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# Assessing baseline levels of coral health in a newly established marine protected area in a global scuba diving hotspot

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ABSTRACT

While coral reefs are increasingly threatened worldwide, they are also increasingly used for recreational activities. Given the environmental and socio-economic significance of coral reefs, understanding the links between human activities and coral health and evaluating the efficacy of marine protected areas (MPAs) as a management regime to prevent further deterioration are critically important. The aim of this study was to quantify indicators of coral health at sites inside and outside a newly rezoned MPA framework in the dive tourism hotspot of Koh Tao, Thailand. We found that patterns in the health and diversity of coral communities one year on did not reflect the protected status conferred by newly zoned MPAs, but instead reflected past history of recreational use around the island. Sites characterised as past high-use sites had lower mean percent cover of hard corals overall and of corals in the typically disease- and disturbance-susceptible family Acroporidae, but higher mean cover of species in the more weedy family Agariciidae. Past high use sites also had higher mean prevalence of infectious diseases and other indicators of compromised health. Sites within the newly established MPAs are currently subjected to higher levels of environmental and anthropogenic pressures, with sedimentation, algal overgrowth, feeding scars from *Drupella* snails, and breakage particularly prevalent compared to sites in non-MPA areas. Given the greater prevalence of these factors within protected sites, the capacity of the MPA framework to effectively prevent further deterioration of Koh Tao's reefs is unclear. Nevertheless, our study constitutes a strong baseline for future long-term evaluations of the potential of MPAs to maintain coral health and diversity on highly threatened reefs.



## 1. Introduction

The accelerating pace of coral loss worldwide (Selig and Bruno, 2010; De'ath et al., 2012) and the need to understand the underlying causes of the declines are now widely recognised. There is no single cause but rather multiple factors acting alone or in synergy, such as rising sea surface temperatures (SSTs), ocean acidification, and nutrient run-off (Jackson et al., 2001; Harvell et al., 2007; Hoegh-Guldberg et al., 2008; Burke et al., 2012). All of these factors are likely to increase the impact of coral diseases on reef community structure and associated ecosystem services, highlighting disease as another issue of growing concern. First described in the Caribbean in the 1970's (reviewed in Sutherland and Ritchie, 2004), coral diseases have now been shown to affect reefs worldwide and are increasingly threatening Indo-Pacific coral reefs (Harvell et al., 2007; Willis et al., 2004; Myers and Raymundo, 2009; Weil et al., 2012), even at remote uninhabited reefs (Vargas-Angel, 2009; Williams et al., 2011a,b). However, research on coral disease is still in its infancy and there have been consistent calls for further studies on causes of the increasing frequency of disease outbreaks worldwide and on measures for their mitigation, including the potential of marine protected areas (MPAs) to ameliorate coral health (Richardson, 1998; Harvell et al., 1999, 2007; Raymundo et al., 2009; Roder et al., 2013).

Links between a range of environmental factors and increasing disease prevalence suggest a role for changing climate in the rise of coral diseases. In particular, recent studies suggest a link with global warming and rising SSTs (Harvell et al., 2002; Bruno et al.,

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2007; Sato et al., 2009; Heron et al., 2010; Maynard et al., 2011; Ruiz-Moreno et al., 2012). Evidence of rising disease prevalence following bleaching events (Bruno et al., 2007; Maynard et al., 2011) and seasonal patterns of disease outbreaks (Sato et al., 2009; Haapkyla et al., 2011) also indicate that disease levels can be high in the absence of local human pressures. Climate warming could have the dual effect of increasing pathogen virulence while decreasing coral host resilience (Harvell et al., 2002, 2007; Bruno et al., 2007; Heron et al., 2010; Ruiz-Moreno et al., 2012). Other abiotic factors associated with climate change, such as ocean acidification (Williams et al., 2014), and anthropogenic stressors, such as escalating human population sizes and decreased water quality (Pollock et al., 2014), can act synergistically with sea temperature warming to further impede corals' resistance to infectious diseases (Harvell, 2007; Hoegh-Guldberg et al., 2008; Danovaro et al., 2008; Van der Meij et al., 2010).

The role of human-related activities in coral disease dynamics is poorly understood but likely to be highly complex (Harvell, 2007, 2009). Loss of ecosystem complexity through overfishing, increased nutrient-run off associated with coastal development, and activities like dredging that increase sedimentation, have all been proposed as potential causes of disease outbreaks (Kaczmarsky, 2006; De'ath and Fabricius, 2010; van der Mey et al., 2010; Aeby et al., 2011; Haapkyla et al., 2011; Lamb and Willis, 2011; Ruiz-Moreno et al., 2012; Pollock et al., 2014). Recently, links between coral disease and human activities in areas of high tourist visitation (Danovaro et al., 2008; Lamb and Willis, 2011; Onton et al., 2011; Lamb et al., 2014) highlight reef-based activities as an additional cause for concern. Snorkelling and diving activities may cause breakage of coral colonies, reducing corals' resistance to infections (Page et al., 2009; Guzner et al., 2010; Lamb and Willis, 2011; Onton et al., 2011 Lamb et al., 2014). Recreational activities on coral reefs may also introduce new pathogens or further increase pollution and nitrification (e.g. fish feeding, sunscreen) (Danovaro et al., 2008; Lamb and Willis, 2011). There is thus a crucial need to understand the links between human activities and coral health to better manage coral reefs worldwide (Lamb and Willis, 2011; Onton et al., 2011; Lamb et al., 2014).

In Thailand, 70% of annual tourism income is related to coastal marine activities (Sethapun, 2000). The island of Koh Tao alone receives more than 300,000 visitors a year, of which at least 60% participate in scuba diving or snorkelling activities (Nichols, 2013). Over the last decade, the island has become the centre of scuba diver training in southeast Asia, and hosts the second largest dive industry in the world, with over 50 dive schools responsible for fully one-third of all PADI certifications issued globally in 2009 (Wongthong and Harvey, 2014). Therefore, diving pressure far exceeds the recommended carrying capacity of a coral reef for scuba diving (5000–6000 divers/year; Hawkins and Roberts, 1997; Zakai and Chadwick-Furman, 2002). Moreover, supporting such a flourishing scuba diving industry has required rapid coastal development at the expense of the preservation of the Island's natural resources. Related human impacts caused by deforestation of coastal areas for tourist accommodation, overexploitation of fishing resources and poor sewage treatment are now putting further pressure on the Island's coral reefs (Wilkinson and Brodie, 2011; Weterings, 2011; Scott, 2012). Reefs surrounding Koh Tao were also severely affected by 2 mass bleaching events in 1998 and 2010 (Yeemin et al., 2006; Chavanich et al., 2012). A study investigating the impacts of marine-based recreational activities on coral health around the Island shortly after the 2010 bleaching event found a 3-fold increase in disease prevalence at high use sites (Lamb et al., 2014), underscoring the need for strategies to manage recreational impacts on coral health and the potential of management interventions to increase reef resilience following bleaching disturbances.

To address threats related to tourism expansion on Koh Tao, a group called "Save Koh Tao" (SKT) in conjunction with the Prince of Songkla University and the Thai Department of Marine and Coastal Resources (DMCR) designed and implemented a coastal zoning, regulatory and management plan for the Island in July of 2012 (Platong et al., 2012). Included in this plan was the establishment of an MPA covering the northwest quadrant of the Island and a new designation for a 300 m radius around Shark Island (see Fig. 1). The areas designated as MPAs around Koh Tao had previously been zoned as 'Protection' or 'Conservation' areas as early as 1988, but locals were largely unaware of the designation and there was little to no enforcement (Szuster and Dietrich, 2014). The new MPAs are designated as strict No-Take areas, primarily to address high fishing pressure at these sites, but with hoped-for, flow-on effects for coral health as a consequence of reduced fishing-related injuries.

The effectiveness of MPAs, in general, is a much-debated topic (Jameson et al., 2002; Halpern, 2003; Degnbol et al., 2006; Graham et al., 2011), and their capacity to mitigate coral disease is even more questionable (Coelho and Manfrino, 2007), although in some cases, lack of compliance confounds the interpretation of their role in ameliorating coral health (Page et al., 2009). Apart from Raymundo et al. (2009), who found decreased coral disease inside reserves, most studies indicate a general failure of MPAs to address the rising incidence of coral disease (Coelho and Manfrino, 2007; McClanahan et al., 2008; Page et al., 2009). They argue that coral diseases are associated with threats, like rising ocean temperatures, which are beyond the scope of protection provided by Marine

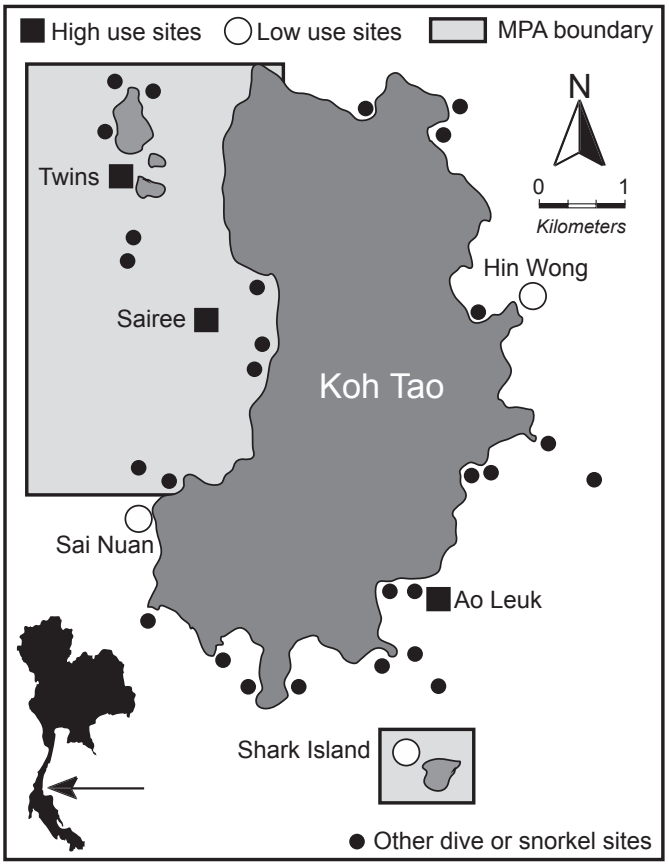


**Fig. 1.** Map showing locations of the six study sites around the Island of Koh Tao, Thailand. Grey squares delimit the MPA framework. Black squares represent past high-use sites; White circles represent past low-use sites.