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Euclidean distance of ln(x+1) transformed mean sizes were calculated at the 270, 150, 80, 60, 40, 30, 20, 15, 10, and 5 group-levels, where sampling sites within those classes were amalgamated at each level in the hierarchy. A total of 46 site groupings were used at the 270-cluster level (i.e. 46 site groups) representing information from 75 sites pooled where multiple sites occurred in the same environmental class.

The biological dissimilarity of suspension-feeder functional groups was used as an indicator of biological pattern at the level of functional groups. Data on relative abundance was transformed with the Hellinger's transformation and used to calculate Bray-Curtis dissimilarity at different levels of the classification hierarchy. At the 270-cluster level 17 site groups were available for analysis. The composition of reef fish assemblages was used as an indicator of biological pattern at the community-level, where the mean abundance of common reef fish was used to calculate Bray-Curtis dissimilarity among different levels of the classification. Information on fish assemblages from 38 site groups was available at the 270-group level.

Patterns of biological variability represented in each environmental class was explored with histograms and tested with a Mantel's test with a measure of distance in biological pattern (Euclidian distance for the population-level differences and Bray-Curtis or Hellinger's Distance for community-level and functional groupo response variables) and environmental distance of individual coastal classes (measured by the Gower metric)(Legendre and Legendre 1998). This test provided a measure of association between biological similarity and environmental similarity at the 270-group level. Statistical analyses were run in the program R version 4 (Casgrain, et al. 2004).

Patterns in the difference of mean sea urchin size as a function of increasing environmental distance showed a pattern of a steep negative trend, dropping from a Euclidean distance of approximately 0.21 at the 270-group level to 0.13 at the 40-group level (Figure 19). This level of biological distance stayed similar to the 20-group level, where there was sharp decrease in the biological distance. This trend was also accompanied by a decrease in the number of biological groups to make comparisons (i.e. the original 46 sites were pooled into 8 groups). A Mantel's test of the similarity between the Gower distance of environmental variables and the Euclidean distance of mean sea urchin size was non-significant at the 270-group level (Mantel's r = -0.071, Mantel's t approximation = -0.990, P-value = 0.161). This result indicates that although the greatest amount of biological distinction occurred at the 270-group level, the correspondence of that pattern with the physical environment types defined in the classification was not significant according to the Mantel's test.

For the biological distance for reef fish communities, there was a pattern of increasing biological distance with increasing environmental distance to approximately the 20-group level, where there was a sharp decrease in the distance to the 15-group level (Figure 19), indicating that biological pattern at the community level occurs at intermediate levels of environmental distance. This analysis also showed that there were relatively small changes in biological distance from the 270-group to the 80-group levels in the dendrogram. The Mantel's test of the similarity between the Gower distance of environmental variables and Bray-Curtis dissimilarity of the fish assemblages at the 270-group level was significant (Mantel's r = 0.364, Mantel's t approximation = 3.546, P-value = 0.0002). This result indicated that at moderate levels of biological distinction (i.e. the 270-group level) there was a correspondence between the physical environment types defined in the classification.

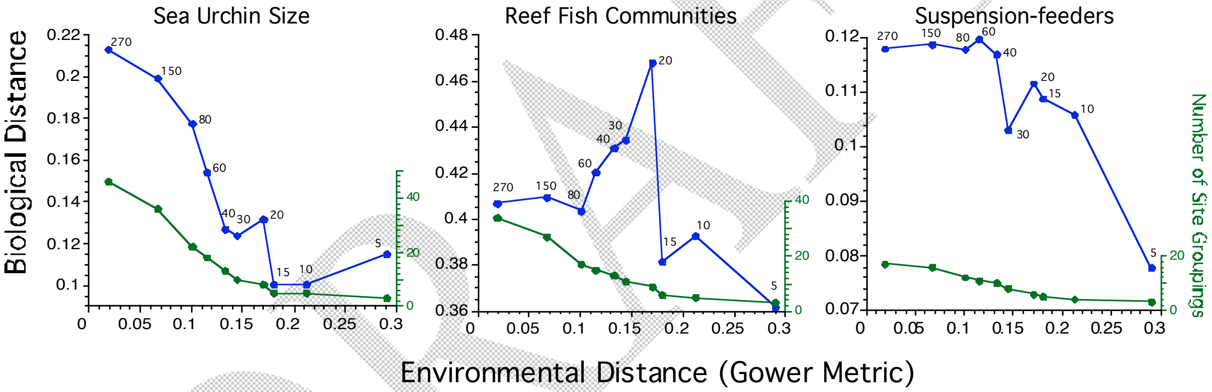

Figure 19. Relationships between biological distance (measured as Euclidean distance for sea urchin size, or Bray-Curtis dissimilarity for reef fishes and suspension-feeders) and environmental distance (measured by the Gower metric) at various levels in the classification hierarchy. Numbers above the blue line refer to the group levels in the classification and the green lines refer to the number of sites grouped at each level in the dendrogram.

The relative abundance of suspension-feeding functional groups showed a relatively high level of biological distance from the 270-group level in the dendrogram to the 40-group level (Figure 19). This trend was followed by a decrease in biological distance from a Bray-Curtis values of approximately 0.11 to 0.08 (i.e. the 5-group level in the dendrogram). The Mantel's test between the Gower distance of environmental variables and Bray-Curtis dissimilarity of suspension-feeder functional groups at the 270-group level was also significant (Mantel's r = 0.221, Mantel's t approximation = 1.949, P-value = 0.026). This means that at the highest level of biological distinction (i.e. at the 270-group level), there was a correspondence between physical environment types defined in the classification.

Discussion

These trends suggest that an optimal classification across different levels of biological organisation and for different ecosystem elements could use a distinction at the 20-group level, which maximises biological distinction at a reasonably high level of distance between environmental classes. As the dendrogram retains the hierarchical association between groups, applications requiring a higher degree of detail between environmental classes can also be used. In other words, the 20-group level distinction would serve as an optimal "working classification" to apply to management issues of the Fiordland marine environment. For example, one management application is an analysis of the different management zones proposed by the GOFF Integrated Management Plan. From the 20-group cluster, about 71% of the coastal fringe (i.e. 2970 segments) covered by the classification lies outside designated Representative Areas (RAs, Table 3). The representation of some individual environmental classes in RAs is spread out across several fjords (e.g. Cluster #3 has a small representation in Milford, Bligh Charles and Wet Jacket Arm (Table 3). Although the relative area of this environmental class is disproportionately spread across the 4 fjords, the allocation of similar habitat types across multiple reserves can be considered an advantageous design feature. For Classes 9 and 107, a considerable amount of this coastal environment is contained within RAs (i.e. 57.9 and 61.7%, respectively). Other environmental classes are poorly represented, if at all, within the various Representative Areas, with up to 80 or 90 %of large environmental classes being outside RAs (e.g. Clusters 2 and 7). This result suggests that modifications of the existing design or alternative spatial management tools should be considered to ensure that there is adequate representation of those habitats across multiple fjords.

Analyses indicate that different levels of biological organisation have different correlations with environmental distance. Differences in similarity in sea urchin mean size had a correlation of -0.07, epifaunal invertebrates 0.221 and reef fishes 0.221, suggesting that there is a greater correlation between physical habitats and community and functional-group levels of biological organisation. Different patterns of association also occurred between changes of biological distance with increasing distance of environmental distance (Figure 19). The reduction in the ability to distinguish biological pattern at the population level (i.e. for sea urchin size) drops off as a monotonic function, with a comparatively lower amount of biological distance at the 40 group level. In contrast, the pattern for reef fish communities appeared to be at intermediate levels, rising between 80 and 30 groups, suggesting that intermediate levels of the classification have more ability to distinguish biological pattern. Suspension-feeders appeared to maintain a relatively higher level of biological distance to about 30 or 20 groups where there was a monotonic drop in the amount of biological pattern that could be distinguished with increasing environmental distance. Although the high end of these patterns (i.e. in environmental distance) may be slightly driven by fewer numbers of biological sites (i.e. amalgamated data), these patterns indicate that there are variations in the ability of the classification to distinguish biological pattern across different levels of biological organisation. Further analyses into the mechanisms behind these observed patterns may help understand the ability of environmental classifications to represent biological patterns. For example, different biogeographic patterns in fish community assembly may be driven by patterns other than those in the physical environment, but rather linked to other biological processes, such as recruitment variability and/or adult selection of biological habitats, such as kelp forests. An incorporation of biological as well as physical variables may be able to explain some of these variations.

General Conclusions and Recommendations

(1) The use of a range of physical data layers to establish relationships to biological variables can provide information on the types of physical variables associated with biological attributes, but also the form of the relationship. This information can provide a tool for determining possible thresholds in determining biological pattern and give rise to testable hypotheses about the organisation of biological patterns (whether at the population-, species-, or community-level). The relationships documented in this study for a subset of the total possible models run demonstrate the range of variability possible, both with respect to the number of physical variables associated with a given pattern and the statistical performance of individual models. There appears to be more consistency with the types of physical variables associated for population- and community-level patterns, while species-level patterns tend to have less correspondence across different levels of biological organisation. The reasons to why this may be requires more research, both in terms of modelling different parameters, but also in developing more directed experimental studies to be able to contrast possible functional relationships between physical parameters and biological patterns.

(2) The amount of data available to make statistical relationships between physical environmental variables and biological patterns needs careful consideration. As in this study, and possibly in other studies of similar nature, data collection (both physical and biological) has been done for reasons other than for developing environmental classifications. This may create some bias in the general outcomes of statistical modelling, however there is considerable insight to be gained by contrasting a number of different data sources and levels of biological organisation to make more robust comparisons and draw more general conclusions about the levels of correspondence between physical and biological pattern.

(3) Ground-truthing of predictive models indicates that there can be considerable variation in the correspondence between expected and observed values. This raises a number of questions regarding the methodology and approach for developing classifications based on an iterative process of data acquisition, modelling, data acquisition, with further modelling. For example, data accumulation in the ground-truthing of predictive models can be constrained in areas where there is less confidence in the model outcomes and/or concentrating on areas that are data poor. This may be particularly important in improving the classification strength, but can also lead to insights to why particular predictions do not hold up in field-validations. In dynamic systems, such as in shallow subtidal reefs, there may be considerable inter-annual variations, that could also contribute to poor correlations between predicted and observed patterns. An example is for sea urchin population size structure, where there has been documented die-offs of cohorts and recruitment pulses which are constantly changing size structure attributes.

(4) The development of a physical-based environmental classification needs to be able to consider differences in the correspondence with biological pattern. Biological variation does not necessarily correspond with physical variation, as illustrated by the amount of biological distance between sea urchin size structure, and reef fish community similarity and suspension-feeder functional groups. Thresholds in the amount of biological variation explained by environmental distance can possibly be used to determine a adequate level of environmental classes to use for a given management application. Further contrasts of different spatial scales and levels of aggregation for regional-scale variation may prove to be valuable for increasing our understanding of functional relationships.

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