A Framework for Including Noise with Other Anthropogenic Stressors in Cumulative Impact Assessments

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ABSTRACT

Cumulative impact assessment (CIA; also called cumulative effect assessment: CEA) is a required component of many environmental impact assessment processes around the world. These CIAs are generally obliged to consider the impacts of a proposed project or action upon the environment in combination with past, present and sometimes also reasonably foreseeable future activities. However, data and appropriate tools are currently insufficient to achieve this lofty goal, especially for marine species where habitats are mobile and data is hard to collect. At present, CIAs usually take place as part of project-based assessments without a sufficiently wide ecosystem scope, which limits effective management. Additionally, sub-lethal and non-lethal impacts of anthropogenic activities, such as conditions related to stress, are generally not considered, despite rising concern about these issues. Similarly, most CIAs or related efforts to assess accumulated exposure to anthropogenic stressors have so far not included noise. To address these issues, Okeanos – Stiftung für das Meer held an international, multi-disciplinary workshop in Monterey, California, in August 2009, on the cumulative impacts of ocean noise and other anthropogenic stressors on marine mammals. Participants focused on three aspects: how currently available tools for regionally mapping several anthropogenic pressures on the environment could be applied to the management of species; how the reported consequences in marine mammals of exposure to these pressures, as well as their known interactions within an individual, could be modelled; and how population modelling could best include cumulative impact assessment. The available data for many marine mammals is sparse, but participants felt all three approaches could be realised in at least two data-rich populations: southern resident killer whales and North Atlantic right whales. These case studies could then be used as proxies for other cetacean species, or even other marine mammals. Participants also believe that reducing ocean noise is an achievable goal that will help marine life cope with less tractable threats such as climate change.

Keywords: cumulative impact assessment, effects, management procedure, noise, stress, population modelling

BACKGROUND

Despite the primary management focus on sound exposures that lead to injury or death in marine mammals, growing concern surrounds sub-lethal and non-lethal impacts that may suppress reproduction or accumulate to invisibly increase mortality rates. For example, coronary disease, immune suppression, anxiety and depression, cognitive and learning difficulties, and infertility have all been linked to chronic stress in humans (see reviews by Bateson, 2007; Clark & Stansfeld, 2007; Romero, 2007; and references therein). It is quite reasonable to assume that prolonged or repeated exposure to one or more sources of noise, either alone or in combination with exposure to other threats (both real and perceived), can induce chronic stress in marine species (see Wright *et al.*, 2007a; b and references therein). The various consequences of chronic stress that might follow could make a population more susceptible to the addition of new threats (here-after referred to as 'drivers') into their environment. Likewise, conditions related to chronic stress may also slow the recovery of a population where one particular driver has been removed, perhaps through management action.

Successfully determining when cumulative exposures may result in such population-level impacts is thus becoming a pressing issue for managers. This is especially true for endangered species or small populations, where small reductions in reproductive output or small increases in mortality rates can be devastating to viability

for those populations. Despite legislative mandates for full cumulative impact assessments (CIAs; also called cumulative effect assessment: CEA), current project-centric authorisation and other regulative processes can actually hinder any such efforts. Furthermore, consideration of cumulative impacts to date (e.g., Halpern *et al*., 2008; 2009) have not generally included noise. This is partly because there is much discussion within the bioacoustics community around how total expose just to noise from various sources should be assessed. Finally, much of the data required for thorough CIAs are not available for many populations of marine mammal and other marine species. Accordingly, Okeanos – Foundation for the Sea convened an expert panel in Monterey, California, in August and September 2009 to consider the options and proposed a way forward. Participants were very carefully selected to bring in a wide range of expertise from many disciplines and a number of fresh faces from outside marine mammal science and policy, in an effort to increase the chances of producing new ideas (see SC/61/E15 for more details). The following represents a summary of the resulting discussions. The original report (Wright, 2009) should be considered the definitive version of this material, in case of any conflict.

ASSESSING CUMULATIVE IMPACTS

Despite the fact the meeting was intended to focus on ways to incorporate noise into effective CIAs, participants quickly realised that noise could not be given special attention in a CIA. This is not to say that noise is less important than other drivers, however, as participants also noted that any CIA that did not include noise would be incomplete. It was also realised that various stages of CIA would be needed as data availability is a key constraint for managers attempting CIAs. It was also important that each step could build upon previous ones as more data become available, rather than requiring entirely new efforts.

CUMULATIVE EXPOSURE MAPPING

Huge amounts but distributed over huge area (not sure how they actually dealt with time) so the data density was actually quite low.

Kappel *et al*. (2009) detail the possibilities for mapping total cumulative exposure to drivers for marine mammals. In short, an ideal first step, the distribution of physical habitats or ecosystems should be mapped out and then overlaid with the distribution of each (class of) driver present. However, it is important to keep in mind that many marine ecosystems can move in space and time. If data permits, acoustic habitat should be included while recognising that different species will experience this habitat in very different ways. Next, estimates of relative ecosystem vulnerability and/or driver importance can be included to produce a map of cumulative exposure, similar to those presented by Halpern *et al*. (2008; 2009). Such maps can then be used to identify relatively pristine areas that might be important for conservation, important habitats already under strain, or areas of already high impact that could be 'sacrificed' as preferred locations for additional drivers.

The Halpern *et al*. (2008; 2009) example represents the collection of huge amounts of data (albeit distributed over huge areas, meaning that the data density was actually quite low). However, similar maps constructed at a much more conceptual level can still be effectively achieved with much fewer data. This can be done as simply as overlaying maps of marine activities and indentifying areas of high and low human use.

Noise could be included here through the addition of layers for each source, but this would make for cumbersome and thus inefficient modelling. For model simplicity, aggregated layers of different classes of noise with similar characteristic and/or impacts could be added instead. Two noise classes would probably be sufficient. The first would be chronic or continuous noise sources (such as shipping) that can result in masking of sounds of interest and the reduction of habitat value indefinitely. The second would be acute noise sources (such as transient impulses), which generally have higher peak noise levels than chronic sources that can result in injury or even death, under certain circumstances. Acute sources also tend to be more localized and present for shorter durations than chronic sources.

POPULATION MODELS

Once the exposure maps are created, population distributions can then be overlaid to produce a rudimentary indication of the average total exposure to a population. However, a more effective use of this information would be through population models, if the data are available (see Cooke *et al*., 2007). Stage-based population models could be employed to translate the exposure data into population-level consequences. This also requires that the

eco-system vulnerability estimates used by Halpern *et al*. (2008; 2009) be replaced with more specific vulnerability estimates for the population of concern.

To fully consider cumulative impacts, however, is likely to require the use of spatially explicit individual-based models (IBMs). In IBMs, each individual animal would move through the various exposure layers, rather than the total exposure index, accumulating a history of exposure for each class of driver. Clark *et al*. (2009) provides an example of how this could be done for noise. The aggregation of impacts would then occur on an individual basis, rather than directly at the population-level (or stage-level). These would then accumulate at the population level through changes in individual fecundity and survival, producing a more accurate representation of the way that population-level effects are actually generated.

CUMULATIVE IMPACT MODELS

It may be possible, in certain cases where the data are available, to add a further modelling layer into an IBM that would represent physiological processes within an individual (see Wright *et al*., 2009). This would require data not only on the specific impacts of exposure to each driver on an animal, but also the subsequent physiological consequences. Within this layer, the immediate effects of the various drivers on, for example, endocrine function, or the availability of foraging or reproductive opportunities would be able to interact in various ways. However, the key here is that their subsequent consequences would also be able to combine and interact with each other as well as the original effects. These various interactions and their consequences would ultimately influence the likelihood of mortality or the reproductive potential of each animal, thus raising the impacts to the level of the population. It is expected that synergistic and antagonistic effects may be produced by the physiological network in this model layer, which could then be compared to published data on overall impacts (see Kroeker, 2009) to validate the model. This modelling layer would replace the vulnerability estimates used in earlier steps.

Unfortunately, it is still not clear at this time how the psychological effects of chronic stress and other factors could be included at anything more than a very basic conceptual level.

APPLICATION AND PATH FORWARD

The extent to which the above framework can be achieved for any given species is highly dependent upon the data available. Mapping cumulative exposure should be almost always possible, at least to a certain extent. However, to achieve this, regulatory agencies may need to make efforts (at least initially) to aggregate information on the distribution of activities under their jurisdiction. In many cases data are available to also include population distributions into the CIA. This would allow some level of population modelling. However, it is at this point that CIA effors with marine mammals start to become very limited by the availability of reliable and appropriate data sets.

The creation of reliable IBMs that realistically incorporate the various drivers are most likely only possible for a few populations, as these will probably require large amounts of data. Despite this, it is expected that full, cumulative impact IBMs would be possible for at least two cetacean populations where relatively large amounts of data exist. These are the North Atlantic right whale (*Eubalaena glacialis*) and the southern resident killer whale (*Orcinus orca*). Once these models are built, they could then be used as examples of how different pressures can combine and impact populations (e.g., through changes in demographic rates), and inform management decisions, perhaps based on exposure data alone, in other odontocete and mysticete species, as well as other marine mammals. For example, they may be able to identify combinations of drivers that could be particularly damaging. Alternatively, they might provide indications of thresholds at which different consequences are likely to emerge.

Despite the legal mandates, application of the above, or similar, to management processes will require a certain amount of political will. This will be needed both to ensure implementation and to appropriately revise regulations and management processes. For example, it would be useful for the United States Government Agencies to include a full report on the drivers to which each species is exposed in their marine mammal Stock Assessment Reports. This would represent an important and substantial step towards cumulative exposure mapping in U.S. waters. Similarly, a shift away from project-based management, perhaps to ecosystem based management as is currently being discussed in the U.S. and elsewhere, will refocus processed more towards the animals and their ecosystems, inherently facilitating better CIAs as a result.

To that end, participants noted that marine spatial planning would offer a very suitable management environment for CIAs. Participants also expressed a belief that reducing ocean noise is an achievable goal that will help

marine life cope with less tractable threats such as climate change. Several participants are continuing to work to realise these goals beyond the conclusion of the workshop.

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