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Missing the boat: Critical threats to coral reefs are neglected at global scale

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ABSTRACT

Coral reefs have experienced a global decline due to overfishing, pollution, and warming oceans that are becoming increasingly acidic. To help halt and reverse this decline, interventions should be aimed at those threats reef experts and managers identify as most severe. The survey included responses from 170 managers, representing organizations from 50 countries and territories, and found that respondents generally agreed on the two major threats: overfishing and coastal development. However, resource allocation did not match this consensus on major threats. In particular, while overfishing receives much attention, coastal development and its attendant pollution are largely neglected and underfunded. These results call for a re-examination of how resources are allocated in coral reef conservation, with more attention given to aligning how money is spent with what are perceived to be the primary threats.

1. Introduction

Despite their well-documented importance to humans, coral reefs continue to decline at a steady pace [1–3]. *Reefs at Risk Revisited* (RRR), cited six primary stressors leading to the majority of decline in coral reefs: overfishing and destructive fishing, watershed-based pollution, marine-based pollution and damage, coastal development, thermal stress, and ocean acidification [3]. This report consolidated input from the world's leading experts on coral reefs and highlighted that these stressors are increasing in step with rising human population and activities (e.g., coastal development). Despite the collective efforts of many conservation organizations and governments to protect reefs, conservationists have been unable to keep pace with these anthropogenic threats. The authors of RRR conclude that the threat level increased by 30% between 1998 and 2011 [3] while coral coverage on reefs continued to decline [2].

It is clear that current reef conservation efforts are not sufficient. There are concurrent needs for both innovative approaches and a calibration of current reef conservation efforts with the magnitude of threats to these systems [4–7]. It is important to ask if resources are being put to best use [4,6,8]. To begin this process, reef conservationists must first assess if their resources (i.e., time and money) are being strategically allocated to address the major threats they face locally. This type of self-evaluation is critical to undertake, as threats change over time and conservationists and natural resource managers must continually track shifts in conservation priorities to determine whether their actions match those shifts [5]. While several studies have mapped the global distribution of threats [3,9,10] no studies have addressed the question of whether local coral reef conservation has adequately allocated resources to match the perceived local intensity of various threats to coral reefs.

An examination of the match between perceived threats and resource allocation is especially critical for coral reefs, because it is common for reef managers to cite a lack of resources as a limiting factor in their ability to achieve success (Author, personal observation). Using a survey of 170 reef managers from 110 different institutions around the world, an assessment was conducted to test whether perceived levels of the top six threats to coral reefs in their jurisdiction matched the relative amount of time and money allocated within their institutions. Specifically, the survey was designed to answer three main questions: (1) What is the perceived relative strength of threats to coral reef health? ; (2) Does the allocation of conservation and management resources match the degree of the perceived threat? ; and (3) If there are mismatches, why?

2. Material and methods

The experts surveyed for this study were comprised of practitioners with extensive experience (an average of 11.5 years) and knowledge of the coral reef conservation and management activities in their jurisdiction. Potential respondents were identified through The Nature Conservancy's Reef Resilience Network. This network was used because it is representative of the diversity of reef managers across the globe in that it includes reef managers from government, NGO,

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Table 1
List of geographies represented in the reef manager survey.

Geography name	
American Samoa[a]	Maldives
Australia	Marshall Islands
Bahamas	Mexico
Belize	Mozambique
Bermuda	Myanmar
Bonaire	New Zealand
Brazil	Palau
Cayman Islands	Philippines
Commonwealth of Northern Mariana Islands[a]	Pohnpei
Colombia	Puerto Rico[a]
Curacao	Saudi Arabia
Dominican Republic	Seychelles
Egypt	Solomon Islands
Fiji	Somalia
Germany	South Africa
Grenada	St. Eustatius
Guam[a]	St. Vincent and the Grenadines
Hawaii[a]	Tanzania
India	Thailand
Indonesia	Tonga
Jamaica	Trinidad and Tobago
Kenya	United Kingdom
Kosrae	Florida[a]
Lebanon	US Virgin Islands[a]
Madagascar	Venezuela
Malaysia	

[a] U.S. territories.

academic, and community organizations and managers working in more than 70 different countries and territories. From the larger pool of 750, 550 individuals were randomly chosen to receive a SurveyMonkey survey via email. The number selected to receive a survey (550) was chosen because returns on surveys in social science are often 20–30% and sample sizes of 100 are considered robust enough for evaluation and comparison [11]. The survey is available as Online Supplementary Material (OSM). The general goal of the study was provided in the introductory information and no incentive was provided to respondents to complete the survey. The survey data were collected between May and September of 2014. A total of 170 individuals responded to the survey. Of this group, 132 individuals completed the entire survey (47% NGOs, 11% academic, 33% government, and 8% private). These 132 respondents were representative of the geographic range of coral reefs as well as institutions involved in managing coral reef communities. Respondents were from 110 different institutions, 45 countries, and 5 territories (see Table 1 for geographies). Each of the respondents was asked to identify their job type (i.e., park manager, fisheries manager, natural/marine resource manager, research scientist, academic scientist, and program manager) and years of experience in coral reef conservation.

Six threat categories were used in the survey: (1) Overfishing and Destructive Fishing, (2) Watershed-based Pollution, (3) Marine-based Pollution and Damage, (4) Coastal Development, (5) Thermal Stress, and (6) Ocean Acidification. These categories were selected because they were identified as the top threats to coral reefs in RRR [3]. The same threat definitions provided by RRR were used (Table 2) to ensure consistency and clarity, and also allow the results to be placed in the context of RRR studies.

The perceived threat level of the six major threats was determined by asking respondents to rate the threats according to severity of threat to coral health in the respondent's jurisdiction. It is important to note the responses were not about global threats, but threats being experienced locally. To assess how time and money were being allocated to address each of the six major threats in those jurisdictions, the respondents were asked to estimate the amount of time and money their institution spent on each threat. Whether severity of threat aligned with the resources being directed to that threat was determined by comparing the ratings of threat severity and resource allocation.

All responses were pooled for each threat and the mean was calculated for each threat rating to estimate perceived threat ratings. In order to determine how much time was being spent to address each threat, all respondents combined were considered. All of the time estimates were pooled and a mean was calculated. In order to compare time or money spent to the perceived threat rating, only respondents that answered the questions about time and money were included in the threat ratings analyses.

Demographic and job description information about each respondent were reviewed to ensure the survey population was not biased towards a particular threat (i.e., overfishing) in terms of organizational or occupational mandate. Only three respondents identified themselves as a fisheries manager and only three institutions were identified as a fisheries agency or department. The vast majority of respondents represented organizations with broader natural resource or coral reef management purposes. The same steps were repeated in order to determine portion of budget dedicated to addressing each threat and how that compared to the perceived threat ratings.

To determine whether respondents currently perceived mismatches in threat severity and resource allocation to that threat, the respondents were asked whether resources allocated to addressing each particular threat were too little, too much, or just right for their jurisdiction. The responses were summed by threat category. To determine whether there was a strong opinion about a mismatch of allocations in general, all responses were combined in all threat categories. Respondents were given an opportunity to explain their responses if they had answered “too much” or “too little.”

To understand what factors respondents perceived to be major influences on decision-making about resource allocation, respondents were asked to select up to three options from eleven pre-selected choices, allowing them to also write in other responses. The eleven choices were intended to be comprehensive and selected based on past experience of working with coral reef managers at more than 25 international reef management workshops over 10 years in which over 600 managers attended (Author, personal observation). The responses were summed for each factor and the percentage was calculated across all responses. The six written responses that were provided were categorized into already existing factors.

2.1. Data analysis

Perceived threat level and resource allocation (time and money) data were analyzed using linear mixed-effects models with threat type as the fixed factor and respondent ID as the random effect factor. All analyses were conducted using R 3.1.2 (R Core Team 2015). The effect of threat type was tested by comparing the resulting deviance to F statistics (Type II sum of squares) using R car package. Tukey multiple comparisons were conducted using R multcomp package. Data from survey questions that assessed frequency of categorical responses, that is, whether there was too much or too little allocation to certain threats and factors that influence resource allocation decisions, were analyzed using chi-squared tests. Pairwise Fisher's test was used to test for differences between categories (P value adjustment method: holm).

3. Results

All threats were not viewed equally and a few threats emerged consistently as the most important. For respondents that answered time allocation questions, overfishing and coastal development were the most highly rated threats, and did not differ statistically from each other [Fig. 1a; n=95]. Watershed pollution and thermal stress did not differ statistically and were intermediate in rating and significantly lower than both overfishing and coastal development ($P < 0.03$ all contrasts). Marine pollution and ocean acidification did not differ from

Table 2
Threat definitions provided to survey respondents. These are the same definitions used in Reefs at Risk Revisited (2011).

Threat type	Definition
Overfishing and destructive fishing	Includes unsustainable harvesting of fish or invertebrates, and damaging fishing practices such as the use of explosives or poisons
Coastal development	Includes coastal engineering, land filling, run-off from coastal construction, sewage discharge, and impacts from unsustainable tourism
Watershed-based pollution	Includes erosion and nutrient fertilizer runoff from agriculture delivered by rivers and coastal waters
Thermal stress	Incudes warming sea temperatures, which can induce widespread or “mass” coral bleaching
Marine-based pollution and damage	Includes solid waste, nutrients, and toxins from oil and gas installations and shipping; and physical damage from anchors and ship groundings
Ocean acidification	Driven by increased carbon dioxide concentrations, which can reduce coral growth rates

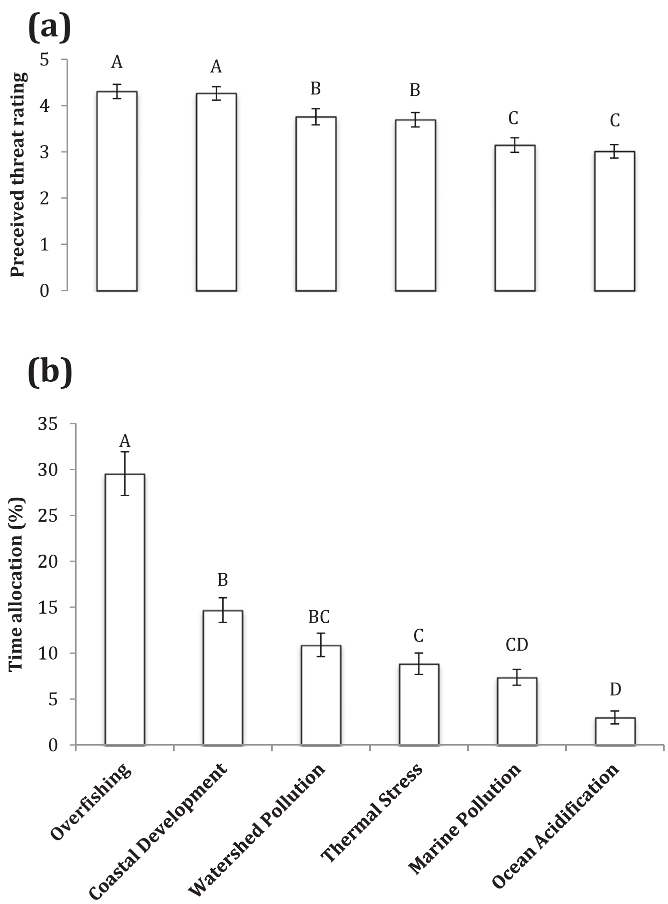

Fig. 1. Results of survey looking at effects of top six threats to coral reefs (threat rating scale of 0–6, with 0=no threat and 6=extreme threat) on: (a) perceived threat rating, n=95, (b) resource (time) allocation to abate those threats, n=95.

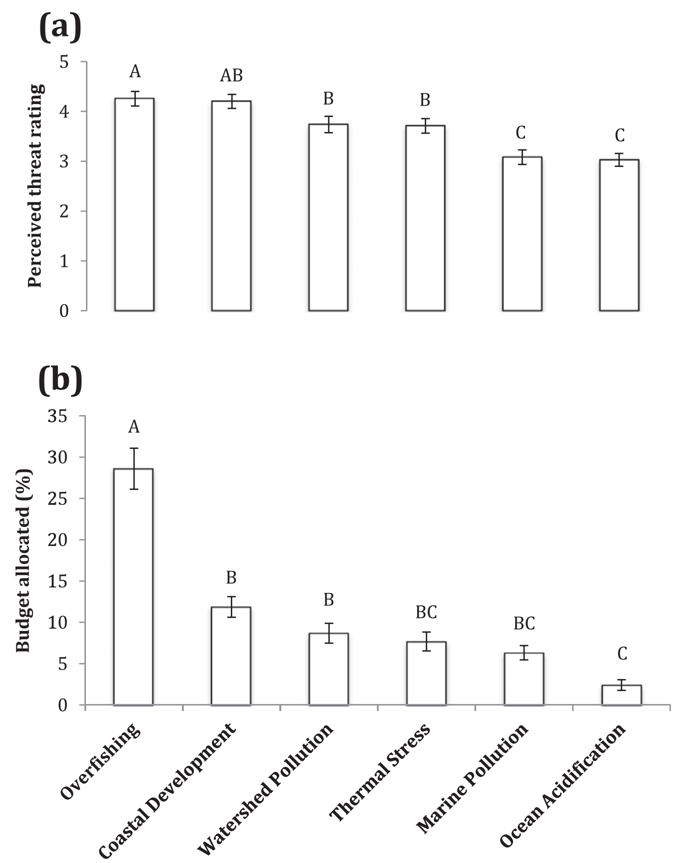

Fig. 2. Results of survey looking at effects of top six threats to coral reefs (threat rating scale of 0–6, with 0=no threat and 6=extreme threat) on: (a) perceived threat rating, n=110, and (b) resource (budget) allocation to abate those threats, n=110.

each other ($P > 0.98$) and were rated significantly lower than all other threats ($P < 0.01$ all cases).

For respondents that answered budget allocation questions [Fig. 2a; n=110], the pattern of the effect of threat type on perceived threat rating was similar. Coastal development and overfishing continued to be the most highly rated threats, whereas marine pollution and ocean acidification continued to be the lowest rated threats.

Time allocation varied among threat types (Fig. 1b). Managers by far allocated the most time to dealing with the threat of overfishing ($P < 0.01$ all contrasts). On average, this comprised nearly 30% of managers' time. Managers allocated significantly less time (~50% less) to coastal development and watershed pollution ($P > 0.01$ both contrasts), despite the fact coastal development had a similarly high threat rating as overfishing [Figs. 1a and 2a]. The least amount of time was allocated to marine pollution, thermal stress and ocean acidification, each of which comprised ~5% or less of managers time. For budget allocation, the patterns in the effects of threat type were nearly identical to that of time allocation [Figs. 1b and 2b], except that the pattern became even more pronounced. For example, managers spent ~66% less money on coastal development in comparison to overfishing ($P < 0.001$), despite the fact that they rated these threats as equal [Fig. 2b].

When managers were asked if they spent too little, just right, too much or don't know for all threats combined, 40% responded “too little” and 40% responded “just right”, and fewer than 5% responded “too much” (χ^2=40.36; df=3, $P < 0.05$ for Fishers contrasts) [Fig. 3a]. When broken down by threat, answers for each threat generally followed the same pattern as for all threats combined [Fig. 3b]. However, there was still some statistically significant variation in the pattern among different threats (χ^2=29.34; df=15, $P < 0.02$). The number of managers that responded “just right” and that responded “don't know” did not differ significantly for acidification (P=0.58), but this difference was significant for all other threats ($P < 0.004$).

Among different factors that may influence decisions about how resources were allocated [Fig. 4], number of responses differed significantly (χ^2=29.34; df=15, $P < 0.02$). Government mandates, do-

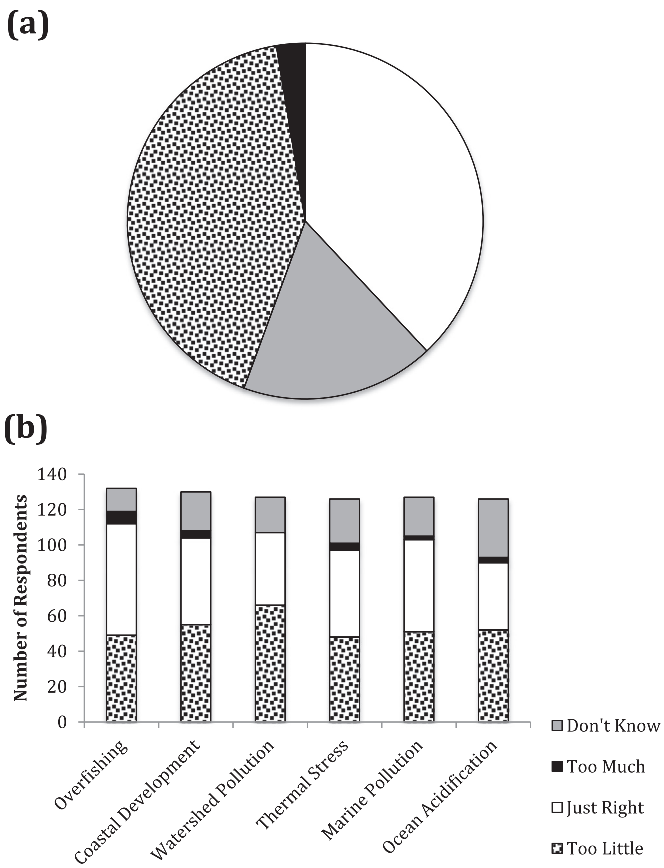

Fig. 3. Survey responses to question about how resources are being allocated to address threat. (a) All responses are combined in these data without regard to specific threat, to demonstrate general trends of allocation. (b) Responses are shown by threat category. N=134.

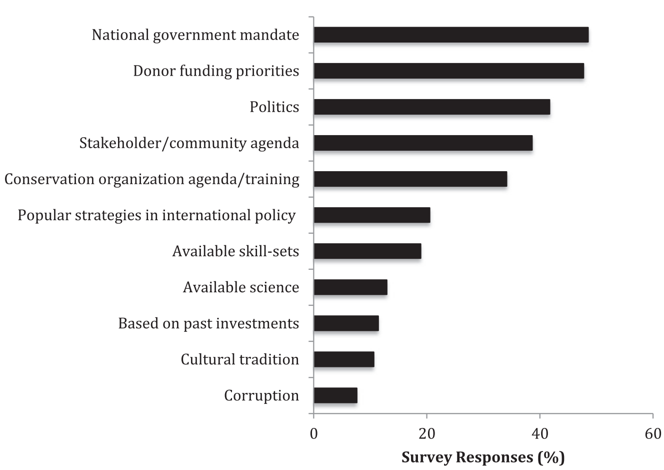

Fig. 4. Survey responses to question asking respondents to identify which factors influence decisions about how resources are allocated. Respondents (N=132) selected the top three factors from eleven pre-selected choices and were given the opportunity to write in additional factors.

nor funding, and politics received the highest number of responses, followed by stakeholder/community and conservation organization agendas.

4. Discussion

The results of the global survey indicate that overfishing and coastal development stand out as the highest ranked threats [Figs. 1a and 2a]. Interestingly, this result differs from RRR [3] assessment of coral threat intensity, which used globally available proxy data as opposed to surveys of local experts and managers. The input data for the RRR "proxy analysis of threat" included human population density and infrastructure features such as location and size of cities, ports, and hotels, as well as more complex modeled estimates such as sediment inputs from rivers. For each of these mapped stressors, distance-based rules were developed, such that threat declines as distance from the stressor increases [3]. In the RRR threat ranking, overfishing was clearly identified as the biggest threat to coral reefs, with over 55% of coral reefs at risk from overfishing. The next highest ranked threat was coastal development, with about half as many reefs being at risk from this threat.

The survey suggests a different reality for local managers. The biggest difference is the identification of coastal development and pollution as a major threat. While neither the survey approach, nor proxy mapping measure threat directly by documenting impact on corals, the survey approach does allow an examination of alignment between perceived threat and resource allocation. That examination uncovered a striking mismatch in the perceived severity of some threats and the amount of resources allocated to address those threats. Specifically, a disproportionate amount of resources are allocated towards addressing overfishing in comparison to other similarly, highly rated threats. Most notably this mismatch occurs with coastal development, but also for watershed-based pollution and thermal stress. For example, despite having similarly high threat level ratings, less than half the resources are allocated to coastal development relative to overfishing.

4.1. *Why is there a mismatch?*

There are numerous mechanisms that could be driving these observed mismatches. It is possible, for instance, faced with limited resources, managers are choosing to make a difference with at least one serious threat rather than spreading themselves thin across several serious threats. Alternatively, a threat could be neglected because the tools to address it may not be readily available or familiar to local managers. However, this would not explain the neglect of coastal development and pollution, because there are well-known approaches for reducing these threats [12]. Another possible reason for this mismatch could be that it is potentially easier to influence policies impacting fishers than policies impacting landowners and developers. Finally, the managers may not realize there is a mismatch. As it turns out, the survey results support this last hypothesis. The majority of respondents did *not* recognize there was a mismatch – and when they did acknowledge a mismatch, respondents commonly cited limited resources as the cause [Fig. 3a and b]. Over 55% of respondents did not recognize that this large mismatch occurs, indicating that more agencies would benefit from evaluating how they are responding to the most serious threats. The limited awareness about the potential mismatch also suggests that the mismatch is not intentional; rather it is being caused by other factors not apparent to resource managers. Possible reasons why managers do not realize there is a mismatch include: 1) quantitative data on budgets and time allocation are not readily available for many organizations so comparison is not easily done and 2) whether there are mismatches may not be routinely examined in strategy reviews.

Managers face many pressures and demands that may intervene between what they think they should do and what they actually do. The survey uncovered five major factors that influence managers' decisions: 1) government mandate, 2) donor priorities, 3) stakeholder/community support, 4) political agenda, and 5) conservation organization agenda. Many respondents highlighted the lack of understanding of environmental problems and management priorities by politicians and community stakeholders, and pointed out that their support was critical in taking action. If these factors are indeed drivers of the mismatch in resource allocation, then it will be imperative that governments, NGOs, and the donor community begin to recognize that a more holistic approach is necessary to achieve natural resource management goals and evaluate their current funding strategies. Such an approach would be more balanced, incorporating the broader range of threats that impact coral reef ecosystems.

4.2. Does the mismatch matter?

Because conservation need far outweighs resources available to address those needs, making sure resources are efficiently allocated is key for maximizing success [8]. While this objective seems obvious, allocating resources for the greatest return on investment (ROI) is still a novel concept in conservation priority setting [8]. For coral reefs, survey results call into question the allocation of resources since investments are disproportionately focused on one threat, while neglecting other seemingly equally important threats. This mismatch matters because the threats that are getting less resource attention are real and substantial [13–15]. Neglecting a major threat such as pollution, not only reduces our ability to mitigate the impact of multiple stressors on reefs but also puts our existing, massive investment in overfishing abatement at risk. For example, coral reef conservation most often occurs through MPAs and establishment of zoned areas that restrict fishing. While these boundaries can curtail overharvesting, they cannot stop incursion by coastal pollution or marine-based pollution. Thus, while a manager may succeed in addressing the threat of overfishing, their success may be undone by pollution.

5. Conclusions

The recent global declines documented for coral reefs demand that we reexamine what is being done to promote coral reef persistence into the future. Current efforts to develop tools and frameworks to improve cost-effectiveness and conservation outcomes will help managers [5,7,8] but until decision-makers embrace the importance of a holistic approach, priority setting at the site level will still be challenged by funding directives from above. While new strategies are needed, we must also look at how we are using the resources already in hand and consider whether they are being used efficiently. Taking a whole system approach in coral reef management is likely to produce better outcomes and greatly improve the conservation ROI. The results of this study illuminate a starting point to improve how limited resources are allocated and call for inclusion of a broader range of threats to coral reefs in future management activities. Governments and other funders of threat abatement activities must take the lead in ending our tendency toward myopic coral reef conservation. Coral reef conservationists should routinely evaluate whether their local interventions match the actual threats, and allocate resources accordingly. In order to reverse the decline, closer attention must be paid to ROI for conservation action and the overwhelming focus on a single threat at the cost of all other threats needs to come to an end.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2016.09.009.

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