

## Appendix E

# Cause-Effect Pathway Extract

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## **The effects of bioturbation by stingrays at Ningaloo Reef, Western Australia**

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Stingrays are an important part of the biomass of the fishes in shallow, coastal ecosystems, particularly in inter-reefal areas. In these habitats they are thought to be keystone species, responsible for modifying physical and biological habitats through their foraging and predation. However, there have been few attempts to quantify the effects of these animals on benthic environments. Here, we examine the effects of bioturbation by rays on sand flats of the lagoon of Ningaloo Reef WA. At Mangrove Bay we surveyed 15, 10x10 m quadrats during August 2009, September 2010 and February 2011. We recorded all pits that could be identified as due to ray feeding. Of these, 98 were selected randomly to be measured (length, breadth, depth) on a daily basis for a week. Over the 21 day period, a total of 2.01 cubic m of sediment was excavated by ray pits equating to a wet weight of 1,411.3 kg and 2.42% of the total area sampled. Based on these figures, up to 42% of the soft sediments in our study area would be re-worked by stingray feeding to an average depth of 5.16 cm over a year. Within the 15 quadrats, new pits were formed at a rate of 0.41/day and then maintained a clear shape for an average of 1.57 days, after which time they could no longer be measured. All evidence of the pit was lost after an average of 3.3 d. In addition to the turnover of sediment and removal of prey, pits created sheltered habitats for a range of organisms, including larval fish, crabs and gastropods. The role of stingrays is compared with that of other organisms that are seen as important ecosystem engineers in soft-sediment environments such as dugongs, crabs and callinasiid shrimps.

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## **Cause-Effect pathways in mangrove ecosystems; can they make management easier?**

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Conventional regulation relies on the modelling of physical systems to connect changes in human activity to the metric of system performance. Management of complex natural systems also requires models that link patterns of human impact to changes in the relevant metric of system performance. Unfortunately however, the determination of all but the most simple cause and effect pathways regarding biological systems, including mangroves, remains largely incomplete. Present research outcomes now allow us to gain some idea of the pathways often associated with mangrove habitat degradation or loss. Conceptual modelling illustrates that, while a number of natural factors affect mangroves, anthropogenic impacts can be fairly easily defined. This allows us to focus our attention when considering activities that may impact upon these ecosystems. This paper will describe cause/effect pathways applicable to all mangrove systems and the impacts associated with them.