Coral Reefs and Ecosystem Connectivity

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Introduction

Marine environments are not closed systems, but often have a fluid transfer and cycling of organisms, nutrients, and ecosystem functions. This is especially true for the ecosystems connected to coral reefs; Coral reef ecosystems are considered some of the most diverse and productive habitats on Earth and play vital environmental roles while also being economically and socially important (Hughes, et al. 2010; Moberg & Folke, 1999; Mumby & Steneck, 2008). There are more than one hundred countries worldwide with coral reefs off their coasts and some of these biogentic structures are large enough that they can be seen from space (Moberg & Folke, 1999; Mumby & Steneck, 2008). Reef ecosystems provide habitat for many marine species (over 1/3 of all fish species can be found on reefs) and also provide local people with services and goods in the form of food, tourism, and coastline protection (Moberg & Folke, 1999).

These living landscapes are vital not only to the animals that live directly on the reef and the people that benefit from them, but also to many nearby ecosystems like mangrove forests and seagrass beds (Odgen & Gladfelter, 1983). The multitude of habitats associated with coral reefs make up a system where all interconnected habitats depend on and benefit from one another (UNESCO, 1983). This occurs by the habitats dispensing various ecosystem services such as facilitating animal and larval dispersal, providing shelter and/or nursey grounds for organisms, and enabling nutrient flow between habitats that are mutually beneficial to the nearby ecosystems (Adam et al., 2001; Botsford et al., 2009; Nagelkerken et al., 2011; Odgen & Gladfelter, 1983). Coral reefs and nearby habitats, however, face a myriad of threats and are in grave danger as they are becoming increasingly perturbed by human devolvement, disease, climate change, and habitat degradation (Adam et al., 2001; Hughes et al., 2010; Mccook et al., 2009; Mumby & Steneck, 2008). This transfer of goods, services, and animals between ecosystems means in order to protect the world's coral reefs, all associated habitats must be understood and also protected (Mumby & Hastings, 2008). This paper will discuss the common communities typically associated with reef environments, how these habitats interact, and what that means for conservation.

Associated Habitats

There are a variety of coral reef types with each having distinct characteristics and functions, but the four most common types include: fringing, atoll, platform, and barrier reefs Moberg and Folk, 1999). The degree at which coral reefs are connected and interact with other habitats and systems varies depending on the type of reef and its location globally (Moberg and Folk, 1999), but there are some more commonly associated communities. The habitats that most commonly interact with large reef systems, such as the Great Barrier Reef in Australia, include (in order of relation to mainland out to open water): mainland beaches/coastlines, mangrove forests, seagrass beds, lagoons/flats, shoals, and open ocean (Great Barrier Reef Marine Park Authority, 2014; Figure 1.).

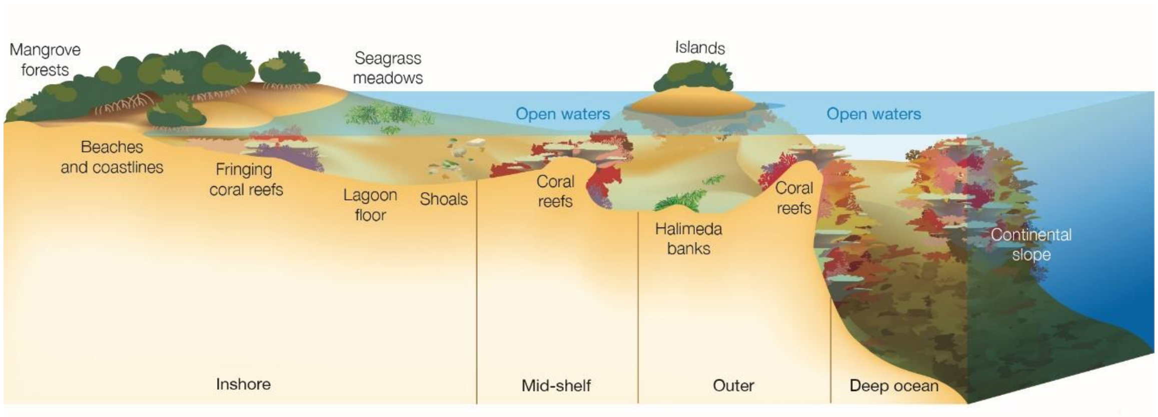

Figure 1. Graphic depicting common major habitats that make up a coral reef system and interact. This image particularly illustrates the communities which make up the Great Barrier Reef Region in Australia (Retrieved from the 2014 Great Barrier Reef Outlook Report copyright: Great Barrier Reef Marine Park Authority, 2014).

Habitat ecosystem functions and their connections

Each habitat plays unique and important roles independently, but also has a level of interconnection with the coral reef(s) and other communities in the area.

Mangroves, seagrass, and reefs. Mangrove forests occur along sheltered areas where fine bottom sediments allow mangrove trees to settle and accumulate (Great Barrier Reef Marine Park Authority, 2014). Their branching root systems anchor the sediment in place and provide shelter for marine and terrestrial species and they also act as carbon sinks and coastal storm buffers while simultaneously cycling nutrients and improving water quality (Ewel et al., 1998; Goudkamp and Chin, 2006; Laffoley & Grimsditch, 2009; Schaffelke et al., 2005). Seagrass beds are found inshore in shallow waters and provide habitat for many invertebrate and vertebrate species, sequester carbon, stabilize sediment, cycle nutrients, and provide a source of food for sea turtles, manatees, and dugongs (Conservation International, 2008; Great Barrier Reef Marine Park Authority, 2014; Odgen & Gladfelter, 1983). While some of the connections to coral reefs might already be apparent from the above mentioned ecosystem functions, mangrove forests and seagrass beds are two of the most well studied ecosystems associated with coral reefs, and play vital roles in regards to organism dispersal, nutrient cycling, and physical interactions between the three habitats (Mumby and Hastings, 2008; Nagelkerken et al., 2000; Odgen & Gladfelter, 1983).

Physical interactions between the three habitats are numerous and functions of each allow for overall formation and health of the others (Moberg & Folke, 1999; Odgen & Gladfelter, 1983; UNESCO, 1983). Seagrass beds and mangroves rely on generally calm waters and the presence of sediment in which to root, both of which are provided by coral reefs (Great Barrier Reef Marine Park Authority, 2014).The physical presence of the reef buffers wave activity and the erosion of fore-reef produces fine, calcareous sediment over time which is then dispersed by water movement (Goudkamp & Chin, 2006; UNESCO, 1983). Both seagrass and mangroves stabilize sediment which protects the nearby ecosystems (land and marine) from erosion and degradation (Ewel et al., 1998; Moberg & Folke, 1999). Additionally, seagrass and mangroves help improve water quality in reef ecosystems (Goudkamp & Chin, 2006; Moberg & Folke, 1999; Schaffelke et al., 2005; UNESCO, 1983).

The flow of organisms between coral reefs, seagrass beds, and mangrove forests are often quite fluid and happen on both short term (daily or seasonal migrations) and long term (life-stage migrations) scales with both resulting in a transfer of energy between systems (Mumby, 2006; UNESCO, 1983). Both seagrass and mangrove habitats are well-known nursery environments for many coral reef species as they provide abundant shelter and food for vulnerable juvenile organisms (Nagelkerken et al., 2000; Odgen & Gladfelter, 1983; Robertson et al., 1987; UNESCO 1983). The dispersal of organisms is not limited to larval and juvenile stages, however, as some adult species may utilize one habitat for shelter, but venture out to neighboring habitats in order to feed or spawn (UNESCO 1983; Mumby, 2006). For example, sea urchins may take shelter within coral reef crevices, but move out from them to forage on the fringing sea grass beds (UNESCO, 1983).

Nitrogen and phosphorous are needed for primary production and are limiting factors in marine environments such as mangroves, seagrass beds, and coral reefs, which all utilize such nutrients (Odgen & Gladfelter, 1983; Goudkamp & Chin, 2006; Moberg & Folke, 1999; UNESCO, 1983). Mangroves and seagrass export nutrients increasing primary productivity in the system and the transfer of organisms, detailed above, further cycles nutrients between habitats via defecation (Moberg & Folke, 1999; UNESCO, 1983). The organic matter shed (leaf or woody detritus) by seagrass and mangrove plants increase the nutrients in the system to provide food within their habitats and are transported by currents to other nearby ecosystems (Moberg & Folke, 1999; UNESCO, 1983).

Other major habitats. Coastline beaches are where the ocean meets the land and can be rocky, sandy, muddy, or otherwise depending on location, and often help protect the mainland from erosion while also providing animals like sea turtles and shore birds with nesting habitats (Clemens et al., 2008; Great Barrier Reef Marine Park Authority, 2014; Hermann et al., 2011). These coastlines are intimately connected to coral reefs as much of the sediment that makes up coastal beaches and nearshore bottom substrate come from the broken up calcareous skeletal material that originates as reef-front but is then broken into gravel by wave action and then organisms like urchins and fishes that utilize the nearby habitats (UNESCO, 1983). Additionally, those aforementioned sea turtles spend much of their adult lives foraging and traveling throughout other connected systems such as seagrass beds, reefs, and open ocean (Great Barrier Reef Marine Park Authority, 2014; Hermann et al., 2011).

Lagoon and shoals are seafloor habitats typically inshore of barrier reef systems in water depths ranging from shallow (~20m) to up to 40m with shoals being on the deeper edge of the spectrum having a rocky bottom versus sandy bottom (Cappo et al., 2007; Great Barrier Reef Marine Park Authority, 2014; 2012). Both habitats house variable marine species including both invertebrate species (sea fans, sponges, crabs, worms, and microbial organisms and algae) and vertebrate species (sharks, rays, sea turtles, and many fish targeted by commercial fisheries) (Cappo et al. 2007, Cappo and Kelley, 2001; Great Barrier Reef Marine Park Authority, 2014). The dispersal of organisms between these two environments is fluid as they are typically adjacent to each other, but they also provide food, shelter, and nursery habitat for organisms that utilize nearshore and offshore ecosystems. Additionally, many of these areas are heavily fished, which can have negative effects on the coral reef system (Cappo et al., 2009; Great Barrier Reef Marine Park Authority, 2014).

Open sea out starts out beyond the reefs themselves and include the deeper waters where light does not penetrate as easily, causing this habitat to be less densely inhabited by marine flora and fauna in comparison to the above mentioned habitats. Here, microorganisms like plankton are the most abundant, which support larger offshore species such as pelagic fishes and marine mammals (Great Barrier Reef Marine Park Authority, 2014). While deeper waters may seem to be very unlike the other coral reef associated communities, the open ocean still interacts with and depends on reefs. Many large fish species spend their juvenile stages in the protection of nursery habitats like mangroves, seagrass beds, and reefs and eventually make their way to deeper less protective waters (Nagelkerken et al., 2000; Robertson & Duke, 1987). It has also been found that coral reefs support the food web of pelagic food webs by exporting surplus organic materials and dissolved organic matter (Moberg and Folke, 1999). Most offshore marine mammals like baleen or toothed whales do not heavily utilize nearshore reefs habitats, but often inhabit adjacent open water habitats- for example, around 30 species of whales and dolphins are known to inhabit the Great Barrier Reef Region (Great Barrier Reef Marine Park Authority, 2014; Valentine et al., 2004). In particular cases, more direct interactions do take place between marine mammals and reefs- some dolphins forage near reefs or exhibit a coral and sponge rubbing behavior (to potentially for medicinal/exfoliation purposes) (Ziltener et al., 2015) and a common prey species of baleen whales, copepods, have been documented to aggregate and swarm in coral reef habitats (Hamner & Carleton, 1979). Additionally, large species like marine mammals contribute to overall ecosystem primary productivity as they enhance nutrient availability for planktonic species via their feces (Roman & McCarthy, 2010).

Conclusions

Coral reefs and the surrounding communities are intimately intertwined and rely heavily on each other for ecosystem functions. Mangrove forests and seagrass beds are crucial to coral reef systems, but lagoons, shoals, beaches, and open water habitats all affect one another and play a part in supporting healthy and biodiverse coral reefs (Great Barrier Reef Marine Park Authority, 2014). The fluidity of nutrients, organisms, sediments, and physical interactions make the system complex and the balance crucial (UNESCO, 1983). There are both positive and negative implications that result from ecosystems that are so interconnected and dependent on one another. In regard to negative impacts, the influencing factors affecting one habitat can potentially (and typically does) affect all connected communities by threatening the balance of the system. Many of the main habitats with major ecosystem functions in coral reef ecosystems are currently being threatened, including: dredging in seagrass meadows, deforestation of mangroves, commercial overfishing in lagoons and open water, and bleaching of coral species (Great Barrier Reef Marine Park Authority, 2014; Moberg and Folke, 1999; Mumby and Hastings, 2008; Mumby & Steneck, 2008; UNESCO, 1983). These threats can disturb the balance and flow of the system in regards to sediment control and dispersal, the balance of absorbed and released chemical and nutrients, and disrupt the migration of organisms.

Interconnectivity, however, is not always a con, and is often considered more of an advantage. It has been found that reef systems that are adjacent to nearby associated habitats are more resilient and better handle stress and perturbations from threats like hurricanes than reefs that are more isolated (Adam et al., 2011; Mumby & Hastings, 2008). For example, when nutrient levels become out of balance, algal growth can start to take over a reef, but Mumby and Hastings (2008) found that reefs with adjacent mangrove forests had the ability to recover much more effectively because of the fluid dispersal of animals, specifically parrotfish which eat algae, between habitats. This connection of habitats functions as a buffer for the associated communities and improves the resiliency of coral reef ecosystems (Adam et al., 2011; Mumby & Hastings, 2008).

The scale and the rate of disturbances and threats towards coral reefs will most likely increase with global climate change; therefore, figuring out how to better protect them is a priority (Adam et al., 2011; Mumby, 2006). In order to do so, the connectivity of ecosystems must be addressed by policy makers when considering how to conserve and preserve coral reef ecosystems (Adam et al., 2011; McCook, et al., 2009; Mumby, 2006; Mumby and Hastings, 2008). Protecting coral reef is not just vital for the connected habitats, but also to the people who depend on the goods and services which they provide (Conservation International, 2008; Costanza et al., 1998; Moberg & Folke, 1999). More recently, it has become clear that just protecting one habitat, the reefs themselves, is not enough and habitat connectivity must be considered when designing effective marine protected areas (MPAs) and protect reef resiliency

(Botsford, et al., 2009; Hughes, 2011; McCook, et al., 2009; Mumby, 2006). Fortunately, advances in technology are allowing researchers to better understand and prove how habitats are connected and model dispersals like the movement of larva in order to better create MPAs and marine reserves in order to conserve coral reef biodiversity and their connected communities (Adam et al., 2011; Botsford et al., 2009; Hughes, 2010; Mumby 2006).

Literature Cited

Adam, T. C., Schmitt, R. J., Holbrook, S. J., Brooks, A. J., Edmunds, P. J., Carpenter, R. C., & Bernardi, G. (2011). Herbivory, Connectivity, and Ecosystem Resilience: Response of a Coral Reef to a Large-Scale Perturbation. *PLoS ONE, 6*(8). doi:10.1371/journal.pone.0023717

Botsford, L. W., White, J. W., Coffroth, M. A., Paris, C. B., Planes, S., Shearer, T. L., . . . Jones, G. P. (2009). Connectivity and resilience of coral reef metapopulations in marine protected areas: Matching empirical efforts to predictive needs. *Coral Reefs, 28*(2), 327-337. doi:10.1007/s00338-009-0466-z

Cappo, M. & Kelley, R. (2001). Connectivity in the Great Barrier Reef World Heritage Area - an overview of pathways and processes. In EJ Wolanski (Ed.), *Oceanographic Processes of Coral Reefs: Physical and Biological Links in the Great Barrier Reef* (pp. 161-188). CRC Press.

Cappo, M., De'Ath, G., & Speare, P. (2007). Inter-reef vertebrate communities of the Great Barrier Reef Marine Park determined by baited remote underwater video stations. *Marine Ecology Progress Series Mar. Ecol. Prog. Ser., 350,* 209-221. doi:10.3354/meps07189

Cappo, M.C., MacNeil, M.A., Stowar, M.J. & Doherty, P.J. (2009). The influence of zoning (closure to fishing) on fish communities of the deep shoals and reef bases of the southern Great Barrier Reef. Part 1 - Baited video surveys of the Pompey, Swain and Capricorn-Bunker groups of reefs off Mackay and Gladstone. MTSRF Research Report No. 37. Reef and Rainforest Research Centre and Australian Institute of Marine Science. 53 p.

Clemens, R. S., Weston, M. A., Haslem, A., Silcocks, A., & Ferris, J. (2010). Identification of significant shorebird areas: Thresholds and criteria. *Diversity and Distributions, 16*(2), 229-242. doi:10.1111/j.1472-4642.2009.00635.x

Conservation International. (2008). *Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation*. Center for Applied Biodiversity Science, Conservation International, Arlington, VA, USA.

Odgen, J. C., & Gladfelter, E. H. (1983). *Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean* (138 pp, Unesco Rep in marine Science. No. 23).

Costanza, R., D'arge, R., Groot, R. D., Farber, S., Grasso, M., Hannon, B., . . . Belt, M. V. (1998). The value of the world's ecosystem services and natural capital. *Ecological Economics, 25*(1), 3-15. doi:10.1016/s0921-8009(98)00020-2

Ewel, K. C., Twilley, R. R., & Ong, J. E. (1998). Different Kinds of Mangrove Forests Provide Different Goods and Services. *Global Ecology and Biogeography Letters, 7*(1), 83. doi:10.2307/2997700

Great Barrier Reef Marine Park Authority. (2012). *Informing the outlook for Great Barrier Reef coastal ecosystems,* Great Barrier Reef Marine Park Authority, Townsville.

Great Barrier Reef Marine Park Authority. (2014). *Great Barrier Reef outlook report 2014: in brief*, GBRMPA, Townsville.

Goudkamp, K., & Chin, A. (2006). Mangroves and Saltmarshes in Chin. A, (ed) *The State of the Great Barrier Reef On-line*, Great Barrier Reef Marine Park Authority, Townsville.

Hamann, M., Grech, A., Wolanski, E., & Lambrechts, J. (2011). Modelling the fate of marine turtle hatchlings. *Ecological Modelling, 222*(8), 1515-1521. doi:10.1016/j.ecolmodel.2011.02.003

Hamner, W. M., & Carleton, J. H. (1979). Copepod swarms: Attributes and role in coral reefecosystems. *Limnol. Oceangr. Limnology and Oceanography, 24*(1), 1-14. doi:10.4319/lo.1979.24.1.0001

Hughes, T. P., Graham, N. A., Jackson, J. B., Mumby, P. J., & Steneck, R. S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution, 25*(11), 633-642. doi:10.1016/j.tree.2010.07.011

Laffoley, D.d'A. & Grimsditch, G. (eds). 2009. *The management of natural coastal carbon sinks*. IUCN, Gland, Switzerland. 53 pp

Mccook, L. J., Almany, G. R., Berumen, M. L., Day, J. C., Green, A. L., Jones, G. P., . . . Thorrold, S. R. (2009). Management under uncertainty: Guide-lines for incorporating connectivity into the protection of coral reefs. *Coral Reefs, 28*(2), 353-366. doi:10.1007/s00338-008-0463-7

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics, 29*(2), 215-233. doi:10.1016/s0921-8009(99)00009-9

Mumby, P. J. (2006). Connectivity of reef fish between mangroves and coral reefs: Algorithms for the design of marine reserves at seascape scales. *Biological Conservation, 128*(2), 215-222. doi:10.1016/j.biocon.2005.09.042

Mumby, P. J., & Hastings, A. (2007). The impact of ecosystem connectivity on coral reef resilience. *Journal of Applied Ecology, 45*(3), 854-862. doi:10.1111/j.1365-2664.2008.01459.x

Mumby, P., & Steneck, R. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends in Ecology & Evolution, 23*(10), 555-563. doi:10.1016/j.tree.2008.06.011

Nagelkerken, I., Velde, G. V., Gorissen, M., Meijer, G., Hof, T. V., & Hartog, C. D. (2000). Importance of Mangroves, Seagrass Beds and the Shallow Coral Reef as a Nursery for Important Coral Reef Fishes, Using a Visual Census Technique. *Estuarine, Coastal and Shelf Science, 51*(1), 31-44. doi:10.1006/ecss.2000.0617

Robertson, A. I., & Duke, N. C. (1987). Mangroves as nursery sites: Comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. *Mar. Biol. Marine Biology, 96*(2), 193-205. doi:10.1007/bf00427019

Roman, J., & Mccarthy, J. J. (2010). The Whale Pump: Marine Mammals Enhance Primary Productivity in a Coastal Basin. *PLoS ONE, 5*(10). doi:10.1371/journal.pone.0013255

Schaffelke, B., Mellors, J., & Duke, N. C. (2005). Water quality in the Great Barrier Reef region: Responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin, 51*(1-4), 279-296. doi:10.1016/j.marpolbul.2004.10.025

Valentine, P. S., Birtles, A., Curnock, M., Arnold, P., & Dunstan, A. (2004). Getting closer to whales—passenger expectations and experiences, and the management of swim with dwarf minke whale interactions in the Great Barrier Reef. *Tourism Management, 25*(6), 647-655. doi:10.1016/j.tourman.2003.09.001

Ziltener, A., Kreicker, S., & Gross, S. (2015). Selective self-rubbing behaviour in Indo-Pacific bottlenose dolphins off Hurghada, Northern Red Sea, Egypt. Poster presented and published in accordance with the Anthropological Institute and Museum, University of Zurich and Dolphin Watch Alliance, Switzerland. Can be accessed at: http://www.dolphinwatchalliance.org/projekt_forschung_en.html