

# 1,000 feet above a coral reef:

## A seascape approach to designing marine protected areas

By Rikki Grober-Dunsmore, Victor Bonito, and Thomas Frazer

**F**ROM THE VANTAGE OF AN OPEN-COCKPIT AIRPLANE, the colors of the water below shift from light green to aqua blue to rich cobalt. These color changes signify the different patches of habitat that lie beneath the surface: sea grass beds, shallow reefs, halos of sand, and deep channels. From 300 m (1,000 ft) above, this habitat mosaic hints at the connectedness of the coral reef ecosystem. Habitat patches of varying shapes and sizes are linked to one another by movement of fish, nutrients, and energy flows, creating patterns of connectivity across spatial scales from the reef patch to the barrier reef. Because the elements of coral reef ecosystems are interconnected, managing them as a whole, rather than as a series of disconnected parts, makes sense. Landscape ecology is ideally suited for addressing real-world problems, from designing migration corridors for elephants in Africa to creating networks of protected areas for giant otters in the Peruvian rain forest. By using a “seascape” perspective, scientists and managers can address concerns at a scale appropriate to resource management needs in coral reef ecosystems (Forman 1995).

Such a bird’s-eye or seascape perspective will be critical for designing marine protected areas (MPAs) (fig. 1), which have grown increasingly popular as ecosystem-based tools for improving fisheries management and protecting biodiversity. Effectiveness is contingent on understanding key ecological patterns and processes at appropriate spatial scales, and may depend upon maintaining critical linkages among essential habitat patches to conserve reef fish communities. Unfortunately, how the design of any particular MPA will influence its effectiveness, especially in highly complex and dynamic coral reef ecosystems, is unclear. Coral reefs exist as heterogeneous ecosystems consisting of various habitat patches that can differ markedly in their spatial arrangement and composition. Evidence is increasing for the importance of maintaining habitat linkages that support key ecosystem processes, which in turn sustain viable reef fish populations. A failure to consider and maintain functional habitat linkages that affect important ecological processes in the design of protected areas is likely to result in undesirable changes in community structure and possibly the loss of key species. Consequently, while reef habitat may be essential to reef fish production, different MPA designs—size, shape, and proximity to habitat types—may produce different results. For example, movement of



**Figure 1.** In this study we used benthic habitat maps, created by the NOAA Biogeography Team for the U.S. Virgin Islands, from which we calculated landscape-scale metrics of the seascape spatial patterning for each study reef. In the Ikonos aerial imagery (above, left) and classified benthic habitat maps (above, right), each color represents a different habitat type: pink = bedrock, orange = reef, purple = gorgonian plain, yellow = sand, white = sea grass. Given aerial imagery and habitat classification capability, this information can be used to design more effective MPAs.

fishes may be more likely outside the boundaries of MPAs given certain arrangements of habitat types (see Chapman and Kramer 2000). Thus, a key to future success in protecting reef habitat and fisheries is quantifying how alternative design options will impact a desired outcome. Simply setting aside areas based on jurisdictional or political motivations may not be sufficient.

## Seascape patterns and reef fish in the Caribbean

We present here a brief overview of some of our recent work in which we applied terrestrial landscape ecology principles to the issue of MPA design and management in coral reef ecosystems. Our objectives are to (1) demonstrate the benefits of a landscape ecology approach in coral reef ecosystems and (2) examine the utility of large-scale benthic habitat maps for tracking fish movement in order to predict the structure and spatial patterns of reef fish assemblage as proxies for selecting priority conservation sites. Our research to date has spanned the globe, with specific work carried out in both the Caribbean and South Pacific, including study sites in the Florida Keys, Turks and Caicos islands, U.S. Virgin Islands (Grober-Dunsmore et al. 2007; Grober-Dunsmore et al. 2008), and Fiji islands.

In the Caribbean, we conducted fish censuses (fig. 2) at reefs in the U.S. Virgin Islands, the Florida Keys National Marine Sanctuary, and the Turks and Caicos islands. Using a Geographic Information System (GIS), we spatially analyzed various reef fish parameters derived from these data. We tested hypotheses to investigate how well different landscape metrics predict reef fish assemblage structure and examined the importance of habitat linkages. General landscape metrics such as habitat diversity and patch density were not predictors of reef fish assemblage structure. However, as expected, reef context (the spatial pattern of surrounding habitat patches) was a strong predictor of reef fish assemblage structure. Specific relationships were functionally consistent with the ecology of the fishes of interest. For example, reefs with large amounts of sea grass nearby harbored the greatest numbers of fishes, particularly mobile invertebrate feeders and exploited fishes such as grunts and snappers. Species richness for the entire fish community and within these latter groups of fishes was also strongly associated with reef context (fig. 3). We detected fish-habitat relationships as far as 1 kilometer (0.6 mi) from study reefs, suggesting that fish movements result in habitat encounter rates that may influence their patterns of distribution. Consequently, functional habitat connectivity of habitat patches appears important in structuring reef fish assemblages, and suggests that landscape-scale metrics may provide insights useful to managers designing MPAs.



COURTESY OF VICTOR BONITO

**Figure 2.** Scientist Rikki Grober-Dunsmore conducts a reef fish census.

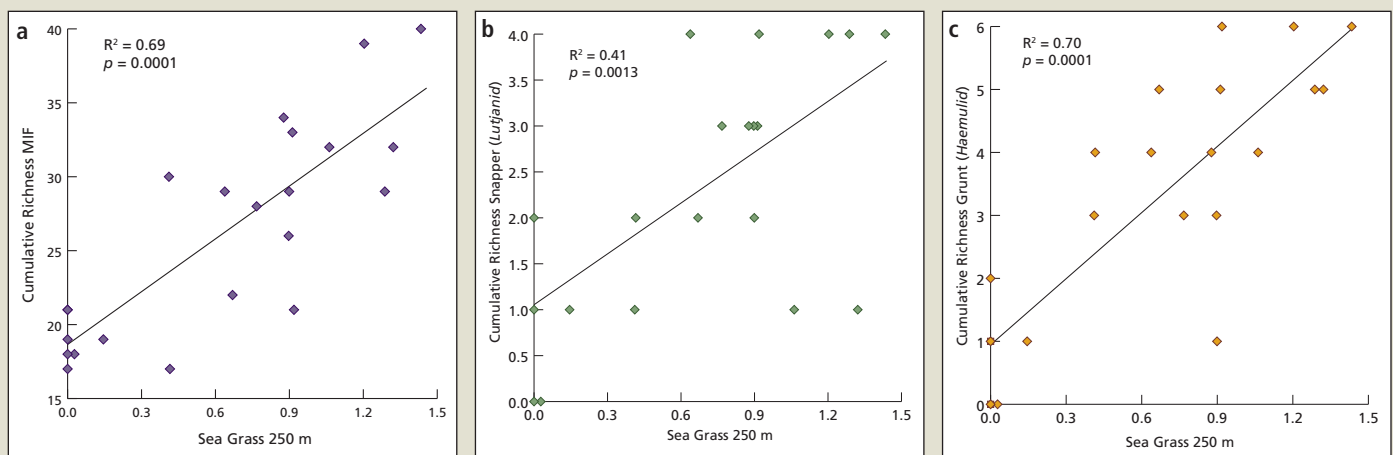


**Figure 3.** The graphs show the relationship of cumulative species richness to spatial extent of sea grass and reveal that species richness is strongly associated with reef context. In 2002, we sampled (a) mobile invertebrate feeders (MIFs), (b) snapper (lutjanids), and (c) grunt (haemulids) within 22 study reefs in St. John, U.S. Virgin Islands. The x-axis is spatial extent of sea grass,  $\log_{10}(x+1)$  transformed. Source: Grober-Dunsmore et al. 2007.



COURTESY OF VICTOR BONITO

**Figure 4.** At the coral reef community in Fiji, South Pacific Islands, we asked the question: “Does the location and surrounding seascape of a particular MPA influence whether reef fishes will remain within the boundaries of an MPA or move outside and be susceptible to fishing mortality?” Research findings from acoustic tagging revealed that fishes moved consistently across MPA boundaries within a continuous reef patch. While periodic excursions outside the reef patch occurred, it appears that the underlying seascape can influence reef fish movements.

## Measuring reef fish movement in Fiji

To build on these findings and better understand how seascape features influence reef fish distribution, movement patterns, and ultimately MPA effectiveness, our scientific team traveled to the Coral Coast of Vitu Levu in Fiji (fig. 4). Here we asked the question “Does the location and surrounding seascape of a particular MPA influence whether reef fishes will remain within the boundaries of an MPA or move outside and be susceptible

to fishing mortality?” To date, most research has focused on describing patterns of fish assemblage structure given variation in landscape structure (Kendall et al. 2003; Dorenbosch et al. 2007; Grober-Dunsmore et al. 2007, 2008), rather than on identifying and quantifying key ecological mechanisms that underlie the observed patterns. By using high-tech acoustic tagging technologies, we were able to track the movements of targeted reef fishes using a landscape ecology approach to improve our understanding of the linkages among habitat types.



**Figure 5.** Fijian fishers Betty and Teresia (left and right, respectively, with author Rikki Grober-Dunsmore in the center) teach scientists about the movement patterns and behaviors of targeted reef fishes in their local village of Votua, along the southern coast of Fiji.

In collaboration with local communities (fig. 5), we evaluated whether Lethrinids (bottom-feeding fishes) captured at common village fishing areas were part of the same population as those intended for conservation within the adjacent MPA. Our team caught Lethrinids in the channel and shallow back reef (i.e., “reef flat habitat”) within and outside the MPA, which we implanted with acoustic tags that allowed us to track their movements for up to five months. Fishes tagged from disparate habitats (fig. 6) exhibited different temporal and spatial diurnal patterns of movement. Fishes tagged in the channel were detected predictably inside the channel during the day, but at night left the channel and were detected on adjacent reef flat habitat not within the MPA (fig. 7). Fishes tagged on the reef flat moved primarily during the night within reef flat habitat, and were detected periodically in the channel. These fishes crossed MPA boundaries, moving freely across the continuous fringing reef flat habitat and traveling distances up to 1 kilometer (0.6 mi). Although the entire home range of Lethrinids does not appear to be incorporated within the present MPA design, the MPA may afford considerable protection of Lethrinids because fishing pressure occurs almost exclusively during the day. Fishes generally left the MPA during the night, when fishing rarely occurs. Consequently, fishes may derive “temporal refugia” from fishing pressure because they remain inside the MPA during the periods when fishing generally occurs. Comprehensive diurnal habitat requirements may be met with minor adjustments in MPA boundaries. Finally, fishes that reside primarily outside the MPA may be afforded benefits by the MPA because they appear to use the reef flat area for foraging.



**Figure 6.** By inserting an acoustic pinger into fish such as *Lethrinus harak*, we were able to track the movement patterns of reef fishes inside and outside the MPA. The pinger sends a beeping signal to a receiver.



**Figure 7.** A seascape perspective (aerial image) of Votua Reef along the Coral Coast of Fiji shows the deep-channel and back-reef flat habitat in which we tracked reef fish to determine how various habitat features inhibit or facilitate movement.

## Summary

Increasingly, marine scientists are adopting a seascape approach to examine coral reef ecosystem patterns and processes across spatial scales in order to address pressing resource management concerns such as conserving essential fish habitat and designing MPA networks (Friedlander et al. 2007; Grober-Dunsmore et al. 2007; Pittman et al. 2007). Our work over the past several years confirms that landscape ecology can also assist in understanding interactions between movement behavior and the spatial patterning of the seascape, ultimately leading to more ecologically meaningful MPA designs. Ongoing spatial planning efforts around the world (e.g., Australia, New Zealand, California, and Hawaii) are using a seascape perspective to better manage and conserve coral reef ecosystems.

---

*A failure to consider and maintain functional habitat linkages that affect important ecological processes in the design of protected areas is likely to result in undesirable changes in community structure and possibly the loss of key species.*

---

## Acknowledgments

Funding for this work was provided by the Canon National Parks Science Scholars Program (award to Rikki Grober-Dunsmore) and the Biological Resources Discipline of the U.S. Geological Survey. Logistical support was provided by Virgin Islands National Park with field assistance from Jason Hale, Thomas Kelly, Sherri Caseau, and Iuri Herzfeld. In the U.S. Virgin Islands, special thanks are owed to Rafe Boulon and Caroline Rogers at Virgin Islands National Park. In the Florida Keys the support of the Florida Keys National Marine Sanctuary, in particular Billy Causey and Brian Keller, is greatly appreciated. Field support in the Florida Keys and Turks and Caicos was provided by Duncan Vaughn and the School for Field Studies. In Fiji the University of the South Pacific's Institute of Marine Sciences facilitated our research. In particular, Bill Aalbersberg, James Comley, and Tawake Aliferiti assisted in countless ways. Votua village deserves particular recognition, especially the field support crew of Team Kabatia. Thank you all.

## References

- Chapman, M. R., and D. L. Kramer. 2000. Movements of fishes within and among fringing coral reefs in Barbados. *Environmental Biology of Fishes* 57:11–24.
- Dorenbosch, M., W. C. E. P. Verberk, I. Nagelkerken, and G. van der Velde. 2007. Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs. *Marine Ecology Progress Series* 334:103–116.
- Forman, R. T. 1995. *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press, New York, New York, USA.
- Friedlander, A. M., E. K. Brown, and M. E. Monaco. 2007. Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii. *Ecological Applications* 17(3):715–730.
- Grober-Dunsmore, R., T. K. Frazer, J. P. Beets, W. J. Lindberg, P. Zwick, and N. Funicelli. 2008. Influence of landscape structure on reef fish assemblages. *Landscape Ecology* 23:37–53.
- Grober-Dunsmore, R., T. K. Frazer, W. J. Lindberg, and J. Beets. 2007. Reef fish and habitat relationships in a Caribbean seascape: The importance of reef context. *Coral Reefs* 26:201–216.
- Kendall, M. S., J. Christensen, and Z. Hillis-Starr. 2003. Multi-scale data used to analyze the spatial distribution of French grunts, *Haemulon flavolineatum*, relative to hard and soft bottom in a benthic landscape. *Environmental Biology of Fishes* 66:19–26.
- Pittman, S. J., J. D. Christensen, C. Caldow, C. Menza, and M. E. Monaco. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. *Ecological Modelling* 204:9–21.

## About the authors

**Rikki Grober-Dunsmore** was a 2002 Canon Scholar from the University of Florida. She completed her dissertation, "Application of landscape ecology principles to the design and management of marine protected areas in coral reef ecosystems," in 2004. Dr. Grober-Dunsmore is an associate professor at the Institute for Applied Sciences at the University of the South Pacific in Fiji, South Pacific Islands. She can be reached at [dunsmore\\_l@usp.ac.fj](mailto:dunsmore_l@usp.ac.fj).

**Victor Bonito** is founder of Reef Explorer Fiji, working as a coral reef ecologist developing research and educational programs to improve success of marine conservation efforts.

**Thomas Frazer** is associate director of the School of Forest Resources and Conservation, University of Florida, and oversees the school's Fisheries and Aquatic Sciences Program. Dr. Frazer's area of interest and expertise is the ecology of oceanic and coastal marine systems.