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Ensuring appropriate and proportionate responses to environmental threats: A response to Caras and Pasternak

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ABSTRACT

The ecological consequences of coral mining can be severe, with immediate reduction in reef-associated biodiversity and longer term implications for linked habitats such as mangrove forests and seagrass meadows. However, research into the effects of coral mining must take into account other environmental processes which may affect reef communities and the socio-economic context within which coral mining takes place if appropriate and proportionate management responses are to be identified. This article builds upon recently published research detailing the adverse effects of coral mining in Indonesia to illustrate the significance of these points. We use the previous paper to demonstrate that accurate identification of the ecological impacts of coral mining requires the use of appropriate control sites and recognizing natural stresses which may account for short-term variability in ecological parameters. We also underline the need to appreciate that government institutions can directly or indirectly facilitate coral mining, whilst proposed alternative income-generating activities intended to reduce coral mining should be tailored to the local economic, cultural and environmental context if they are to gain community support. This demonstrates the value of an integrated approach to analyzing marine resource usage which combines information from the natural and social sciences to address environmental problems such as coral mining.

1. Introduction

Coral mining has long been a concern to tropical marine conservation [1,2] with attention mainly focused on the impacts of mining in the eastern Indian Ocean [3,4]. Studies have also highlighted the extent and environmental consequences of coral mining in Indonesia [5,6]. The identification of appropriate management strategies to address coral mining necessitates an understanding of its environmental significance in the context of other threats to coral reefs and the socio-economic drivers for this activity. Taking a recently published paper examining coral mining in eastern Indonesia as an example [7], we illustrate these points through demonstrating the complexity in determining the environmental impacts of coral mining and the constraints and opportunities associated with actions to address this activity in Indonesia. We outline the benefits of integrating research perspectives from the natural and social sciences to position coral mining in its appropriate environmental and socio-cultural context.

Corals are collected for a variety of purposes, from use as a local building material to international export for the aquarium trade. Coral mining for construction involves the use of coral pieces or colonies directly as building stones or the burning of coral fragments to a lime-rich powder which is mixed with cement and sand to produce mortar. Slow growing 'massive' species such as *Porites*, common on reef flats are targeted rather than branching corals which dominate the reef crest and slope, more due to the quantity of lime which can be produced rather than ease of access [4]. This activity is common throughout south-east Asia and the eastern Indian Ocean, reflecting the absence of alternative building materials or demand for construction materials linked to rapid tourism development [5].

1.1. Ecological impacts of coral mining

The principal impact from coral mining is the direct removal of habitat, although other impacts such as trampling by the miner and

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localized short-term turbidity and sedimentation also result. Diverse coral assemblages provide high niche diversity and many species inhabiting these niches are vulnerable to habitat degradation. Coral mining typically reduces live coral cover, with coral recruitment also becoming more difficult in a silted environment [8]. For example, at Mafia Island, Tanzania, live coral cover on a mined site was found to be one third of that on the un-mined site [4].

The loss and degradation of reef habitat and its negative impact upon fish communities has been documented throughout the tropics [9]. In the Maldives, the mining of coral reef flat habitat for the construction industry resulted in an 80% reduction in fish species number, and an 87% reduction in the number of fish [10]. Of particular importance at an ecosystem level are the observed changes in the trophic structure of coral reef fish assemblages in the Maldives following extensive coral mining, with planktivores and herbivores reducing in size and abundance [2]. The loss of herbivores from the reef has the potential to rapidly reduce the resilience of a reef to future stressors such as periods of bleaching [11].

The topographical complexity of coral reefs, or 'rugosity', is an important determinant of reef fish productivity [12]. Decreased rugosity is thought to be the overriding factor in altering the fish assemblage structure in coral mined habitats [2]. The density of reef fish is likely to decrease as a result of increasing post-settlement mortality arising from a lack of hiding places and appropriate food for newly settled juveniles [13]. The loss of reef breakwaters through mining has also been observed to lead to the loss of shoreline and mangrove forest through increased erosion rates [4]. Loss of adjacent nursery habitats has additional and far reaching potential consequences for regional fisheries [9,14].

2. Identifying the causes of ecological change

Understanding and separating the many complex natural and anthropogenic influences on marine systems is typically difficult, requiring surveys or experiments that are of sufficient statistical power to answer the question at hand. This can be further complicated by the lack of long-term data relating to environmental conditions, past and current human exploitation patterns, and the impact of events such as coral bleaching, disease and storms, all of which impact upon coral reef health.

Variables including percentage of live and dead coral cover, coral species richness, and mollusc dominance were compared in two locations 1 km apart in a marine national park located in eastern Indonesia [7]. Significant differences in these parameters were attributed by these authors to a coral mining event which took place approximately two decades earlier. Whilst the potential impacts of coral mining cannot be disputed, and this activity is likely to have occurred at the location in question, this research highlights the need for assessments of impacts in the marine environment to be statistically rigorous and based on solid experimental design. The reefs of this region have been extensively investigated for their physical and biological characteristics, both spatially and temporally [15–17] and as a result we propose that the biological results reported by Caras and Pasternak [7] are the result of factors other than coral mining.

An experimental design that compares locations to determine an impact requires both a statistically powerful sampling design and a representative control site of similar environmental and ecological characteristics to the impact site [18,19]. Such a powerful design with a valid control site was not utilised by Caras and Pasternak [7]. The sites compared by the latter have differences in spatial orientation influencing the effect of storm events and high currents that can change turbidity, sedimentation and levels of physical stress. Such factors have the capacity to change the community composition of reef, thereby compromising their capacity to be compared. Site replication was also not present, therefore the differences between the two sites could also be due to a random or uncontrolled effect not considered.

For example, the potential for short-term temporal and spatial variability in live coral cover over five years on these reefs has been demonstrated [16,17]. The intersite variability documented by Caras and Pasternak [7] may have been caused by rapidly progressing coral diseases found at these sites [15] or by the over-use of resources [17]. These data indicate that spatial differences reported by Caras and Pasternak [7] are probably more likely the effect of a combination of natural and anthropogenic stresses. Understanding ecological change in systems as diverse as coral reefs is complex and the issues raised here demonstrate the need for systematic long-term monitoring to accurately identify spatial and temporal changes in coral reef health and elucidate their underlying causes. This is imperative if the reefs are to be managed effectively. Coral mining may be having an ecological impact, but this question requires monitoring and experiments specifically designed to elicit such information.

3. Identifying appropriate management strategies for coral mining

Heightened enforcement is frequently cited as a necessity in light of the adverse environmental impacts associated with coral mining [7,20]. However, the complex political and administrative context of marine resource management in Indonesia does not lend itself readily to such recommendations [21]. Law 27 (2007) on Coastal and Small Island Management states that the collection of coral from any of Indonesia's protected areas is prohibited, along with coral mining which 'causes destruction of coral reef ecosystems' (authors' translation). Whilst this framework law still requires implementing legislation in order to take effect, it appears to constitute a clear proscription against coral mining and supersedes previous legislation which confused the issue through prohibiting live coral removal whilst allowing the extraction of dead coral.

However, enforcement would still necessitate that authorities prove 'destruction' of the coral reef resulting from any mining activity, whilst eye-witness evidence of coral removal would likely be required in any legal action [22]. Given the limitations on resources available to park authorities, stricter enforcement would imply a greater degree of self-reporting on the behalf of villages where coral mining represents a source of income, which would be difficult to imagine regardless of the fact that relations between local resource users and national park authorities are rarely amicable. Furthermore, the complicity of local government in mining coral for construction purposes, as demonstrated in Bali [23] as well as the Wakatobi National Park [7] underlines the fact that enforcement must be seen to operate on a equal and accountable basis and not automatically target the 'usual suspects' commonly represented by poor or marginalized user groups. This is reinforced in the case of the Wakatobi, where recent surveys indicate that just 0.2% of households derive an income from coral mining [24]. Recommendations for more stringent enforcement measures to combat coral mining for construction purposes targeting local subsistence fishers, as proposed by Caras and Pasternak [7] amongst others, is therefore fraught with difficulty.

4. Providing alternative income strategies to reduce coral mining

Cost-benefit analyses of coral mining and other destructive activities [20,23] serve as a reminder that coral mining may be a preferred activity over tourism owing to the greater predictability of income generated and the relative ease of participation. This in

turn underlines the need to develop practical alternative income-generating activities which counteract these potential benefits. The cultivation of seaweed species including *Gracilaria* and *Eucheuma* for the production of agar and carrageenan respectively offers considerable potential in both of these respects and the output from this sector is growing at a remarkable rate, with Indonesia expected to be the leading exporter of raw dried seaweed in 2010 [25]. With local governments increasingly responsible for their own tax revenues under regional autonomy, the incentives to promote seaweed cultivation across Indonesia have been given considerable recent impetus. Research indicates that almost a quarter of households in the Wakatobi depend upon seaweed for their primary source of income, outweighing all other marine resource uses [24]. However, recommendations to further encourage the adoption of seaweed cultivation as a solution to the perceived problems of coral mining [7] should recognize the vulnerability of individuals to prices determined by a highly limited number of buyers in a monopsony market and the benefits of maintaining a diverse array of household income sources [26,27]. The case for the further development of seaweed farming, although potentially economically powerful, needs to be considered in respect to its potential negative effects on seagrass meadows and the consequences for macrofaunal and fish assemblages [28,29]. There is some potential to develop tourism as an alternative employment strategy to reduce reliance on coral mining and other destructive fishing activities [30]. However, this requires a considerable amount of long-term investment in training and skills for individuals to enter into the tourism industry, whilst the remote location of the Wakatobi is likely to continue to constrain tourism activity in the area. Encouraging economic development strategies which involve the supply of alternative building materials at a competitive price to coral would be far more likely to achieve the goal of eliminating the use of coral for construction purposes.

5. Conclusion

Coral mining is deservedly an issue of concern to conservationists and can exert negative impacts upon communities dependent on reef resources whilst reducing the resilience of reefs to overfishing and, in the longer term, climate change. However, a careful elucidation of cause and effect is necessary in order that scarce management resources are directed towards the true drivers of anthropogenic stress upon coral reefs. The scope for considerable temporal and spatial variation in indicators of reef quality reflects the importance of collecting accurate and precise data in order to achieve this goal. Furthermore, inappropriate or unnecessary strategies targeting supposed perpetrators of coral mining will be manifest in greater environmental and economic costs in the longer term, which simply cannot be afforded under present conditions of increasing degradation of coral reefs and associated habitats. Integrating data from the natural and social sciences in order to derive environmentally and culturally appropriate responses to threats such as coral mining is therefore crucial if scientists are to enable managers and resource users to conserve marine resources for future generations.

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