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Long-term environmental impact of coral mining at the Wakatobi marine park, Indonesia

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ABSTRACT

Coral mining for use as construction material is a major cause of reef degradation in several coastal nations. We studied the long-term impact of coral mining at the Wakatobi marine park, Indonesia, where a substantial mining event was undertaken two decades ago in order to supply building material for a jetty. The mined area shows significant differences in reef viability compared to a control reef 1000 m away: the percentage of dead coral in the substrate, the percentage of live coral coverage, the species richness and abundance of hard corals are all greatly reduced. For the most part, soft corals and other (non-coral) invertebrates do not show significant differences in richness, abundance or diversity, but their species composition differs greatly: the control site abounds giant clams, whereas these are absent at the mined site; instead, the dominant species there is *Strombus*, an algae-grazing gastropod associated with stressed reefs. We conclude that the mined reef flat failed to recover from the severe mining event, despite being un-mined for over 20 years. Our results demonstrate that without effective management and enforcement, coral mining may cause a long-term, destructive impact on the coral reef ecosystem. We propose the following management steps: first, law enforcement measures must become more stringent; second, alternative income sources such as aquaculture, ecotourism, or even land-based alternatives need to be actively promoted and financed; third, alternative building materials such as landrock and concrete should become more accessible and affordable; and fourth, education and awareness regarding both the MPA regulations and the environmental impact of coral mining have to be strengthened.

1. Introduction

Coral reefs are the 'rainforests of the sea', containing the richest biodiversity of all marine ecosystems. In addition, they are of major economic benefit to many countries, supporting millions of people living in coastal, tropical environments; the value of resources and services derived from reefs was estimated at $375 billion per year [7]. However, these ecosystems are in serious decline worldwide [34] due to human impact (e.g. global warming, water acidification and unsustainable resource use; [27]). The future survival and regeneration of coral reef ecosystems requires an improved understanding of their dynamics and of the processes that support or undermine their resilience, coupled with stronger, more innovative management efforts [1]. Threats to coral reefs increase daily, and the need for the protection of these habitats is at an all time high. In South East Asia, anthropogenic stresses are at their most destructive. High population pressure, especially in coastal communities, intensifies pressure on near shore resources, often producing an unsustainable outcome. Singularly among the factors affecting reefs, coral mining is a largely unstudied subject. The effect on coral community, adjacent fisheries and recruitment/recovery levels are not well understood. Coral mining for use as construction material is cited as a major cause of reef degradation in a number of tropical coastal regions, including East Africa [11], South Asia [3], South East Asia [4] and in the Pacific [29]. Extraction of corals has a detrimental effect on the reef: it decreases the abundance and richness of the corals and fish (e.g. [11]), increases land retreat and sedimentation (e.g. [29]), and decreases shoreline protection against Tsunami waves [12]. Thus, coral mining creates a significant long-term loss to society and economics, including a loss in fisheries value, coastal protection, and tourism. The skeletal framework of reefs, which is removed through mining of coral and rock, is built up over hundreds to thousands of years and will take as long to grow back and recover. When considering these factors, the cost of destroying or mismanaging one square kilometer of reef results in losses of up to US $6.6 million [22].

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The extraction of solids from the sea might sound like a peculiar option-why mine in water when land is made of solid materials? To understand this, one needs to understand the demographic make-up of the studied area. Two very different societies share the sea's resources. The Bajo ('sea gipsies') do not associate themselves with land at all. Traditionally practicing a maritime nomadic lifestyle and building seasonal stilt-suspended houses on the reef flat, they have in recent years been forced by the Indonesian government into permanent villages. Therefore, current Bajo dwellings are constructed atop solid platforms on the reef flat. Due to their reluctant contact with land, the Bajo turned to the reef flat for obtaining building materials for these solid platforms [24]. The size of a Bajo house's foundation platform serves as a reflectance of its inhabitants' financial status; moreover, coral solids are used by the Bajo people as a financial commodity much like currency. Sadly, an alternative building material - fossilised coral rock, which is found in abundance along the coastline - is much denser and harder to break, extract and transport, and therefore seldom used. The other community residing in the area is villages of Kaledupans, whose inhabitants (unlike the Bajo) are predominantly Indonesian with a land-based culture. Their coral mining is usually limited to the production of lime, which is used for creating mortar and also in sewage (cess) pits and white wash [24]. Here too, the alternative material-inland fossilised coral rock–is not used since it produces lower-grade lime which is also less white, an important disadvantage when marketing the whitewash. Corals are collected in shallow water, broken into smaller pieces and then burned in a kiln or open fire until only lime remains. A relatively low conversion ratio of about 1.8:1, corals to lime by weight, is obtained after burning the coral skeletons (i.e. every kilogramme of lime that is produced requires at least 1.8 kg of coral [2]). Although the practice of small-scale coral burning appears to be widespread in Indonesia, it is perhaps best known from Bali where these practices led to a dramatic decrease in coral cover, richness and abundance. Although coral mining in Bali has now largely ended, it led to significant and expensive beach erosion problems, and subsequent monitoring has shown very little recovery of mined sites throughout Bali [30].

Throughout coastal Indonesia, corals are used for construction, either as building blocks for walls and foundations or crushed and fired to produce lime (an important constituent of cement). Their use in construction is reported from Java, Kalimantan, Bali, Lombok, Sulawesi, and Maluku [5,25] and consists mainly of genera with dense calcium carbonate skeletons such as Platygyra, Porites and Favia [30]. Our preliminary anthropological and ecological field observations, as well as interviews with local miners, revealed that although referred to as 'coral mining', the actual materials being mined at the reef flat do not necessarily consist of live corals. There are two main sources for materials: the first is 'coral rock' or 'coral rag' - fossilised limestone which constitutes the foundation for most of the substrate on the reef flat. Typically found as flat slabs of loosely packed conglomerated calcium sand, it is usually covered with sand and rubble and can be dislodged using a lever (Fig. 1). The second mining material is hard coral, which may be alive or dead. As corals and coral rock dwindle around the village, mining expands along the reef flat. Mining is confined to low-tide time and is done mostly on an opportunistic basis; the collectors do not rely on it for a dominant fraction of their income. However, in the event of high demand, a shift into more mining can be observed and with it evidence of less particular or choosy collection. The building of the jetty at Hoga Island, 20 years ago, provides a good example: it is constructed predominantly of now-dead corals that were collected alive, as evidenced by their polyp structure which is still visible. The jetty represents temporary shifts from random, opportunistic collection of rock material to fast gleaning, non selective aggregation of solids from reef flats close to the construction site.

Fig. 1. Miner using a crowbar on a reef flat at Hoga Island, Indonesia.

2. Materials and methods

We compared two sites at the Hoga island reef flat (Fig. 2). The first site, named 'buoy-2' (coordinates: 9394878, 584032), was an area within close proximity to the jetty, which – 20 years ago – served as the main source of corals and solids for the jetty's construction. The second site, named 'Pak-Kasim' (coordinates: 9395496, 583812), was located approximately 1 km north of 'buoy-2' and served as a control group which only suffered sporadic, low-intensity mining but was not affected by the massive mining event associated with the jetty's construction. Both study sites were very similar in depth, vertical relief and distance from the crest (see [9]). At each of the two sites, four 50 m-long transects were marked on the reef. At each transect, at high tide, we surveyed the following reef parameters: (1) Rugosity: along the transect lines, a 10 m metal chain was laid and allowed to acquire the vertical relief of the reef. Rugosity was then calculated as the horizontal length of the chain in situ, divided by the actual length of the chain. (2) Reef substrate: along each transect, at 25 cm intervals, the substrate directly below the transect line was recorded. Additionally, where sessile flora/fauna was detected, its growth form, species and colony size were noted. (3) Coral surveys: along each 50 m transect, ten 5×5 m quadrates were surveyed for hard and soft corals. Each colony was identified to genus level and measured. (4) Invertebrates: a 5 m-wide belt (2.5 m on each side of the 50 m transect line) was surveyed for invertebrates which were identified as specifically as possible (to at least the family level). For each of the above-mentioned reef parameters, differences between the two sites were analyzed for statistical significance using one-way ANOVA tests. Since there were four 50 m transects (i.e. repeats) at each site, the degrees of freedom for each test (except when marked n.a.) are 1 (between groups) and 6 (within groups).

3. Results

The results of the study are summarised in Table 1. Although the rugosity is similar at the two sites, the composition of the substrate of the reef is significantly different: at buoy-2, it is about equal parts dead corals and inorganic material (sand and rubble) while at Pak-kasim the substrate is mainly dead corals. Significant differences also exist in the overall percentage of live coverage which is doubled at Pak-kasim, and the percentage of hard corals' live