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Research article

Ecological carrying capacity assessment of diving site: A case study of Mabul Island, Malaysia

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ABSTRACT

Despite considered a non-consumptive use of the marine environment, diving-related activities can cause damages to coral reefs. It is imminent to assess the maximum numbers of divers that can be accommodated by a diving site before it is subject to irreversible deterioration. This study aimed to assess the ecological carrying capacity of a diving site in Mabul Island, Malaysia. Photo-quadrat line transect method was used in the benthic survey. The ecological carrying capacity was assessed based on the relationship between the number of divers and the proportion of diver damaged hard corals in Mabul Island. The results indicated that the proportion of diver damaged hard corals occurred exponentially with increasing use. The ecological carrying capacity of Mabul Island is 15,600–16,800 divers per diving site per year at current levels of diver education and training with a quarterly threshold of 3900–4200 per site. Our calculation shows that management intervention (e.g. limiting diving) is justified at 8–14% of hard coral damage. In addition, the use of coral reef dominated diving sites should be managed according to their sensitivity to diver damage and the depth of the reefs.

1. Introduction

Southeast Asia is home to the world's largest network of coral reefs with reef ecosystem service value estimated at US$2.3 billion annually (Tun et al., 2008). Despite their great ecological and economic value, coral reefs around the world are under various climate- and human-related threats. Recent studies indicate that the estimated annual loss of coral cover was about 1% over the last 20 years and 2% (or 3168 km^2 per year) between 1997 and 2003 (Bruno and Selig, 2007), and that 19% of the historically extant coral reefs have already been lost and an additional 15% would soon be lost (Wilkinson, 2008).

Coral reef-based tourism is usually considered an ecologically benign form of use when compared to extractive practices such as the harvesting of corals and fish for commercial purposes (Dearden et al., 2007). It is believed that part of the revenue from tourism may be used to preserve tourism resources such as natural beauty and biodiversity (Buckley, 2012). As an important part of coral reef-based tourism, SCUBA diving has grown rapidly (Ong and Musa, 2011). Based on the Professional Association of Diving Instructors (PADI), the world's largest diving training organization, at least 30 million people have been certified to dive worldwide and over 900,000 new certifications per year have been added since 2001 (PADI, 2014). Financial gain from the diving industry has contributed significantly to regional economies (Stoeckl et al., 2010).

However, the development of reef-based tourism can have adverse impact on coral reefs. Reef-based tourism stimulates coastal development including the building of tourism facilities, such as, roads, stores and hotels. Sewage from accommodation and catering activities will increase turbidity, raise nutrient levels in water and contain pollutants including endocrine disrupting chemicals and even toxic substances (Dearden et al., 2007; Reopanichkul et al., 2009). In addition, recreation activities like sport fishing, diving and snorkeling themselves can inflict direct harm on coral reefs (Hasler and Ott, 2008; Chung et al., 2013; Van Beukering et al., 2015). Therefore, it is urgent and important to manage coral reef-based tourism to minimize its impact on coral reefs and to ensure its sustainable development.

1.1. Impacts of diving activities on coral reefs

Chung et al. (2013) found that during a dive, a diver in Hong Kong contacted marine biota 14.7 times on average and significantly more contacts are made by divers carry cameras or wearing

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gloves. Coral damage generally occurs when divers kick, hold, bump into, stand on or kneel on the bottom (Lloret et al., 2006). As a result, there was a significant positive correlation between the number of damaged coral colonies and the number of divers visiting a diving site (Au et al., 2014). The degree of damage is also related to coral morphology (Riegl and Velimirov, 1991; Allison, 1996; Rouphael and Inglis, 1997, 2001; Au et al., 2014). Rouphael and Inglis (1997) suggested that considerable variability in the physical and biological characteristics of coral reefs might indicate differential susceptibility to impacts and hence, the number of visitors that could be accommodated in them. Juhasz et al. (2010) stated that different growth forms of coral responded differently to physical disturbances caused by humans with massive colonies having a higher tolerance than branching colonies. Thus, the susceptibility of different morphological forms to breakage would lead to a shift of species dominance.

1.2. Carrying capacity and marine tourism

Ecological carrying capacity, defined as the ability of a resource to withstand recreational use without unacceptable damage to its ecological components, is widely used in managing diving tourism (Shelby and Heberlein, 1987). However, there is no universally accepted criterion to quantify the carrying capacity on diving sites. Salm (1986) professed that diving site carrying capacity could be expressed as the number of divers per site per year and was a measure of the number of divers a reef could tolerate without becoming significantly degraded. Table 1 summarizes carrying capacity assessment methods in different diving sites used in previous studies. From the Table, it is clear that ecological carrying capacity is usually empirically determined with quadrat or photoquadrat survey being the most widely accepted method to get information on coral status of a dive site. Other than the magic number, ie., the maximum number of divers/dives that a site can sustain, the relationship between diver impact and diving activity level are also of interest. Hawkins and Roberts (1997) argued that this relationship was not linear but might take the shape of a J- or S-curve. If it is a J-curve, diver-induced impacts would appear minor up to a certain level of activity but would quickly become considerable upon reaching a critical level. However, if a phase shift also occurs after the period of exponential growth in damage to the habitat, and degradation of the habitat stabilizes at an unhealthy condition, then it has become an S-curve. This method clearly indicates the possible relationship between diver impact and diving intensity and allows for quantitative determination of the ecological carrying capacity. Therefore, in this study, the ecological carrying capacity was assessed based on the relationship (linear, J- or S-curve) between the number of divers and the proportion of diver damaged hard corals in Mabul Island by adopting the Hawkins and Roberts' (1997) method.

1.3. Diving tourism on Mabul Island

With an area of 0.2 km^2 and a population of <2000 (Mapjabil, 2010), Mabul Island is a small oval shaped island in the Celebes Sea of Malaysia and located to the adjacent east of Sipadan (Fig. 1). The Island has a flat terrain with a height of 2–10 m above the sea level. Mabul Island is within the Coral Triangle, an area with the highest coral diversity. Yet the corals there (27% live coral coverage) are in fair conditions only when compared with the average for East Malaysia (40.8%), due in part to the rapid resort development on the Island (Reef Check Malaysia Bhd, 2012). Overfishing, cyanide fishing and dynamite fishing have also contributed to the destruction of corals. There are eleven resorts and homestays offering different price range accommodations on this small Island. It takes about 35–45 min to travel from Semporna to Mabul Island by speedboat. Mabul Island used to be the transit point for tourists who made diving expeditions to Sipadan Island. However, it has now become a popular destination for muck diving. The number of tourists visiting Mabul Island from 2000 to 2014 has increased by 3.43 times (personal communication with Sabah Tourism Board, on 15 May 2015, Fig. 2).

1.4. Study aim

Most studies estimating carrying capacity of diving sites were conducted in the Caribbean Sea, Red Sea and Australia (Table 1). There is a lack of similar study for Southeast Asia where coral diversity is the highest. Therefore, by assessing the maximum numbers of divers that can be accommodated by a diving site in Mabul Island, this study can provide critical information about an important area of coral reef-related tourism, which is essential to the sustainable development of the industry. In addition, while many studies have already examined the impact of diving tourism on coral reefs, there is a lack of research on the relationship between the depth of coral reefs and its ecological carrying capacity. Thus, in this study, we also examined how depth would affect the ecological carrying capacity of the diving site, as there is usually a stratification of coral growth forms along the depth profile, and different growth forms have different susceptibility to breakage.

Table 1
Methods and results of previous studies determining carrying capacities for coral reefs around the world.

Capacity (no. of divers $site^{-1}$ $year^{-1}$)	Location	Methodology	Reference
4000–6000	Bonaire, The Netherlands Antilles	Used photoquadrat survey to establish the inverse relationship between diving frequency and coral coverage of a site and empirically determined carrying capacity by referring to the level of damage caused.	Dixon et al. (1993, 1995)
Max. 5000	Eastern Australia	Adopted what other studies said about carrying capacity.	Harriott et al. (1997)
5000–6000	Egypt, Bonaire and Saba	Correlated damage levels to reef (quadrat survey) at several environmentally similar sites with their diving intensities; carrying capacity is the point beyond which damage accumulates rapidly.	Hawkins and Roberts (1997)
5000–6000	Eilat, Israel.	Empirically determined by referring to the level of damage caused in existing sites.	Zakai and Chadwick-Furman (2002)
Max. 7000	Sodwana Bay, South Africa	Regressed diving intensity and other variables on coral damage index for each transect; arbitrarily accepted 10% increase in damage at 41% chance.	Schleyer and Tomalin (2000)
7000	St. Lucia	Empirically set by making reference to Schleyer and Tomalin (2000)	Barker and Roberts (2004)
13,000–14,000	Hurghada, Egypt	Predicted the optimal number of divers that can visit a reef based on the balance between dollar values of their spending subsidy versus the em-dollar equivalents of the metabolic stress they cause.	Serour and Kangas (2005)
15,600 visitors/beach	Ras Mohammed National Park, Egypt.	Counted tramplers and correlated trampler numbers with coral damage data obtained from transect survey.	Leujak and Ormond (2008)

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