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# Gauging allowable harm limits to cumulative, sub-lethal effects of human activities on wildlife: A case-study approach using two whale populations

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ABSTRACT

As sublethal human pressures on marine wildlife and their habitats increase and interact in complex ways, there is a pressing need for methods to quantify cumulative impacts of these stressors on populations, and policy decisions about allowable harm limits. Few studies quantify population consequences of individual stressors, and fewer quantify synergistic effects. Incorporating all sources of uncertainty can cause predictions to span the range from negligible to catastrophic. Two places were identified to bound this problem through energetic mechanisms that reduce prey available to individuals. First, the US Marine Mammal Protection Act's Potential Biological Removal (PBR) equation was used as a placeholder allowable harm limit to represent the number of animals that can be removed annually without depleting a population below agreed-upon management targets. That rephrased the research question from, "How big could cumulative impacts be?" to "How big would cumulative impacts have to be to exceed an agreed-upon threshold?" Secondly, two data-rich case studies, namely Gulf of Maine humpback and northeast Pacific resident killer whales, were used as examples to parameterize the weakest link, namely between prey availability and demography. Given no additional information, the model predicted that human activities need only reduce prey available to the killer whale population by ~10% to cause a population-level take, through reduced fecundity and/or survival, equivalent to PBR. By contrast, in the humpback population, reduction in prey availability of ~50% was needed to cause a similar, PBR-sized effect. The paper describes an approach – results are merely illustrative. The two case studies differ in prey specialization, life history, and, no doubt, proximity to carrying capacity. This method of inverting the problem refocuses discussions around what the level of prey depletion – via competition with commercial fisheries, displacement from feeding areas through noise-generating activities, or acoustic masking of signals used to detect prey – would have to occur to exceed allowable harm limits set for lethal takes in fisheries or other, more easily quantifiable, human activities.



## 1. Introduction

Pressing challenges in wildlife conservation and natural resource management include the need for research methods to quantify cumulative impacts of both lethal and sub-lethal stressors on impacted populations, and policy decisions about allowable harm limits [1]. As direct and indirect human impacts on animal populations grow (e.g., via habitat degradation; displacement from important habitats; competition with fishing for prey species; bycatch in fisheries; or pollution, including chemical and noise pollution), guidance is needed to identify reference points and prioritize mitigation measures before declines become irreversible [2,3]. Previous attempts to quantify cumulative impacts of anthropogenic activities have faced a common set of problems [4,5]. Few studies quantify population consequences of individual stressors, and fewer still quantify synergistic effects [6]. Incorporating all sources of uncertainty can cause predictions with such large confidence intervals as to become practically useless in real-world decision-making. Given these difficulties, it is no surprise that cumulative impacts are poorly handled in environmental assessments and impact assessments [7].

Much progress has been made in fundamental research to develop tools that can ultimately predict population consequences of

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cumulative impacts of multiple sublethal stressors, but current policies set standards that science is poorly equipped to reach. Consider exposure of marine mammals to ocean noise. The US National Environmental Policy Act requires that a judgement call be made regarding whether a proposed project will cause a "negligible" effect [8], which implies an ability to relate the number of marine mammal "takes" relative to population size. Conceptually, this standard is similar to the way other statutes (e.g., US Marine Mammal Protection Act) assess sustainability of bycatch of marine mammals in fisheries [9], except that (a) the term "negligible" has a clearly defined meaning in the context of bycatch under MMPA, and (b) numbers are vastly harder to estimate when dealing with many cryptic, sublethal stressors than counting by-caught animals in well-monitored fisheries. Given the rapid growth of human populations and economies, and resulting industrialization, simple decision-support tools and guidance are needed urgently [5].

To date, efforts to quantify cumulative impacts of multiple sublethal stressors on marine mammal populations fall short of estimating population consequences in absolute terms. This is not a criticism of the science. The task at hand is extremely complex; it may be unreasonable to set policies that hinge on an ability to quantify whether cumulative human impacts on a population, let alone an ecosystem, are negligible. Emerging techniques are heading in that direction, but so far, cumulative human impacts models tend to stop at the point of conceptual frameworks [10] or decision-support tools to prioritize which stressors may be most important in a system [11]. Newer methods are combining quantitative, qualitative and expert-driven models to consider relative magnitude and direction of various anthropogenic threats [12], and a number of studies have used spatially explicit methods to map how various threats are superimposed [13,14].

Recent progress made in understanding how multiple sublethal stressors interact is impressive, but in order to make that progress, some important simplifying assumptions have had to be made, including *inter alia*: the assumption that all stressor layers are of roughly equal importance; subjective decisions in how to put different kinds of stressors in the same currency (i.e., how to normalize them); an untenable or untested assumption that stressors combine in a linear way; an untenable or untested assumption that species or ecosystems respond to individual and cumulative stressors in a linear way; and reliance on expert judgement in how to weight vulnerability of species or ecosystems to various stressors [15]. Simplifying assumptions about how to combine multiple stressors are particularly important. Cumulative impacts can be additive, synergistic or antagonistic (i.e., compensatory) [16]. In the absence of methods to quantify effects one expects to be synergistic (i.e., that the whole should be greater than the sum of its parts), many methods simply sum individual stressors in an additive way [15].

As marine ecologists and statisticians develop increasingly sophisticated methods to estimate absolute numbers of individuals in a population that may be harmed or killed by the cumulative effect of sublethal injuries (e.g., [17]), a number of applied methods are underway to elide some of the more data-sparse steps in that process to generate rules of thumb about whether a particular activity or development is likely to cause greater than negligible effects. One such rule of thumb relates to the time it takes a marine community to recover from a given perturbation [18], which was used to gauge retrospectively the cumulative impacts arising from two alternative fishing methods. Although simplification necessitates loss of detail, it may be logistically impossible (or ethically unacceptable) to measure whether every pairwise combination of effects combine in a linear or nonlinear way [19] and it may never be possible to predict synergistic effects of all possible combinations of multiple stressors. Even if such an exercise were possible, the low precision on any prediction means that a subjective decision may still need to be made about how precautionary a regulator wants to be when comparing a statistical distribution of predicted effect sizes to an allowable harm level.

This paper inverted the problem by starting at the "allowable harm" side of the equation, which reflects a policy decision that may differ from one jurisdiction to another. Two places were identified to bound this problem for activities that may affect wildlife through energetic mechanisms that reduce prey available to individuals. First, allowable harm was quantified relative to a pre-defined and quantitative limit, namely to the mathematically equivalent mortality levels that would be deemed unacceptable for bycatch in well-monitored fisheries. The US Marine Mammal Protection Act's Potential Biological Removal (PBR) equation [9] was used as a placeholder allowable harm limit to represent the maximum number of animals that can be removed annually without compromising a population's recovery to agreed-upon management targets of optimum population size. That rephrased the research question from, "*How big could cumulative impacts be?*" to "*How big would cumulative impacts have to be to exceed this agreed-upon threshold?*" The primary objective was to introduce a new conceptual approach that makes incremental progress on an important topic in marine policy and management. There are specific policies guiding the implementation of PBR for managing fisheries bycatch [9]. The intent here was not to replicate exactly how PBR is implemented, and no attempt was made to reproduce how managers in the USA might respond when a population warrants listing under the Endangered Species Act. On the contrary, the overarching objective was to describe a flexible approach, starting with any given allowable harm limit, based on a stochastic simulation. The computer code used to illustrate the approach is freely available [20]; this code can readily be modified to replace PBR with any quantitative population-level reference point or management objective, such as the New Zealand MALFIRM limit, an IWC rule of thumb that any mortalities exceeding 1% of population size warrant closer attention, or fisheries bycatch limits agreed upon under ASCOBANS (reviewed in [21]). Secondly, long-term studies of northern and southern resident killer whales (northeast Pacific) and Gulf of Maine (northwest Atlantic) humpback whales were used to illustrate the approach by parameterizing the weakest link, namely the one between prey availability and demography (calf and/or adult survival, and/or fecundity). The code can also be adapted to any marine or terrestrial species for which a prey-demography link exists, and an allowable harm limit can be specified.

Inverting the problem permits more tractable future research questions that assess whether all human activities in a region could conceivably reduce prey in the environment or available to wildlife. The intent is not to advocate use of these models in decision-making directly when assessing the risks associated with a single proposed industrial development application. Instead, this approach is intended to help focus discussions about the magnitude of the cumulative risks of all industrial activities in a region, and the plausibility that cumulative sublethal impacts (i.e., reduced fecundity and survival) could cause population-level effects that regulators would not tolerate if they were caused by direct mortality in fisheries.

## 2. Methods

Matrix-based population models were constructed that incorporated annual stochasticity in prey availability in the environment, demographic parameters, and an index representing proportional reduction of the amount of prey in the environment made available to animals. Ideally, one would construct fully