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THEME SECTION

Seascape ecology: application of landscape ecology to the marine environment

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Practicing coastal seascape ecology

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ABSTRACT: Landscape ecology concepts developed from terrestrial systems have recently emerged as theoretical and analytical frameworks that are equally useful for evaluating the ecological consequences of spatial patterns and structural changes in the submerged landscapes of coastal ecosystems. The benefits of applying a spatially-explicit perspective to resource management and restoration planning in the coastal zone are rapidly becoming apparent. This Theme Section on the application of landscape ecology to the estuarine and coastal environment emerged from a special symposium at the Coastal and Estuarine Research Federation (CERF) 20th Biennial Conference (Estuaries and Coasts in a Changing World) held in Portland, Oregon, USA, in November 2009. The 7 contributions in this Theme Section collectively provide substantial insights into the current status and application of the landscape approach in shallow marine environments, and identify significant knowledge gaps, as well as potential directions for the future advancement of 'seascape ecology'.

KEY WORDS: Landscape ecology · Seascapes · Spatial pattern · Spatial planning

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Emergence of seascape ecology

Measurement of spatial patterns plays a central role in monitoring environmental change and for studying the multi-scale processes that drive organism distributions and biodiversity. A conceptual and analytical framework for studying seascapes (i.e. wholly or partially submerged marine landscapes) currently does not exist, but landscape ecology appears to offer a suitable approach for studying the spatial ecology of marine species and communities (Fig. 1). Landscape ecology, developed over a half century ago primarily for managing terrestrial environments, focuses on the causes, changes and ecological functions associated with spatial patterns. The discipline of landscape ecology has developed a unique set of concepts and analytical tools, which combined with a holistic and interdisciplinary perspective has made valuable contributions to the understanding and management of terrestrial environments (Turner et al. 2001, Gergel & Turner 2002). Our lack of knowledge on seascape patterns and their ecological consequences represents both a major void in our understanding of marine and coastal ecology and an exciting new frontier for research (Fig. 1). Although seascape ecology is on the verge of entering mainstream marine ecology, the level of familiarity is still comparable to that reported by terrestrial landscape ecologists in the 1980s, whereby 'ideas were new and were received with a mixture of skepticism and excitement' (Turner 2005). In part, this is due to the persistent limited exchange of perspectives and concepts between terrestrial ecologists and the coastal science community (Kneib 1994, Stergiou & Browman 2005) and the dominance of a relatively fine scale and single scale approach in estuarine and marine ecology (Pittman & McAlpine 2003). Furthermore, the interdisciplinary approach, spatial data types, tools and techniques used in landscape ecology are more typical of geographical sciences than those traditionally applied in coastal ecology, although quantitative spatial techniques are now being taught to the new generation of coastal ecologists (Wright et al. 2007).

Resolution of seascape patterns

Coastal environments exhibit physical patterns that are shaped by many interacting processes, including human activity, at a range of scales in time and space (Fig. 1). Widely recognized spatial patterns include the dendritic networks of tidal channels in coastal wetlands, the spatial zonation of biotic communities across tidal salt marshes and rocky shores, and the intricate mosaics of patches that characterize seagrass beds, coral reefs, mangrove forests and tidal marshes (Boström et al. 2011, this Theme Section). Such broad scale and structurally complex spatial patterns are now being revealed in increasing detail by the latest generation of remote sensing devices mounted on underwater vehicles, floating platforms, survey ships and air- and spacecraft. Although patterns detected by remote sensing imagery are often visually captivating, it is

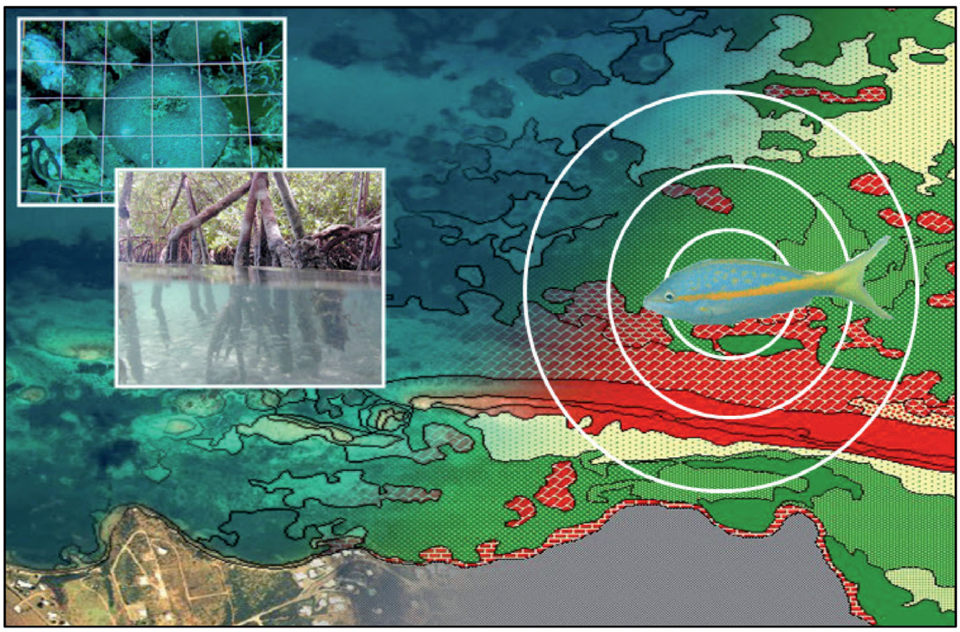

Fig. 1. Landscape ecology analyzes the effects of spatial patterns such as patch structure (e.g. coral cover, seagrass height, mangrove root density) and geometric properties (e.g. patch size, connectivity) on organisms and communities at various temporal and spatial scales

their ecological implications that are scientifically intriguing and most relevant to society. Understanding the relationship of observed patterns, such as those depicted in benthic habitat maps, to the provision of ecosystem goods and services is increasingly important in the face of rapid human-induced changes to the coastal zone. While seascape patterns may be most obvious in the coastal zone, they are not confined to nearshore ecosystems; in the open ocean, dynamic multi-dimensional spatial structure in the form of water currents, eddies, temperature fronts, plankton and seabird patches can be mapped and measured with modern spatial technologies. The application of landscape ecology to the pelagic realm is exceedingly rare. Innovative concepts and analytical techniques are required to interpret these spatially-explicit data and to make these findings applicable to marine management, if coastal and marine spatial planning (CMSP) is to be effective in the sustainable management of global marine resources.

Thematic highlights

This Theme Section emerged from a special full-day conference symposium at the Coastal and Estuarine Research Federation (CERF) 20th Biennial Conference (Estuaries and Coasts in a Changing World) held in Portland, Oregon, USA, in November 2009. A total of 20 speakers from around the world made oral presentations on a wide range of topics addressed through a landscape ecology perspective. We present a collection of 7 papers based on that symposium that include 2 reviews (Boström et al. 2011, Wedding et al. 2011, this Theme Section) and a range of applications of landscape ecology concepts and tools applied to coastal seascapes. Since the early 1990s, the landscape ecology approach has been applied primarily to shallow-water subtidal and intertidal ecosystems (Robbins & Bell 1994), with the majority of studies carried out in seagrass beds (49 %) and tidal marshes (32 %), with fewer studies in coral reefs (11 %) and mangroves (6 %) (Boström et al. 2011). Few seascape studies have considered the consequences of spatial patterns on ecological processes; instead, they have focused on statistical associations between species distributions and seascape geometrics (Boström et al. 2011, Wedding et al. 2011). Notable exceptions include research in the 1990s conducted with a strong focus on predator–prey interactions and movements of nekton in seagrass and salt marsh landscapes on the east coast of the United States (Irlandi et al. 1995, Irlandi & Crawford 1997, Kneib 1997, Micheli & Peterson 1999, Hovel & Lipcius 2001). However, few have developed uniquely marine concepts or metrics. Wedding et al. (2011) reviewed the application of spatial pattern metrics to marine environments and found only one truly unique marine metric, while all others were derived from terrestrial landscape ecology.

Historically, the number of papers applying landscape ecology concepts to coastal environments has remained relatively low, with an average of 5 papers published per year between 1978 and 2010 (Boström et al. 2011). The 7 papers in this Theme Section make a comparatively major contribution to the emerging body of knowledge. As coastal scientists and managers begin to embrace landscape ecology, it is apparent that many of the concepts and analytical techniques are equally applicable to coastal environments, and that much can be gained from the insights and lessons learned from terrestrial applications in order to hone the emerging sub-discipline of seascape ecology. The urgency in understanding the impacts of changing spatial patterns on land and sea is heightened by the rapid global loss and degradation of coastal habitats such as coral reefs, seagrasses, mangroves and salt marshes. The trans-boundary and multidisciplinary nature of landscape ecology provides a suitable approach to address land–sea connectivity. Santos et al. (2011, this Theme Section) and Oliver et al. (2011, this Theme Section) consider the effects of inputs from coastal upland watersheds on the condition and spatial arrangement of marine biotic assemblages that form important shallow water seascapes.

Benthic habitat maps are the marine equivalent of terrestrial vegetation maps and land use or land cover maps and facilitate the application of landscape ecology to quantify the surface structure of the seafloor. Using benthic habitat maps that differ in spatial and thematic (i.e. number of map classes) resolution, Kendall et al. (2011, this Theme Section) explored the effects of seascape patterns on fish assemblages. Kendall et al. (2011) and Santos et al. (2011) conducted an exploratory multi-scale analysis using Geographical Information System (GIS) tools to quantify 2-dimensional seascape geometry. With a strong focus on movement ecology, Hitt et al. (2011, this Theme Section) coupled acoustic tracking technology with benthic habitat maps to explore a new frontier in behavioral landscape ecology, by characterizing individual diel movements of fishes within a coral reef seascape. A stochastic stage-based modeling approach was taken by Mizerek et al. (2011, this Theme Section) to evaluate the potential effects of varying fishing pressure and stocking enhancement in seascapes that included submerged aquatic vegetation (SAV) at different levels of fragmentation. All of the contributions to the Theme Section demonstrate the importance of studying spatial patterns through the application of landscape ecology concepts and tools and the implications for the management of coastal and marine resources.

Future foci in seascape ecolgy

We envisage that the focus on CMSP and spatial prioritization for biodiversity conservation will dramatically increase spatial data acquisition and availability (e.g. habitat maps and remote sensing images of coastal areas). Making sense of these patterns will require a landscape ecology approach for developing and testing novel ecological hypotheses, with substantial potential for providing ecological information at spatial scales that are operationally relevant to management. Perhaps the greatest challenge and defining objective of landscape ecology in both terrestrial and aquatic realms, is to determine the mechanisms by which spatial patterns influence key ecological processes. Some progress has been made in the past 30 yr but much greater effort will be required to reach the same level of practical benefits to coastal management that has already been reached in terrestrial conservation. There are many new and exciting challenges for seascape ecology research; only a few have been addressed to date. Key topic areas include (1) a better understanding of the influence of upland landscape patterns and processes on adjacent seascapes; (2) determining the relevance of seascape structure for key ecological processes such as organism growth, survival (including predator–prey dynamics) and movement; (3) identifying and mapping optimally connected seascapes and movement corridors; (4) determining which of the structural attributes of seascapes drive biotic assemblages and the distribution of biodiversity; (5) quantifying and understanding the impacts of global climate change on seascape patterns, including spatial shifts in seascape structure, fragmentation and loss of seascape elements; and (6) the identification of threshold effects or tipping points in seascape structure resulting in abrupt changes in ecological functions and processes. A glimpse into the wealth of new ecological knowledge that has emerged from terrestrial landscape ecology over the past 3 decades indicates the enormity of the task ahead for marine and coastal ecologists. The inevitable emergence of seascape ecology fits into a broader paradigm shift toward greater spatial awareness in academic studies, the public sector, industry and across human society in general (Goodchild 2010).

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LITERATURE CITED

Boström C, Pittman SJ, Simenstad C, Kneib RT (2011) Seascape ecology of coastal biogenic habitats: advances, gaps, and challenges. Mar Ecol Prog Ser 427:191–217

Gergel SE, Turner MG (eds) (2002) Learning landscape ecology: a practical guide to concepts and techniques. Springer-Verlag, New York

Goodchild MF (2010) Twenty years of progress: GIScience in 2010. J Spatial Info Sci 1:3–20

Hitt S, Pittman SJ, Nemeth RS (2011) Diel movements of fish are linked to benthic seascape structure in a Caribbean coral reef ecosystem. Mar Ecol Prog Ser 427:275–291

Hovel KA, Lipcius RN (2001) Habitat fragmentation in a seagrass landscape: patch size and complexity control blue crab survival. Ecology 82:1814–1829

Irlandi EA, Crawford MK (1997) Habitat linkages: the effect of intertidal saltmarshes and adjacent subtidal habitats on abundance, movement and growth of an estuarine fish. Oecologia 110:222–230

Irlandi EA, Ambrose WG, Orlando BA (1995) Landscape ecology and the marine environment: how spatial configuration of seagrass habitat influences growth and survival of the bay scallop. Oikos 72:307–313

Kendall MS, Miller TJ, Pittman SJ (2011) Patterns of scale-dependency and the influence of map resolution on the seascape ecology of reef fish. Mar Ecol Prog Ser 427:259–274

Kneib RT (1994) Spatial pattern, spatial scale, and feeding in fishes. In: Stouder DJ, Fresh KL, Feller RJ (eds) Theory and application in fish feeding ecology. University of South Carolina Press, Columbia, SC, p 171–185

Kneib RT (1997) The role of tidal marshes in the ecology of estuarine nekton. Oceanogr Mar Biol Annu Rev 35:163–220

Micheli F, Peterson CH (1999) Estuarine vegetated habitats as corridors for predator movements. Conserv Biol 13:869–881

Mizerek T, Regan HM, Hovel KA (2011) Seagrass habitat loss and fragmentation influence management strategies for a blue crab *Callinectes sapidus* fishery. Mar Ecol Prog Ser 427:247–257

Oliver LM, Lehrter JC, Fisher WS (2011) Relating landscape development intensity to coral reef condition in the watersheds of St. Croix, US Virgin Islands. Mar Ecol Prog Ser 427:293–302

Pittman SJ, McAlpine CA (2003) Movement of marine fish and decapod crustaceans: process, theory and application. Adv Mar Biol 44:205–294

Robbins BD, Bell SS (1994) Seagrass landscapes: a terrestrial approach to the marine environment. Trends Ecol Evol 9:301–304

Santos RO, Lirman D, Serafy JE (2011) Quantifying freshwater induced fragmentation of submerged aquatic vegetation communities using a multi-scale landscape ecology approach. Mar Ecol Prog Ser 427:233–246

Stergiou KI, Browman HI (2005) Bridging the gap between terrestrial and marine ecology: introduction. Mar Ecol Prog Ser 304:271–272

Turner MG (2005) Landscape ecology in North America: past, present and future. Ecology 86:1967–1974

Turner MG, Gardner RH, O'Neill RV (2001) Landscape ecology in theory and practice. Springer-Verlag, New York

Wedding LM, Lepczyk CA, Pittman SJ, Friedlander AM, Jorgensen S (2011) Quantifying seascape structure: extending terrestrial spatial pattern metrics to the marine realm. Mar Ecol Prog Ser 427:219–232

Wright DJ, Blongewicz MJ, Halpin PN, Breman J (2007) Arc Marine: GIS for a blue planet. ESRI Press, Redlands, CA