marine life are undertaken in relatively controlled settings, the reality is that the effects of any one pressure do not act in isolation, but rather in concert with the range of pressures experienced by the animal throughout its range. When considering population management, the reproductive output of an animal is inherently linked to energetic budgets. A reduction in energy intake or increase in energy expenditure can have the effect of increasing the reproductive interval of an animal and thus slowing population growth rates. The marine environment is highly dynamic and foraging opportunities for many populations are temporally and spatially limited and may be highly variable between years. Thus, the resilience of an animal to pressures and disturbance, and the potential for impacts on reproductive output will be influenced by the availability of resources throughout the migratory range, as well as the significance of any previous disturbances the animal has experienced.

The cumulative impact assessment here provides a semi-quantitative framework for the evaluation of cumulative impacts to marine mammals, with a focus on underwater noise, that is sensitive to environmental context and applicable to species for which there is not enough information to inform quantitative population consequence of disturbance modelling. The framework is designed to be used in environmental impact assessment and enable informed decision making by regulators and species managers. By allowing for the consideration of baseline pressures on a population that may occur across the species migratory range but be outside of the regulatory jurisdiction of the decision-making authority, the framework provides a realistic and nuanced approach that is sensitive to species context.

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

References

[NRC] National Research Council (US) (2005) Marine mammal populations and ocean noise: determining when ocean noise causes biologically significant effects. National Academy Press, Washington, DC. https://nap.nationalacademies.org/catalog/11147/marine-mammal-populations-and-ocean-noise-determining-when-noise-causes

Ellison WT, Clark CW, Mann DA, Southall BL, Tollit DJ (2016a) A risk assessment framework to assess the biological significance of noise exposure on marine mammals. In: Poster presented at the 21st conference on the biology of marine mammals, San Francisco. http://sea-inc.net/wp-content/uploads/2016/01/EWG-Framework_SMM-poster.jpg

Ellison WT, Racca R, Clark CW, Streever B, Frankel AS, Fleishman E, Angliss RP, Berger J, Ketten DR et al (2016b) Modeling the aggregated exposure and responses of bowhead whales *Balaena mysticetus* to multiple sources of anthropogenic underwater sound. Endanger Species Res 30: 95–108. https://doi.org/10.3354/esr00727

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C et al (2008) A global map of human impact on marine ecosystems. Science 319(5865): 948–952. https://doi.org/10.1126/science.1149345

Kappel CV (2005) Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species. Front Ecol Environ 3(5):275–282. https://doi.org/10.1890/1540-9295(2005)003[0275:LPOTPT]2.0.CO;2

National Academies of Sciences, Engineering, and Medicine (2016) Approaches to understanding the cumulative effects of stressors on marine mammals. National Academies Press, Washington, DC, p 134. https://doi.org/10.17226/23479

Southall BL (2021) Evolutions in Marine Mammal Noise Exposure Criteria. Acoustics Today 17(2):52–60. https://doi.org/10.1121/AT.2021.17.2.52

Southall BL, Finneran JJ, Reichmuth CJ, Nachtigall PE, Ketten DR, Bowles AE, Ellison WT, Nowacek DP, Tyack PL (2019) Errata: marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. Aquat Mamm 45(5):569–572. https://doi.org/10.1578/AM.45.5.2019.569

Southall BL, Tollit D, Amaral J, Clark CW, Ellison WT (2023) Managing human activity and marine mammals: a biologically based, relativistic risk assessment framework. Front Mar Sci 10. https://www.frontiersin.org/articles/10.3389/fmars.2023.1090132

Tyack PL, Thomas L, Costa DP, Hall AJ, Harris CM, Harwood J, Kraus SD, Miller PJO, Moore M et al (2022) Managing the effects of multiple stressors on wildlife populations in their ecosystems: developing a cumulative risk approach. Proc Biol Sci 289(1987):20222058. https://royalsocietypublishing.org/doi/abs/10.1098/rspb.2022.2058

Williams R, Wright AJ, Ashe E, Blight LK, Bruintjes R, Canessa R, Clark CW, Cullis-Suzuki S, Dakin DT et al (2015) Impacts of anthropogenic noise on marine life: publication patterns, new discoveries, and future directions in research and management. Ocean Coast Manag 115:17–24. https://doi.org/10.1016/j.ocecoaman.2015.05.021