National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

New Brighton Pier / Vivian Wong

Integrating interactive stressors within marine spatial planning using spatial modelling and decision support tools

Summary

Limited tools are available to assess the cumulative effects of multiple stressors in marine ecosystems

Marine Spatial Planning (MSP) processes often aim to restore degraded habitats or protect existing high-quality habitats and for both outcomes, spatially explicit information on habitat condition is required.

Most spatial planning approaches consider stressors in isolation – where management targets areas of high or low stressor 'footprints' for restoration or protection respectively.

Despite the advancement of MSP as an important tool for ecosystem-based management, there are currently limited methods for consideration of cumulative effects from multiple, interacting stressors in marine spatial planning processes. Stressors can interact in complex, indirect ways, which can result in surprises or unexpected ecological responses, and it is important to consider these interactions when identifying marine areas for management.

Not considering cumulative effects hampers the ability to effectively manage stressors to maintain and/or recover ecological functioning and the associated ecosystem services. Failure to include cumulative effects also creates a source of uncertainty in management decisions around the capacity of a system to cope with new activities. Consequently, management frameworks are needed that can allow stressors to interact in different ways so that any potential effects of multiple stressors on marine species/habitats can be assessed.

A spatial modelling framework that includes interacting stressors within marine spatial planning has been developed

The framework was developed using novel spatial modelling approaches and decision support tools to generate spatial models that consider a range of scenarios, which incorporate ecological responses to multiple stressors. The framework was assessed using seafloor invertebrate data from Chatham Rise; a well-sampled offshore area of Aotearoa New Zealand that supports a high diversity of seafloor invertebrates.

In particular, the study focused on selected invertebrates that have functionally important roles in marine ecosystems. The framework was used to assess the spatial distribution response of the invertebrates to the potential interactive effects of three prevalent marine ecosystem stressors; turbidity, mud content, and bottom trawling. Decision support tools were used in a hypothetical MSP process to prioritise areas for habitat protection (conservation) and/or restoration in marine management planning.

Species distribution models (SDM) are often used in MSP to predict a species' geographic range based on the environmental characteristics associated with its occurrence or abundance. Data of seafloor invertebrates and environmental variables (e.g., salinity, bathymetry, current velocity) collected from 1990 to 2020 was used to create species distribution models that predicted the distribution of invertebrates on the Chatham Rise.


Muriwai Beach / Kiwiana Videography

The models accounted for the impact of interacting multiple stressors using Interaction Forests — a method recently developed specifically for appraising interactive effects. The models were used to test the potential effects of the three stressors (turbidity, mud content, and bottom trawling) on the spatial distributions of the 12 seafloor invertebrate groups using three different response settings:

1. Without stressors
2. With additive stressor responses
3. With interactive stressor responses

Each setting was tested for each of the invertebrates, and model performance metrics were evaluated to determine the setting that provided the best predictive performance for each.

Multivariate stressor response plots were used to determine the nature of interactive effects. Spatial predictions from the models were then used within the decision support tool 'Zonation' to identify high priority/key areas for the conservation and restoration of the seafloor invertebrates with and without the consideration of stressors.

The importance of stressors for predicting distribution patterns varied across the different invertebrate groups

Habitat suitability models for all 12 seafloor invertebrates performed well. The different groups showed a high level of variability in the modelled response to the interactive stressor combinations (i.e., trawling and mud content vs. trawling and turbidity).

In general, the responses to the interaction of both trawling and turbidity/mud content showed three different modes:

1. The cumulative negative stressor response, where the combination of high values of both trawling and turbidity/mud caused a higher predicted probability of the absence of a particular invertebrate group. *Munida* clearly demonstrated this relationship with stressors (Figure 1).

2. Substantial variability across the gradient of one stressor (i.e., turbidity) with respect to its effect on the response according to the values of another stressors (i.e., trawling). For example, *Caryophilia* showed increasing probability of absence with increasing turbidity, but the influence of trawling on this effect was highly variable; high values of trawling contributed to lower probability of absence at low values of turbidity but contributed to higher probability of absence at high values of turbidity (Figure 1).

3. The cumulative positive response; where high values of both stressors caused a decrease in the probability of absence (e.g., higher habitat suitability). The response was demonstrated by *Hyalinoecia* (Figure 1) and shows how increasing turbidity decreased the probability of absence and how this effect is more pronounced for higher values of trawling.

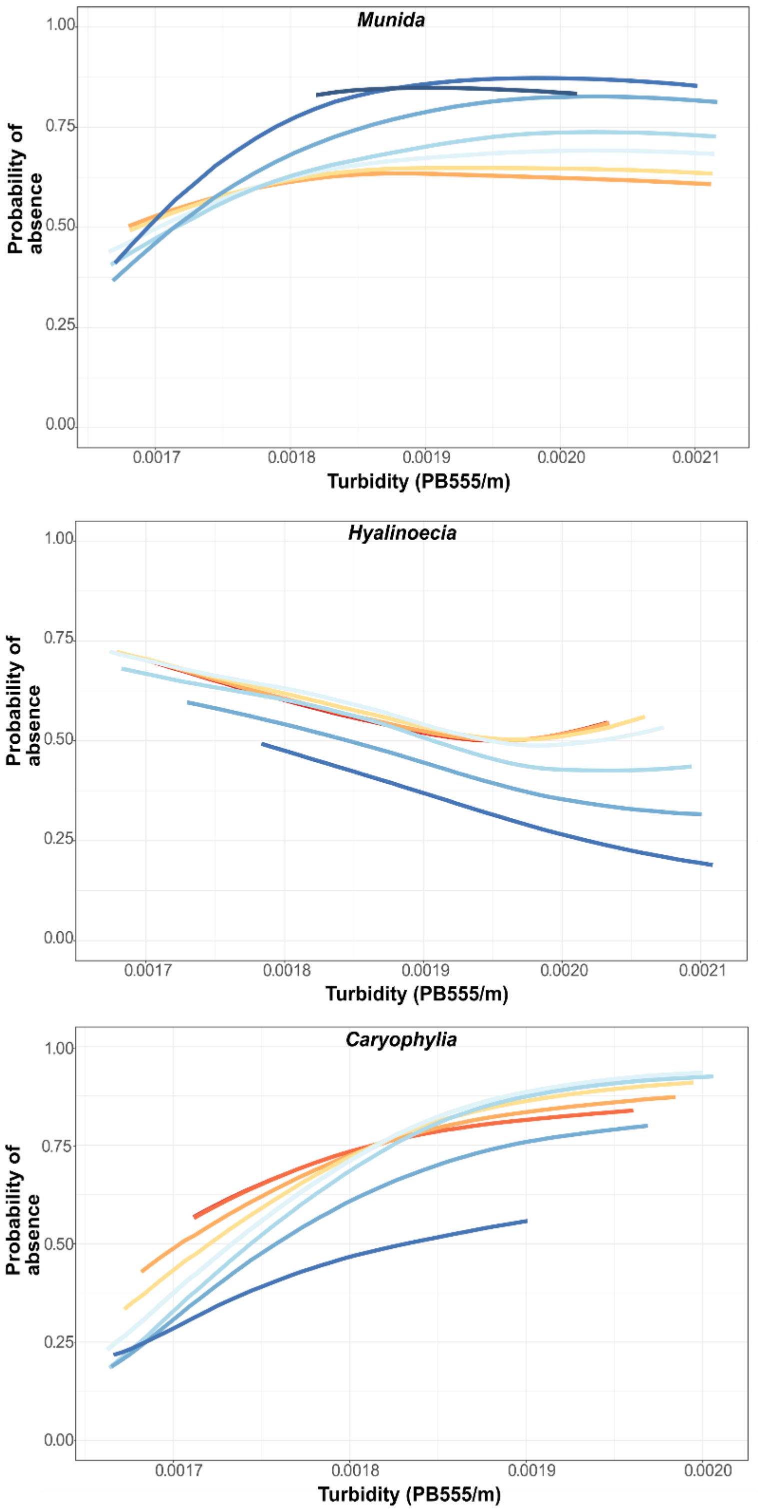

Figure 1: Multivariate stressor response plots for the interactive effects of turbidity or mud content (x-axis) and trawling on the probability of absence (y-axis). For each invertebrate genus, the effect of turbidity/mud on the probability of absence is contingent on the intensity of trawling (reporting as graduated deciles, 10% (low) – 90% (high). The examples exhibit a range of multivariate stressor responses.

Several areas were prioritised for conservation of seafloor invertebrates regardless of the inclusion of multiple stressors

In terms of the highest priority areas for conservation, the Zonation spatial prioritisation revealed similarities and differences between MSP scenarios that accounted for multiple stressors and those that did not (Figure 2, scenarios 1 and 2). Both scenarios determined high priority locations for the protection of benthic invertebrates in the central, and the south-east of the Chatham Rise (Figure 2 [1] and [2]). A discrete location on the northern shelf-break of the Chatham Rise was similarly determined as high priority in each scenario (Figure 2 [3]).

In contrast, some areas that were determined as high priority in the scenario excluding stressors were not selected in the stressor-driven scenario (these included broad areas on the southern shelf-break of the Rise and on the central plateau). In the stressor-driven scenario, a larger area of the eastern Rise is deemed high priority along with a smaller area on the eastern part of the central plateau that seems to be subject to lower turbidity.

Several high priority areas differed for the restoration and conservation scenarios

The scenario that aims to identify the high priority locations for restoration (Figure 2, scenario 3) contrasted in several ways to the scenarios aiming to protect current biodiversity. A large area in the east of the Chatham Rise was deemed high priority for restoration (Figure 2 [4]), which is subjected to high trawling intensity and high turbidity. Further, areas of high trawling intensity on both the southern and northern slopes of the Chatham Rise were selected as high priority for restoration. In scenarios 1 and 2 there were distinct areas that were indicated as high priority locations for the protection of seafloor invertebrates. Each of these areas had relatively low stressor intensity, particularly for trawling, and are areas with known high seafloor biodiversity values.

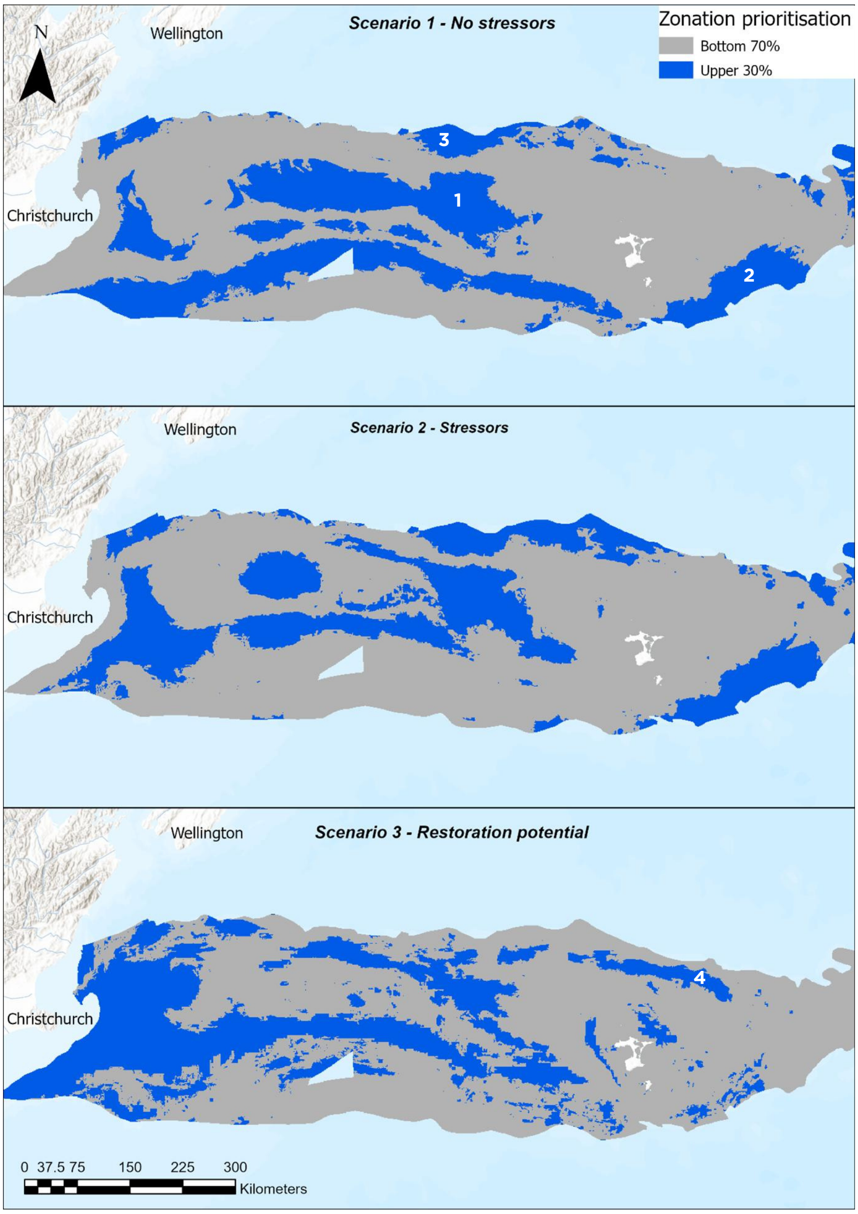

Figure 2: Outputs of spatial prioritisations of the Chatham Rise using the decision support tool Zonation to determine the top 30% of the study area for the protection of the distribution of important benthic invertebrates while omitting the impact of stressors on distribution (Scenario 1), incorporating the impact of stressors on current distribution (Scenario 2), and for prioritising areas for the restoration of biodiversity (Scenario 3). The numbers reference statements in the text.

This research provides important advances for marine spatial planning and ecosystem-based management

The Interaction Forest framework allows for both the identification of biodiversity components that may be affected by stressors and the degree to which they may be affected by potential interactions (via spatial modelling). The approach accounts for diverse stressor responses within marine spatial planning decision-making processes (via Zonation).

The predictions from the models allow the impacts of interacting stressors to be incorporated into MSP, and for decision-makers to explore trade-offs between the protection of various biodiversity components and between resource users. The ability for the models to incorporate multiple stressor responses means they can also be used to look at the likely outcomes of restoration efforts which can provide managers with additional tools to aid decision making.

Ultimately, this research provides an important step forward for incorporating the cumulative effects of multiple stressors in marine spatial planning decision-making processes that can be used for marine ecosystem-based management.

Academic Publication

Brough, T., Leunissen, E., Geange, S., Tracey, D., Mercer, M., Anderson, O., Lundquist, C. (manuscript in review) Integrating interactive stressors within marine spatial planning using spatial modelling and decision support tools.