PATTERNS AND PROCESSES OF REEF RECOVERY AND HUMAN RESOURCE USE IN THE LAKSHADWEEP ISLANDS, INDIAN OCEAN

Thesis submitted by

Rohan Arthur (MSc Wildlife Science)

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Abstract

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Finding solutions that effectively conserve natural areas while simultaneously protecting the sustenance rights of resource stakeholders is a considerable challenge for ecosystem managers and scientists. In complex ecosystems like tropical coral reefs, the problem of management is further confounded by an inadequate understanding of how ecosystem function will respond to changes in environmental or management conditions. Given this uncertainty, managers are looking at ways to support and enhance the natural buffering capacity of ecosystems in the face of change, i.e. ecosystem resilience. Human use of natural areas can profoundly modify this resilience, particularly in the developing tropics, where a large proportion of the population depends directly on natural areas for daily sustenance. In these areas, developing and implementing effective management solutions requires a close understanding of both ecosystem processes and the factors affecting human interactions with the ecosystem.

This study examined the processes of ecosystem change after a major mass mortality of coral in the Lakshadweep Islands and the consequences that changes in resource use and policy have had on the recovery potential of these reefs.

The Lakshadweep Islands are a group of atolls in northern Indian Ocean. The El Niño Southern Oscillation (ENSO) of 1998 resulted in anomalous sea surface temperatures (SSTs) that caused extensive coral mortality in the reefs. I studied the patterns of recovery of coral and fish communities on outer reefs on three atolls, Agatti, Kadmat and Kavaratti from 2000 to 2003. Corals showed a mixed pattern of recovery: sites on the eastern aspects of islands showed little recovery of coral cover, while sites on the west showed a rapid increase in coral cover. This difference between aspects appears to be a function of the degree of exposure of these sites to seasonal monsoonal storms, and differences in the long-term stability of coral settlement substrate between aspects. Genera of coral that showed the most significant gains represented two very different life history strategies. *Porites* and *Goniastrea* were generally more resistant to bleaching stress. In contrast, *Acropora* was highly susceptible to bleaching, but recovered very quickly from disturbances by recruiting in large numbers, and sustaining high growth rates once established.

Fish communities in coral reefs are naturally very variable, but there were noticeable trends in fish assemblages after bleaching in the Lakshadweep. Species richness and diversity increased from 2000 to 2003 at all sites. Herbivorous fishes such as surgeonfish and parrotfish were very abundant in post-bleached reefs, representing up to 70% of all trophic guilds in the reef in 2000. The dominance of herbivores declined with time as coral took over from algal turf in many reefs. Multidimensional scaling (MDS) analysis of fish communities indicated that fish assemblages were moving towards increasing similarity with time, possibly approaching a post-disturbance equilibrium.

I interpret the recovery of Lakshadweep's reefs to disturbance within the conceptual framework of catastrophe theory. Catastrophe theory has been effectively used in several other ecosystems as a phenomenological model of ecosystem change, and the applicability of the two-factor cusp catastrophe is a useful conceptual model of reef responses to disturbance. This theory suggests that in the face of global warming, managers and scientists many need to invest their energies in understanding uncertainty on the one hand while managing for resilience on the other.

Biotic studies in the reefs of the Lakshadweep indicated that although the fine-scale patterns of recovery are variable, the reefs appear to be highly resilient after coral mortality. The current pattern of resource use practised in the Lakshadweep contributed in part to this high resilience. Despite being among the most densely populated locations in India, with over 2200 people/km^2, for most of the year the human population of the Lakshadweep do not depend on the reef for food. This situation largely results from a development initiative started by the Fisheries Department in the 1960s which actively converted reef fishers to pelagic tuna fishing with a series of subsidies and training programmes. This initiative was implemented solely to enhance economic development of the islands, but it has inadvertently released reefs from a potentially large resource extraction pressure. Thus local regulations have played an important if inadvertent role in controlling marine resource use in the Lakshadweep.

The Lakshadweep case study has important lessons for resource conservation in the developing tropics. The coral reefs of the Lakshadweep apparently possess considerable resilience in the face of catastrophic coral mortality. One of the major contributors to this resilience was the relatively low level of fishing pressure on these reefs, despite high human population densities. The policy change that was responsible for a shift away from reef fishing was designed primarily as a developmental activity, but it had significant, but completely unintended positive consequences for

the resilience of the reef. The Marine Protected Area (MPA) is the principal tool currently used to manage the vanishing diversity of threatened ecosystems like coral reefs. While MPAs may still be the most effective solution in marine conservation, MPAs are often difficult and expensive to establish and maintain. It is even more difficult to get local communities to reconcile with a loss of access to resource areas. The Lakshadweep example suggests that there may be alternative paths to enhance ecosystem resilience that are perhaps as effective in achieving conservation goals. It is not often that ecosystem conservation and human development can pull in the same direction, but when they do, this synergy should be encouraged and supported.

Acknowledgements

My first experience of field research was on an island in the Gulf of Kutch – a tiny piece of land with mudflats and mangroves. I lived there for several months with a lighthouse keeper, a Forest Department watchman called *Dada*, and his wife, *Dadi*. *Dadi* was one of those rare innocents you find occasionally, whose world view was almost completely circumscribed by the 1.5 kms^2 of the island, her home for as long as she could remember. Talking with her one day as she cooked the evening meal, she asked me how long I had been studying. Seventeen years, I told her. She looked at me, aghast, and, after a small pause, said kindly, "You know, if you find it so difficult to pass the exams, there is no shame in giving up and trying something else".

Well, *Dadi*, I'm still at it. And, whether you realise it or not, you are part of the reason why I continue to do this. You, and numerous others, without whom my work would not only not have been possible, it would have very little meaning. You will forgive me if my attempt to thank all of you is ineffectual and incomplete.

I am an unruly researcher, and if anyone understands this well, it is my supervisory team. My supervisors, Terry Done, Helene Marsh and Vicki Harriott were indulgent with my most unrealistic ideas, and have nudged me in the right direction with quiet, insistent patience. You are an inspiration, and I am humbled by the unstinting dedication you showed for my work. Graeme Inglis supervised me in the initial years of this project, and he tried in vain to instil in me a rigor of approach, that I could only admire in him. Graeme, I still don't quite know what my question is exactly, but if you ask me enough times, perhaps I will discover it.

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Doing field research in the Lakshadweep is a logistic nightmare, and it would not have been possible without the help of several wonderful organisations in Australia, mainland India, and the Lakshadweep Islands. The dive operation, Lacadives, made diving in the Lakshadweep a dream, providing boats, compressed air, tanks and helpful hands whenever I needed them. In mainland India, the Nature Conservation Foundation provided invaluable support in handling funds, and being my liaison between the islands and the rest of the world. James Cook University, and the Department of TESAG provided institutional support in Australia, along with the Australian Institute of Marine Science. Both Helene Marsh and Peter Valentine, as Heads of Department of TESAG were always encouraging and supportive, particular when dealings with the bureaucracy put my candidature at risk. I would also like to thank Susan Knight, Barbara Pannach, Susan Meehan, Beth Moore, Shirley Bruce, Clive Grant, Robert Scott, Jody Krueger, and all the wonderful administrative staff at TESAG for providing such unstinting support throughout these years.

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experience and intimate knowledge of the island culture and ecology. My thinking about the Lakshadweep has been very largely influenced by you, and I look forward to more rewarding interactions in the future.

The Lakshadweep Islands have a special place in my heart, not merely for its trite picture postcard beauty (it gets old pretty quickly), but because the people of the Lakshadweep accepted me as one of their own. My field assistants and their families have been a vital part of my research – they are the people whose names seldom get on to scientific publications, but without whom so much of our research would be impossible. M.K. Ibrahim (Omni the Small), and Shah Jahan in particular accompanied me on most of my dives, and complained only when I pushed myself beyond what they thought were reasonable limits. Their friendship helped me through many of those long frustrating days in the field, when weather and inertia conspired to make working difficult. I also have to thank Captain Koya, Khalid, Latif, and all the lads in the Lakshadweep who helped in the field, and made living there a pleasure. I owe a special thanks to Prahlad and Mitali Kakkar, Sumer Verma, Anees Adenwala, Parinita Zia Nath, Shaukat Ali, Sarang Kulkarni, and all the good guys from Lacadives and Reefwatch.

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Lastly, I would like to thank the Indian bureaucracy, for teaching me the art of gentle forbearance.

This thesis is dedicated to the memory of Zu, who would have loved the reef in all its irresponsible exuberance, and to the memory of Vicki, for her very responsible exuberance.

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Statement of Sources

Declaration

I declare that this thesis is my own work and has not been submitted in any other form for another degree or diploma at any university or other institutions of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Statement of Contribution of Others

I declare that this thesis is my own work, and has been supported by the following organisations and people. The field budget was funded through a DIVERSITAS/TOTAL Foundation Grant through the Australian Institute of Marine Science. Additional administrative support for the field project was provided by the Nature Conservation Foundation, India, Lacadives Dive School, and Reef Watch Marine Conservation.

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Signature **Date**

Declaration on Ethics

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the *National Statement on Ethics Conduct in Research Involving Humans* (1999), the *Joint NHMRC/AVCC Statement and Guidelines on Research Practice* (1997), the *James Cook University Policy on Experimentation Ethics, Standard Practices and Guidelines* (2001), and the *James Cook University Statement and Guidelines on Research Practice* (2001).

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