Marine versus terrestrial predictive mapping: Geographic modelling constraints of working underwater

K. W. Holmes[1,2], B. Radford[1,2], and K. P. Van Niel[2]

[1]School of Plant Biology
[2]School of Earth and Geographical Sciences
University of Western Australia
35 Stirling Highway, Crawley WA 6009 Australia
Telephone: (+61) 8 6488 3433
Fax: (+61) 8 6488 1037
Email: kholmes@segs.uwa.edu.au

1. Introduction

Maps of seafloor characteristics are in high demand for marine conservation and planning, including: marine park placement and zoning (Friedlander et al., 2003); marine resource management (Bax et al., 1999); human impact monitoring (Kendrick et al., 2002; Plummer et al., 2003); and integrative ecological research (Durako et al., 2002; Fonseca et al., 2002). Predictive habitat modelling is emerging as a useful approach to meet the requirements of these applications, showing promise for mapping stationary biological seafloor inhabitants with hydroacoustics in water too deep for optical remote sensing (Figure 1). In its most common form, predictive habitat or species modelling refers to the formal statistical modelling of relationships between the occurrence of an organism or class (typically presence / absence dependent variables) and quantifiable environmental drivers, which can then be applied to full coverage datasets to produce spatial predictions (Guisan & Zimmerman 2000).

Techniques developed for terrestrial applications are being applied in marine settings, but fundamental differences in the ecology and sample collection lead to an uneasy marriage of terrestrial methods and marine data. This paper presents geographic analysis and modelling issues in marine predictive habitat modelling, which result from or are exacerbated by differences between terrestrial and marine systems. Examples are supplied from current marine mapping projects in southeast and western Australia.

2. Theoretical underpinning

Near-shore (10 – 200-m water depth) marine environments are generally unmapped, under-sampled, and in some cases already experiencing rapid population and distribution changes due to resource extraction pressure (Jackson et al., 2001). Paucity of data is common in many remote terrestrial environments, but is the norm in marine settings, where technology for accurate georeferencing underwater has only become available in the last 5 years. As a result, quantitative broad-scale investigations in marine systems are lacking, and theoretical development is qualitative, in stark contrast with terrestrial systems. Given the gaps in data collection, predictive modelling will be essential, but selection of appropriate models is difficult without a better understanding and quantification of environmental and biological processes driving the system at broad spatial scales.

Underwater ecosystems are not tightly coupled to flows in two dimensions, further complicating prediction of spatial pattern. Populations tend to be more mobile, propagate widely, and face a vastly different array of environmental pressures and predation than those studied in terrestrial environments. This affects the performance of terrestrial models applied to marine settings. Extensive research into potential drivers of ecological pattern, generality of modelling platforms, remote sensing classification and integration of diverse data types and resolutions are essential for evolution of the marine spatial ecology.

3. Data availability, collection, and processing

Predictive habitat modelling requires full coverage datasets correlated with in situ sampling of habitat features for spatial extension. Large-area mapping in near-shore waters has been slow to develop due to lack of affordable remote sensing platforms such as aerial photography and optical satellite-based remote sensing used on land and shallow coastal waters. Technical improvements in hydroacoustic surveying and desktop computing power now present the opportunity for spatially explicit marine mapping, but substantial improvements in hydroacoustic data processing are needed. Owing to differences in data collection, the quantity and quality of data available at low prices for terrestrial regions will not be achievable for marine systems.

Direct sampling and in situ observation in near-shore waters water require remote sampling methods; underwater video is the most economical, widely-used method for habitat mapping (e.g. Ojeda et al., 2004; Brown et al., 2002), but the type of data collected affects the ways it can be used. Because the camera is towed behind a boat or mounted on a submersible, all data is oriented along narrow transects. How video footage is processed impacts modelling and mapping. For example, different maps result from : (1) footage divided into self-similar segments of varying lengths, or (2) descriptions of single video frames as point samples (Figure 2). Without direct samples, only high level classification of organisms and plants is possible, particularly as lighting, turbidity, and camera angle affect visibility, increasing overall modelling uncertainty. In general, working underwater adds enormous expense to all basic sampling, making large-area spatially and temporally distributed sampling unaffordable within standard competitive funding programs, and opportunistic sampling essential for basic science initiatives, although haphazard data collection can complicate modelling.

3. Modelling

Many of the predictive modelling issues to be resolved are not unique to marine disciplines, but common problems tend to be exacerbated by limitations of marine datasets. Current issues include model selection, model assumptions of sample independence (strong spatial autocorrelation along video transects), model equifinality, selection of probability thresholds for construction of binary and multi-class maps, and lack of direct environmental predictors (Austin, 2002).

Spatial scale and perception issues are critical for integrating datasets collected at multiple scales and on different sample support, and affect model interpretation. For example, landscape-scale models may or may not reflect what the field (or video) observer expects, and approaches need to be developed to distinguish incorrect models from perceived differences due to changes in scale. The marine community's unfamiliarity with large-area spatial analysis increases resistance to alternative mapping products, and outreach activities will be required to promote the benefits of more spatially explicit, semi-quantitative maps with associated uncertainty estimates (e.g. Figure 1).

4. Future directions

Terrestrial spatial research offers a sound foundation and many lessons for advancing marine geographic analysis; however, fundamental differences in the underlying environmental and biological processes in terrestrial versus marine systems will dictate the amount of theoretical and methods adaptation required. For advancement of broad-scale marine spatial analysis, and predictive modelling in particular, strong links must be forged between basic ecological theory and models used for prediction. The following list identifies key areas for research:

- Identifying and spatially quantifying processes driving ecological distributions
- Linking marine theory with economically measurable parameters over large areas
- Resolving issues of sample support, scale effects, diverse data integration, and uncertainty measures
- Linking hydroacoustic signals to specific physical and biological characteristics
- Algorithm testing and development, particularly for rare occurrences and accommodating spatial autocorrelation

Advances in these areas will increase confidence in predictive model results, and help make predictive modelling science more generally applicable to a much larger percentage of the earth's surface.

5. Figures

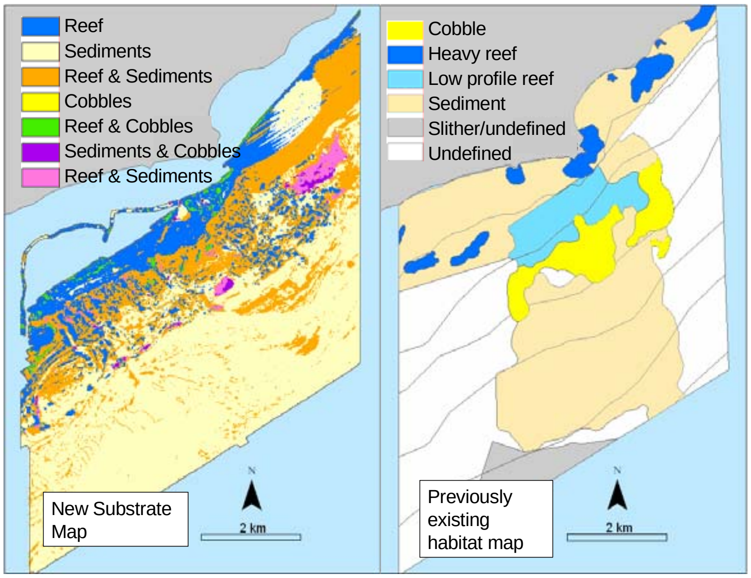

Figure 1. Examples of a habitat map constructed with predictive modelling using a classification tree and hydroacoustic data (left), and standard manual methods (right: Plummer et al. 2003) for Point Addis Marine National Park, southeastern Australia (Parks Victoria – Coastal CRC joint venture: 9 – 60 metres water depth).

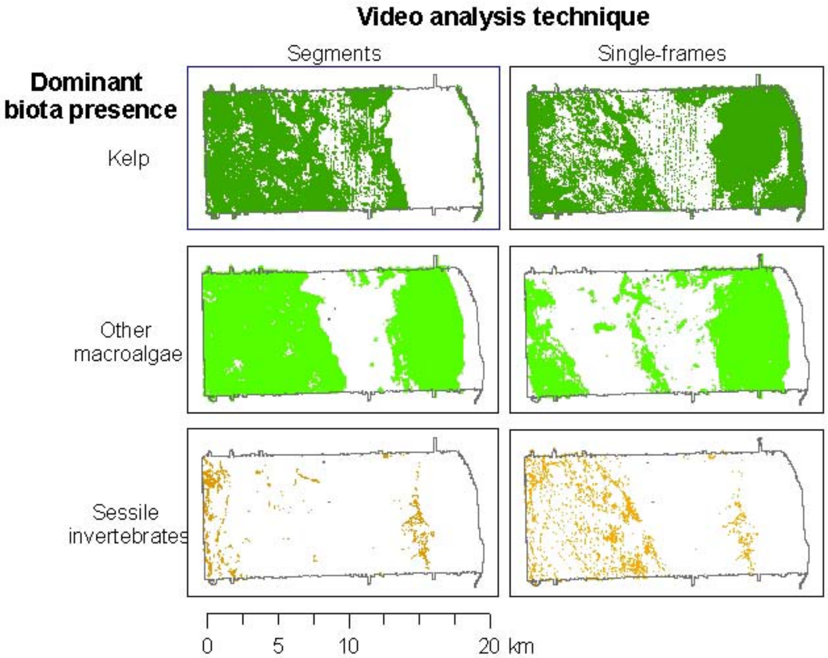

Figure 2. Predictive mapping over 167 sq. km in Jurien Bay, Western Australia, illustrating impact of video analysis method: (left column) described as segments, then sampled at points, and (right column) described on single frames. (8 – 48 metres water depth).

6. Acknowledgements

This work has been supported by Marine Futures (Natural Heritage Trust Strategic funding at The University of Western Australia, 2006-2008), and grew out of the Parks Victoria - Coastal CRC habitat mapping initiative (2004-2006).

7. References

Austin MP. 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. *Ecological modelling* **157**: 101-118.

Bax N, Kloser R, Williams A, Gowlett-Holmes K, Ryan T. 1999. Seafloor habitat definition for spatial management in fisheries: a case study on the continental shelf of southeast Australia. *Oceanologica Acta* **22**: 705-720.

Brown CJ, Cooper KM, Meadows WJ, Limpenny DS, Rees HL. 2002. Small-scale mapping of sea-bed assemblages in the eastern English Channel using sidescan sonar and remote sampling techniques. *Estuarine, Coastal and Shelf Science* **54**: 263-278.

Durako MJ, Hall MO, Merello M. 2002. Patterns of change in the seagrass dominated Florida Bay hydroscape. In *The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook*, Porter JW, Porter KG (eds). CRC Press: Washington D.C.; 523-537.

Fonseca MS, Whitfield PE, Kelly NM, Bell SS. 2002. Modeling seagrass landscape pattern and associated ecological attributes. *Ecological Applications* **12**: 218-237.

Guisan A, Zimmerman NE. 2000. Predictive habitat distribution models in ecology. *Ecological modelling* **135**: 147-186.

Jackson JBC, Kirby MX, Berger WH, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**: 629-639.

Kendrick GA, Aylward MJ, Hegge BJ, Cambridge ML, Hillman K, Wyllie A, Lord DA. 2002. Changes in seagrass coverage in Cockburn Sound, Western Australia between 1967 and 1999. *Aquatic Botany* **73**: 75-87.

Ojeda GY, Gayes PT, Van Dolah RF, Schwab WC. 2004. Spatially quantitative seafloor habitat mapping: example from the northern South Carolina inner continental shelf. *Estuarine, Coastal and Shelf Science* **59**: 399-416.

Plummer A, Morris L, Blake S, Ball D. 2003. Marine Natural Values Study, Victorian Marine National Parks and Sanctuaries. In. Parks Victoria Technical Series No. 1, Parks Victoria, Melbourne.

Silva S, Tseng Y-T. 2005. Classification of seafloor habitats using genetic programming. In *GECCO'05 Late-Breaking Papers, June 25-29*. Washington D.C.; 1-8.