National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Calculating ecological response footprints

Guidance

This guidance uses stressors and seabed ecosystem characteristics to determine the relationship between stressor footprints and the ecological (or species) response footprint (ERF).

An ecological response footprint is made up of size and depth, and assessment of an ERF should consider the following two questions:

- Is the response footprint the same size, larger, smaller, patchy, or divorced from the stressor footprints?
- Is the response footprint proportionally the same depth (magnitude and duration) as the stressor footprints?

It's not necessary to have calculated the present ecological response footprint – that's considered in *Table 1* of An ecological principles-based approach to guide coastal environmental management.

Size and location of ecological response footprint relative to stressor footprint

To determine the relationship between footprints, ask the following questions (Low et al 2023).

Will the ERF be the same size, larger, smaller, patchy or divorced from the stressors' footprints?

Presently, the ecological components of interest (eg species, habitats, and functions) should be determined by local values and targets and any indicators used by government agencies. Ecological functions that should be considered based on their importance to species, biodiversity, and ecosystem services, include those specified as roles in Table 1, Thrush et al 2013.

Is there only one stressor in the area?

If no, calculate the ecological response footprint based on the following factors. It's important to understand whether the ERF will be larger than the stressor footprint and possibly even separated from it.

1. Stressor footprint, or if unknown, the activity footprint and likely stressor dispersal.

2. Biological connectivity.

    a. Does the stressor footprint cover sources of larvae, breeding and nursery areas? If so then the ERF needs to include these areas as well as where adults live. For example, juvenile pipi live in upper estuary mid to low tide muddy sand environments, while adults prefer very low tide to shallow subtidal high current areas. It's not important to have an exhaustive list, but at least record the areas and species that are known to locals. Council scientists, NIWA, Cawthron, university ecologists and museum specialists could also offer advice.

    b. If species are of particular importance, how mobile are they at different life stages? Many shrimp swim daily in the water as both adults and juveniles, other species may be territorial or even sedentary as adults, but not as juveniles and therefore less connected to other places once they become adults. Again an exhaustive list is not necessary.

    c. Distance to similar habitats. These habitats should not be simply described by sediment type and depth (eg intertidal mudflat) but should be ecologically described. For example, dense shellfish beds (oysters, mussels, pipi, horse mussels), tube worm beds and mats, diverse relatively slow growing biologically structured habitats (for example, mixtures of shellfish and sponges, bryozoans, and rhodoliths), vegetated habitats (for example, seagrass, seaweeds, and kelp) and large crustaceans (for example, crabs and shrimps). An exhaustive list is not necessary, but include the common ones and any covering large areas, even if they are unique.

    d. All of the above need to be considered in the context of any need to cross or go around hydrodynamic barriers. For example, locations on the same side of a channel are more connected than those on the other side, locations in the same tidal creek or on the same side as a peninsula are more connected than those in different tidal creeks or bays. In the open ocean, large scale currents, upwellings and downwellings can also form barriers. These factors can be considered by a) measuring the distance between places by water rather than as the crow flies, or b) weighting the distance by the number of barriers.

3. Landscape species and habitat diversity — While it is important to understand biodiversity responses and the pre-stressor starting point, this is information is often unavailable. Habitat diversity (the number of different types of habitats discussed in point 3c) is a useful indicator of biodiversity overall. Fish diversity (number of fish species known to occur in the stressor footprint and close by) is also useful to know and can be estimated by locals.

4. Sensitivity to stressors — How sensitive are the species, habitats or functions occurring within and around the stressors' footprints? An ERF may be smaller than the stressor footprint if the species, habitats or functions are not very sensitive, but larger if they are highly sensitive. The more habitats there are the less likely it is that all habitats will have the same sensitivity and the ERF will be patchy. The likely range of sensitivities should be recorded. This could be simply done as a 5-point scale (high to none).

If yes, there is more than one stressor in the area, then are the stressor footprints separate, do they overlap, or are they in the same location?

If multiple stressor footprints are separate
If stressor footprints are separate, calculate ERF for each separately to determine whether ERF overlap or are separate, based on points 1-4 above.

If multiple stressor footprints overlap
If stressor footprints overlap, calculate ERF for each separately to determine size of ERF overlap, then within overlap area calculate ERF as if multiple stressor footprints occur in the same location (see below).

If multiple stressor footprints occur in the same location
If in the same location, calculate ERF for multiple stressors based on points 1 to 4 above and use the following stressor principles to determine species, habitat and ecosystem function sensitivities. Note that multiple stressors affect the depth (magnitude and time to recover) of the ERF more than the spatial extent.

Stressor questions to consider are:

- Do any of the stressors impact more than one component of the ecological network (more than one species, habitat or function)? Is the impact likely to be in the same direction for each component (eg all negative or positive)? This increases the likelihood of amplification of the stressors effects. For this question and the next it would be useful to either seek advice from council scientists, or NIWA, Cawthron and university ecologists. A conceptual map of how species and habitats are thought to interact and affect each other could also be drawn up by locals. There are some available conceptual models that could be used as a starting point (eg Bulmer et al 2019).
- Do the combined stressors impact the ecological network in such a way as to reduce the other's effect? This is most likely to happen if the ecological response to one of the stressors is generally unimodal (in small amounts it promotes biodiversity or growth, such as nutrients, temperature, and sediment mud) and the stressor level is low. Other examples are those that impact both a valued species and its predator, high suspended sediment reducing the potential for nutrients to form phytoplankton blooms, and high sedimentation rate decreasing the concentration of contaminants.

Table 1. Modified from Thrush et al 2013.

Services category	**Services**	**Functions and processes**
Provisioning services	Production of food Production of raw materials Production of medicines and pharmaceuticals	Primary production Secondary production Trophic relationships Reproductive habitats Refugia for juvenile life stages Ontogenetic habitat shifts Biogeochemical cycles associated with nutrient supply Biogenic habitat Biodiversity
Regulation and maintenance services	Regulation of waste assimilation processes Storing and cycling nutrients Gaseous composition of the atmosphere and climate regulation Sediment formation and stability Maintaining hydraulic cycles and shoreline protection	Biogeochemical cycles Storage and processing Benthic–pelagic coupling Bioturbation/irrigation Biodiversity Shell generation Biogenic structure/reef-makers Fringing vegetation Species, spatial structure, size and density influences on hydraulic processes Resilience
Habitat and ecological community services	Provision of habitat structure Resilience Genetic resources	Invasibility Provision of habitat Maintenance of trophic structure Biodiversity Resilience Facilitation Reproduction
Cultural services	Cultural and spiritual heritage Recreation and tourism Aesthetics Cognitive benefits Non-use benefits Speculative benefits	Ecosystem, community and population dynamics Processes influencing water clarity, habitat diversity Biodiversity

Depth of ecological response footprint relative to the stressor footprint

To determine the depth (magnitude and duration) of ERF relative to stressor footprints, ask the following questions.

Is there more than one stressor?

If no:

- Magnitude will be equivalent to species and habitat sensitivity to the stressor.
- Duration will depend not only on the duration of the stressor footprint, but also on the regeneration times of the disturbed species, the size of the disturbed area relative to the surrounding landscape, and the principles that control recovery feedbacks (Fig 3, Hewitt et al 2022). For short-lived species and processes, and if the duration of the stressor does not extend past the activity creating it (that is the tap can be "turned off"), decisions around minimising degradation can be made on the basis of magnitude.

If yes:

- Magnitude will be at least the magnitude of the combined stressor footprint, unless one of the stressors has a unimodal response with the species or habitats. For example, small amounts of nutrients can be beneficial to some species, small amounts of sedimentation in sandy sediments can increase number of species able to live there, or small amounts of suspended sediment may offset increases in nutrients. Magnitude is likely to be greater than the magnitude of the combined stressor footprints if responses involve species or habitats that are affected both directly and indirectly. Indirect effects occur when something is affected not by the stressor but by something that is affected by the stressor. For example, sedimentation affects the algae growing on the seafloor which in turn affects those species that feed on the algae. Judging the likelihood for an increased magnitude of response is easier if a conceptual map has been made.
- Duration will again depend on the combined duration of the stressors' footprints, extended by the regeneration times of the disturbed species, the size of the disturbed area relative to the surrounding landscape, and the principles that control recovery feedbacks (see Hewitt et al 2022). For short-lived species and processes, and if the duration of the stressor does not extend past the activity creating it (that is the tap can be "turned off"), decisions around minimising degradation can be made based on magnitude. However, it is important to remember that species dependant on slow growing habitats will be slow to recover if recovery is even possible.

References

Bulmer R, Stephenson F & Hewitt J (2019). Exploring the impact of multiple stressors on estuarine ecosystems using a Bayesian Network model. Prepared by NIWA for the Parliamentary Commissioner for the Environment. Report number 2019246HN.

Hewitt J, Gladstone-Gallagher R & Thrush S (2022). Disturbance-recovery dynamics inform seafloor management for recovery. Sustainable Seas National Science Challenge.

Low J, Gladstone-Gallagher R, Hewitt J, Pilditch C, Ellis J & Thrush S (2023). Using Ecosystem Response Footprints to Guide Environmental Management Priorities. Ecosystem Health and Sustainability, 9, 0115.

Thrush S, Townsend M, Hewitt J, Davies K, Lohrer A, Lundquist C et al (2013). The many uses and values of estuarine ecosystems. In: Dymond J, editor. Ecosystem Services in New Zealand – Condition and Trends. New Zealand: Manaaki Whenua Press.