7 Anticipated Impacts of Climate Change on Marine Biodiversity: Using Field Situations that Simulate Climate Change in Singapore

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Increasing evidences demonstrate that climate change affects natural systems and causes significant impacts on biodiversity (IPCC 2007). On marine systems, the impacts of climate change include elevated sea temperature, and changes in salinity, oxygen, pH levels, and circulation, among others. Although it is not easy to isolate climate change impacts on natural systems from adaptation and non-climatic drivers, it is not altogether impossible to anticipate these impacts. Impacts can be seen from existing scenarios that simulate climate change conditions. These impacts may be simple as they do not take into account the uncertainties of the complex interaction of causal factors and the exacerbations of human activities.

Climate change results in the greater frequency of extreme weather events, elevated sea temperatures, rise in sea levels, and more intense stratification of the water column (Chou 1994). These impacts generate entire suites of accompanying environmental effects on coastal and marine systems. The effects include coastal erosion, sudden salinity fluctuation, increased sedimentation, nutrient loading, salt water intrusion, coastal inundation, and changes in coastal geomorphology and circulation patterns (Chou 1992).

Singapore's intensive coastal development, including coastal reclamation, provides many field conditions that adequately represent some aspects of climate change impacts. Attention is drawn to a few case studies, which, in spite of limitations, give an adequate idea of expected impacts on marine biodiversity. These case studies dealt with sedimentation, natural colonisation of human-made habitats, salinity depression, and sea surface temperature elevation.

NATURAL COLONISATION OF ARTIFICIAL HABITAT

The reef flats of a few southern offshore islands have been reclaimed for a variety of reasons. One such island is Pulau Hantu, which was reclaimed to enhance its recreational potential.

Located 8 km south of the main island of Singapore, Pulau Hantu originally consisted of two small adjacent islands, Pulau Hantu Besar (2 ha) and Pulau Hantu Kechil (0.4 ha). These two islands were surrounded by fringing reefs. They also shared a common reef flat between them. Both islands were then reclaimed between March 1974 and April 1975 using 0.4 million m^3 of sand, thereby increasing the total land area to 12.2 ha (Figure 7.1). The reclamation covered most of the reef flats, up to an average 15 m short of the reef crest, with the sand held back by a solid rock bund. The common reef flat between the two islands was buried under sand and transformed into a swimming lagoon that was opened to full tidal influence.

The common reef flat promoted the natural colonisation of hard corals and reef-associated benthic organisms. This situation is similar to sand beaches that are flooded when sea level rises. The colonisation of coastal human-made lagoons by reef communities provides an adequate model in interpreting reef response to newly submerged shores from a raised sea level. A study of the established biodiversity was conducted in 1992 – 17 years after the lagoon was created.

A perpendicular transect was deployed at the north entrance of the lagoon (Figure 7.1), moving from the existing reef crest into the lagoon. Seven 20-m parallel transects, at 10-m intervals of the perpendicular transect, were established. They were labeled as A to G, with A located at the innermost part of the lagoon, and G located at the lagoon entrance. Along each 20-m parallel transect, a 1-m^2 quadrant, with a grid of 100 squares of 100 cm^2 each, was placed at alternate meters, enabling an area of 10 m^2 per parallel transect for assessment. The aerial cover of individual benthic organisms was measured within each square meter quadrant.

The depth profile of the lagoon was constant along the perpendicular transect. There was no exposure even at very low spring tide. The substratum

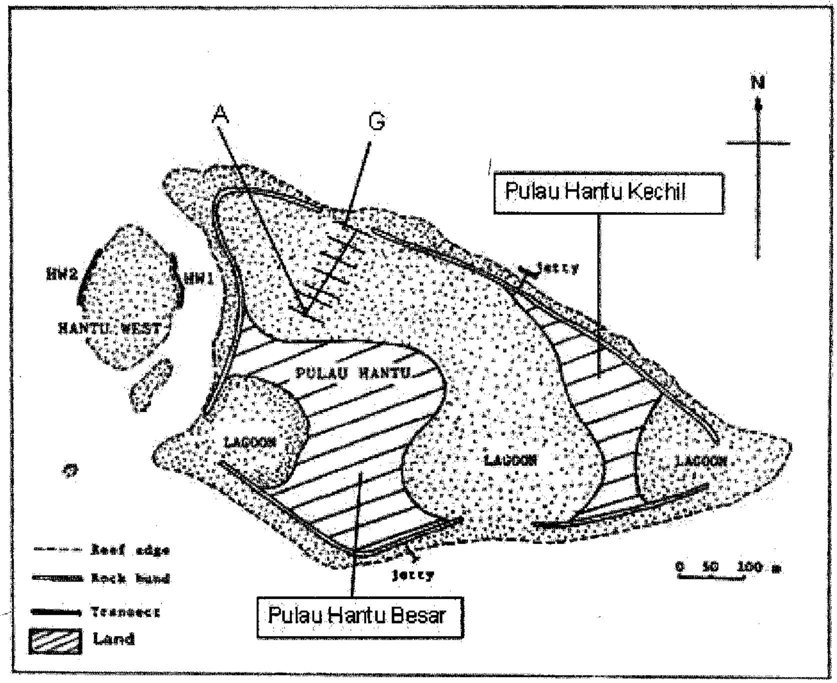

***Figure 7.1** Plan view of Pulau Hantu complex showing location of transects*

was mostly comprised of sand with the presence of a few small rocks. Hard corals were usually found associated with these rocks. Total per cent cover of all organisms, across transects, ranged from 5.6 to 19.9 (Table 7.1). The trend of increasing abundance, from the inner to the outer lagoon, reversed abruptly at the outermost transect.

Apart from the major life form categories recorded within the quadrants, other organisms, such as gastropods, bivalves, hydroids, anemones, zoanthids and polychaetes, were observed together with more motile forms, such as gobies and crustaceans. Sargassum was the major macroalgae. Of the two genera of seagrass, *Halophila* was more abundant than the larger *Enhalus*.

The abundance distribution showed macroalgae to be consistently dominant in all the transects (Table 7.2), together with seagrass and sponges. Tunicates dominated the innermost transect after macroalgae. However, they

Table 7.1 *Per cent cover of benthic organisms across transects at Pulau Hantu lagoon*

Benthic Organisms	Percent Cover						
	A	B	C	D	E	F	G
Hard corals	0.02	0.15	0.34	0.10	1.10	0.70	0.30
Soft corals	0.02	-	0.02	-	-	0.30	-
Sponges	1.20	1.60	2.10	3.50	0.60	0.06	0.07
Seagrass	0.50	2.90	1.40	0.80	0.20	0.04	-
Macroalgae	3.40	5.70	5.20	5.70	18.00	16.00	2.10
Others	0.46	1.65	1.44	1.90	-	2.10	4.02
Total	5.60	12.00	10.50	12.00	19.90	19.20	6.49

Table 7.2 *Percentage abundance and distribution of life forms across transects at Pulau Hantu lagoon*

Life Forms	Percentage Abundance and Distribution						
	A	B	C	D	E	F	G
Hard corals	0.40	1.20	3.70	0.90	5.80	0.60	11.70
Soft corals	0.40	0.01	0.20	0.04		2.70	
Sponges	21.40	12.90	22.50	32.00	2.80	5.10	2.50
Tunicates	7.00	2.20	1.60	6.50	1.40		
Zoanthids	1.00	15.00		0.70		1.60	
Anemones						0.40	3.90
Seagrass	8.90	22.80	14.90	6.70	0.80		
Macoalgae	61.00	45.80	57.20	53.10	89.20	89.60	81.90

tapered off sharply in the remaining transects. Although hard corals were low in abundance, they were well-distributed over all the transects, together with macroalgae and sponges. Anemones were confined to the two outer transects, from which seagrass and zoanthids were absent. The inner transects appeared to support a greater diversity of life forms.

The original reef crest and slope of the island complex support a live coral cover of up to 44 per cent (Chou 1988). The site, nearest the survey transects, had a community structure, comprising of 29.5 per cent live coral cover, 13.3 per cent dead corals, 13.5 per cent algae, and 10.8 per cent other fauna. The original reef community along the non-reclaimed crest and slope, remained a source of larvae and recruits for the natural colonisation of the lagoon.

Within the lagoon, macroalgae and seagrass were the fastest colonisers. Among the fauna, sponges were the fastest and most widespread colonisers. The abundance of macroalgae, seagrass, and sponges was the same as in the other reef flats which were not reclaimed (Chou and Wong 1985). Hard coral colonisation was slow and dominated by massive growth forms of *Goniopora*, *Porites*, *Favites*, *Favia*, *Goniastrea* and *Platygyra*. Most of these small colonies, which were established on loose rocks, indicated the necessity of a hard substrate.

This study indicates how reef communities respond to new sand habitats that are flooded with rising sea levels. However, this study did not consider the impacts of accompanying changes, such as increased storminess, sedimentation from increased run-off, and erosion. Each change has its own influence on colonisation patterns. Recent studies, including that of Goh (2007), indicated the natural colonisation of created sand flats with most coral colonies established on rocks.

SEDIMENTATION

Singapore's marine environment provides an excellent setting for studying the short- and long-term impacts of sedimentation on marine biodiversity. Increased frequency of extreme weather events due to climate change will transport large amounts of sediments into the sea. Intense coastal development since the 1960s, including land reclamation, dredging and dumping of dredged spoils, together with terrestrial run-off, contributed to the sea's heavy sediment load.

Chou (2006) reported that coastal developments destroyed and reduced the area of many natural habitats. The newly created habitats, meanwhile, promoted the establishment of different biological communities that are best suited to the new conditions.

Species distribution patterns have been altered in response to changing environmental conditions. Corals no longer thrive below 6 m of the reef slope as sediment reduced light penetration. Complete species extinction from Singapore waters has been limited and less than expected considering the scale, variety, and intensity of impacts. Abundance has also been reduced. Many species have been found to be less common or rare. This situation is best reflected by the response of the coral reefs. There has been an upward shift in the depth limit of coral growth, thus reducing the zone for favorable growth. From 250 hard coral species, only one species, *Seriatopora hystrix*, is likely to be locally extinct. The lower than expected rate of species richness decline can be attributed to habitat resilience from the originally rich biodiversity and strong marine pollution control measures.

Mud bottoms were dominated by polychaetes, in terms of species diversity, followed by bivalves or gastropods (Chou 1988). Sand bottoms showed variation in faunal diversity dominance between polychaetes and crustaceans. There were evidences that epifaunal diversity was higher than infaunal diversity.

Community structure, which changes in response to localised impacts of sedimentation, can be fairly rapid. This scenario is consistent with intense and excessive rainfall as the climate changes. Near the southern offshore islands, the dumping of dredged spoils, which covered the bottom with thick layers of silt, caused the benthic community diversity to decline between 1989 and 1993 (Chou and Loo 1994). A further study in 1996 revealed that changes in the abundance, familial diversity, and abundance of benthic invertebrate fauna were correlated with sedimentation rate, sediment composition, and ammonia concentration. This was the result when an extensive rock bund was constructed to enclose the sea on the island's eastern part for use as a sanitary landfill (Chou, Yu and Loh 2004).

In the mangrove estuary of Sungei Buloh, distinct changes in the benthic community structure were detected between 1990 and 1992. This was the period when 87 ha of land were gazetted as a nature park. Prior to 1990, all farming activities (pig, poultry, and shrimp) around the area were steadily phased out. The changes were indicative of a response to improved environmental quality (Goh, Loo and Chou 1994).

Similarly, a study of macrobenthic infauna at Sungei Punggol, an estuarine river in the north, showed that coastal reclamation had a damaging effect on the community structure of macrobenthos within the vicinity. However, this resulted in the significant increase of familial diversity and abundance away from the impact (Lu, Goh and Chou 2002).

SALINITY DEPRESSION

Unusually heavy rainfall at the end of 2006 and early 2007, discharging from the Johor River, located northeast of Singapore, caused a sustained drop in salinity in that part of the Johor Strait. Chek Jawa, a protected intertidal habitat on the island of Pulau Ubin, became fully exposed to the outflow. There was mass mortality of sessile and sedentary osmotic-conforming species. Many organisms (such as carpet anemones, sea stars, and sea cucumbers), which were unable to regulate the osmotic concentration of their body fluids, literally exploded as less saline water flooded their body cavities.

A year after the event, investigations showed that recovery was good. Most of the species that were almost wiped out have reappeared in abundance. At the same time, some species, which were not common before, became more abundant. These findings indicated that biodiversity can generally recover as environmental conditions revert to normal conditions. However, long-term changes in the community structure are still inevitable.

ELEVATED TEMPERATURE

The 1998 El Niño phenomenon provided a good opportunity to observe the effects of global warming. Attention was focused mainly on coral reefs, which displayed the most dramatic effect.

The warm temperature caused widespread mass bleaching of hard and soft corals which Singapore experienced for the first time. This event happened in June 1998. Sea surface temperature remained unusually high since January 1998, reaching 34.3°C in June. All hard coral species bleached, together with some species of soft corals and colonial sea anemones. However, sea surface temperature declined rapidly after June to the normal range of 29.5 to 31.5°C.

This temperature decline enabled the bleached corals to recover and limit their mortality to 20 per cent.

CONCLUSIONS

There are existing field conditions that simulate climate change scenarios from which impacts on biodiversity could be directly observed. They supplement laboratory investigations and provide a realistic setting to better understand biodiversity (species and habitats) responses to climate change.

Yap (1994) gave a comprehensive review of the implications of expected climate change impacts on natural coastal ecosystems in the region. Impacts on biodiversity can occur at the species and community levels. At the species level, physiological constraints limit the individual's tolerance to environmental changes. At the community level, changes in the community structure alter the ecosystem functioning of the habitats.

Observations indicated that habitat resilience was likely supported by species diversity. The abovementioned impacts, that simulate climate change conditions, could not be isolated from direct human activity. However, results showed that a rich biodiversity can handle climate change impacts more effectively. It is therefore important to manage areas of high biodiversity, and enhance the biodiversity of degraded or converted habitats. Habitat restoration is a useful defense tool against the impacts of climate change.

A study of inshore fish along the northeastern shore of the Singapore mainland showed that fish density was higher at a reclaimed sandy shore. The reforested mangroves were found to support greater species richness (Jaafar et al. 2004). Various studies also showed that the restoration of degraded habitats reversed species loss (Chou 1998). The restoration of coastal habitats will help increase species richness. Such efforts must be implemented in preparation for climate change impacts rather than used as remedies after the impacts have fully manifested.

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