The Impacts of Climatic Extremes on Coastal and Marine Biodiversity in Singapore and Management Challenges

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Abstract:

Climate change impacts are expected to impose further challenges to the management of the coastal and marine environment. The island nation of Singapore has lost 96% of its mangroves and 60% of its coral reefs to coastal development and maintaining the remaining existing habitats is crucial. Two recent extreme climatic events in Singapore provide important observations to coastal habitat managers in anticipation of a warmer climate with more intense precipitation and extreme weather events in the future. Mass mortality of intertidal organisms occurred in the northeastern part of Singapore caused by an unusually high intensity rainfall over Singapore and Southern Peninsular Malaysia. The extended period of high rainfall from December 2006 to January 2007 and subsequent discharge of large volumes of freshwater from the nearby Johore River resulted in a sustained salinity reduction. In 1998 and 2010, ENSO driven elevated sea temperatures triggered mass coral bleaching events, resulting in 25% (1998) and 10% (2010) coral mortality. The lack of long-term monitoring data on local biodiversity and environmental parameters impedes deeper understanding of the effects of these climatic events on the ecosystems and may not allow for more effective long-term management strategies that are more resilient to extreme weather occurrences.

Introduction

Located in tropical Southeast Asia, which is the global hotspot for coral reefs, the island nation of Singapore has lost 96% of its mangroves (Ng and Sivasothi, 1999) and 60% of its coral reefs (Burke et al., 2002) to coastal development over the past five decades. With limited land area of around 700km^2 supporting a growing population of more than 5 million, maintaining its remaining coastal and marine habitats is crucial. However, this is extremely challenging due to the pressure from development, and the increasingly inevitable climate change impacts.

Similar to coastal and marine environments worldwide, those in Singapore are also exposed to climate change impacts such as elevated sea surface temperatures, increased frequencies of extreme weather, ocean acidification and sea level rise (Chou, 1994). According to the fourth assessment report of the Intergovernmental Panel on Climate Change (Meehl et al., 2007), global sea surface temperature (SST) and sea level are predicted to increase by 1.5 – 2.6°C and 0.19 – 0.58m respectively by the end of this century, while ocean pH is projected to drop by 0.1 – 0.4 units from the current pH of 8.1. More recent studies have since suggested that these predictions of sea level rise have been underestimated, and the increment could be as high as 2m (e.g. Grinsted et al., 2009; Horton et al., 2008; Rahmstorf, 2007, 2010; Vermeer and Rahmstorf, 2009).

These climate impacts generate accompanying environmental effects on coastal and marine systems through coastal erosion, sudden salinity fluctuation, increased sedimentation, nutrient loading, salt water intrusion, coastal inundation, and changes in coastal geomorphology and circulation patterns (Chou, 1992). Mangrove ecosystems are threatened by coastal inundation and erosion owing to sea level rise, while organisms in the intertidal area are vulnerable to osmotic stresses caused by sudden fluctuations in salinity, which are in turn triggered by extreme rainfall events. Coral reefs on the other hand, are susceptible to thermal stress, increased sedimentation and nutrient loading.

With the impending threats brought about by both the ongoing and future climatic changes, there is an urgent need to implement mitigation measures that can ensure the continuation of the local flora and fauna. This is especially imperative since anthropogenic stresses have weakened the state of the natural environment, and are likely to also exacerbate further climatic impacts. Climate change impact assessments on coastal habitats in Singapore is therefore of utmost importance in aiding habitat managers and policy makers. However, limited records of past and present environmental and biodiversity data, together with difficulties in segregating the impacts of climate change from anthropogenic impacts make such assessments difficult. Two recent extreme climatic events in Singapore provide important lessons to coastal habitat managers in anticipation of a warmer climate with more extreme weather events in the future.

Extreme rainfall and mass mortalities of intertidal organisms at Chek Jawa

Chek Jawa is an intertidal flat located on Pulau Ubin (Ubin Island), an offshore island northeast of mainland Singapore. It is a precious part of the natural heritage of Singapore due to the six different habitats found there, i.e. coastal forest, rocky shore, sandy beach, mangrove forest, seagrass bed, and the coral rubble flat (Tan and Yeo, 2003). Exposed during low tides, the intertidal area and seagrass beds support numerous locally rare fauna, including various species of carpet anemones, sea stars, sand dollars and sea cucumbers.

Surrounded by the eastern Johor Straits, Chek Jawa is located directly south, and downstream of the Johor River. Due to freshwater discharge from Johor, the southern peninsular state of Malaysia, Chek Jawa is sometimes subjected to salinity depression akin to estuarine environments . Salinity of the Eastern Johor Strait ranges between 21.5 and 33.0 parts per thousand, with sites further away from the causeway recording higher salinity. Such a pattern is highly influenced by monsoon, rainfall and freshwater discharge from Singapore and Southern Johor (Lim, 1984, Hajisamae and Chou, 2003).

In 2007, mass mortalities of intertidal organisms were first observed on 1st of January by conservation volunteers. Based on anecdotal records of regular visitors to Chek Jawa, macrofauna such as the carpet anemone (*Stichodactyla haddoni*), sea cucumbers (*Holothuria scabra* and *Phyllophorus* sp.), the noble volute (*Cymbiola nobilis*), sea stars (*Archaster typicus* and *Protoreaster nodosus*) and sponges (Phylum Porifera) were affected (unpubl. data).

This devastating episode is believed to have been caused by a large drop in salinity brought about by the unusually intense and prolonged periods of rainfall in both Singapore and Southern Peninsular Malaysia. There were three periods of high rainfall in less than 30 days between December 2006 and January 2007, which have been attributed to interactions between the strong northeasterly monsoonal winds that penetrated further south than usual. They hit the southern end of the Malaysian Peninsula instead of the usual middle section, and the regional circulation phenomenon Madden-Julian Oscillation (MJO) (Tangang et al., 2008). The excessive rainfall and close proximity of Chek Jawa to the Johor River might have led to a sustained period of low water salinity throughout December and January, causing chronic damage to the intertidal community and impairing its recovery.

Recovery occurred as weather conditions returned to normal, with the re-establishment of populations that were decimated due to the extreme rainfall. However, as of 2011, full recovery of the intertidal community was perceived by conservation volunteers who frequented the site, to be incomplete. Apart from causing mass mortalities, the impact allowed the establishment of other species not previously known from the site. The Asian mussel *Musculista senhousia*, which originated from northern Southeast Asia for example, has previously spread to Singapore as an introduced species. Not previously recorded at Chek Jawa, large populations of this mussel quickly established within a few months following the mass death event (Loh, 2008). This opportunistic colonization of Chek Jawa by *M. senhousia* demonstrated the potential of an invasive species to dominate a biodiversity-rich natural habitat, following an abrupt environmental change.

Elevated sea surface temperatures and mass coral bleaching events in 1998 and 2010.

Intense coastal development has largely confined the coral reefs in Singapore to the Southern Islands. Unlike other countries in the region, coral reefs in Singapore are not affected by overfishing or destructive fishing activities (Burke et al., 2002). Direct and indirect effects of coastal development such as land reclamation and high sedimentation rates are the key stresses to the local reefs. While reclamation activities directly bury and kill corals, high sedimentation rates smother corals by blocking out sunlight needed for energy production. Despite the small area of less than $10km^2$, the local coral reefs host more than 250 species of hard corals.

Bleaching responses, in which internalized symbiotic zooxanthellae are expelled from the coral host tissue, are indications of environmental stress (Weiss, 2008). This is harmful to host animals because a large source of energy is lost. Bleaching has been most widely documented in hard corals (e.g., Berkelmans et al., 2004; Eakin, 2010), but also occurs in other marine organisms hosting symbiotic zooxanthellae, including soft corals (Chavanich et al., 2009), sea anemones (Dunn et al., 2002), zoanthids (Kemp et al., 2006) and giant clams (Addessi, 2001).

In affected calcifying marine organisms such as hard corals and giant clams, skeletogenesis and growth are reduced, in the short term likely owing to the physiological response of conserving resources in times of stress, and in the long term due to the assimilation of more thermal-tolerant but less energy-providing symbiont strains (Goreau & Macfarlane, 1990; Tanzil et al., 2009; Manzello, 2010). Because these calcifying organisms form the basic structures of coral reefs, such bleaching events may have severe implications for the future of our coral reef life.

Sea surface temperatures (SSTs) in the Southeast Asian region in 1998 and 2010 rose up to 2°C above the monthly average SST for extended periods (up to three months). Such unusually high SSTs were triggered by a rapid switch from a strong El Niño event to a strong La Niña event (Wang & Zhang, 2002), which was prolonged by the anomalous Philippine Sea anticyclone (PSAC).The sustained elevated SSTs imposed high levels of thermal stress to coral reefs and evoked mass bleaching events of varying scales throughout the region.

The scale and magnitude of bleaching that affected coral reefs worldwide in 1998 were unprecedented. Mortality of shallow water corals was as high as 95% in some parts of the world, although no mortality was recorded on some reefs (Wilkinson & Hodgson, 1999). In Singapore, the bleaching affected most hard coral species and some species of soft corals and colonial sea anemones. Fifty to 90% of all hard corals bleached likely due to the thermal stress. Recovery commenced only when sea surface temperatures returned to normal, and the average bleaching-related coral mortality was estimated at 20% (Tun et al., 1998).In early 2010, SSTs in Southeast Asia exceeded that of 1998, prompting widespread mass bleaching again. The Southeast Asia region experienced bleaching at a severity similar to, or greater than the 1998 event (Tun et al., 2011). In Singapore, 30-60% of hard corals were affected, which was lower than 1998 while the recovery was faster with only less than 10% bleaching-related mortality (Tun et al., 2011).

Fast-growing branching corals *Acropora* and *Pocilliopora* are generally categorized as highly susceptible to thermal stress (Loya et al., 2001; Marshall and Baird, 2000), but both genera were found to be least affected during the 2010 mass bleaching event in Singapore. On the other hand, mortality rates of *Acropora* and *Pocillopora* colonies at Pulau Weh (offshore island north of Sumatra) during the 2010 mass bleaching event were 94% and 87% respectively (Guest et al., 2012). Unlike Singapore which recorded two mass bleaching events in 1998 and 2010, Pulau Weh was not affected by the 1998 bleaching episode. One possible explanation is that the thermally-vulnerable colonies were removed during the 1998 bleaching episode, thus leaving thermally-resistant colonies to reproduce and settle in Singapore reefs (Guest et al., 2012). However, it could also be an acclimatization response of these taxa in Singapore in which more thermally-tolerant symbionts were acquired after the first mass bleaching event in 1998 (Berkelmans & van Oppen, 2006).

Management implications

Elevated SSTs, increased frequency of extreme climatic events, and other climate change-associated phenomena such as sea level rise and ocean acidification are imminent threats not only to the well-being of Singapore's human population, but also to the coastal and marine biodiversity. Habitat degradation and fragmentation for example, which have been driven by rapid development in the past five decades, may have undermined the ability of marine ecosystems to adapt fully to climate change.

Since climate change is inevitable, the more practical management strategy of habitats would be to mitigate their impacts and encourage local adaptation. Enhancing the already compromised ecosystem resilience is essential to minimising damage from climatic change (SCBD, 2010). Measures such as reduction of anthropogenic pressures and more efficient biodiversity management should be taken. In addition, it is also important to understand and conserve both the genetic diversity and connectivity patterns between habitats. Rich genetic diversity can serve to facilitate ecosystem adaptation and strengthen ecosystem resilience, while a strong connectivity network is required for the natural replenishment of populations in events of environmental disturbances.

Both extreme climatic events described in this paper exposed a serious problem with the lack of monitoring data. In the case of Chek Jawa, there was neither a systematic quantification of the extent of the mass mortality event, nor long-term biodiversity monitoring data available to determine the severity. The mass mortality was first discovered on 1st January 2007, but five months lapsed before any monitoring effort was conducted at Chek Jawa. As a result, crucial information on the extent of damage on the intertidal community, or recovery patterns was not available. The lack of baseline salinity data also restricted any assessments of the intensity of the environmental conditions that the intertidal community was subjected to from December 2006 to January 2007. This would hinder any predictions of the impact of similar events in the future. While there is more information on the mass bleaching events on the coral reefs, crucial SST data was unfortunately not (publicly) available for any in-depth analysis. Sea surface temperatures derived from satellite images could be used as an alternative, however, it is lacking in information on interspatial environmental differences that are not captured due to the low resolution (1 degree x 1 degree) of the data.

The lack of long-term monitoring data on local biodiversity and environmental parameters impedes our deeper understanding of the effects of these climatic events on the ecosystems, and also hampers the development of effective long-term management strategies. These experiences have shown that for any effective coastal management regime, it is essential to establish baseline information, and conduct regular monitoring in order to detect any changes in ecosystems, especially in this era of rapid climate change.

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