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Human and coral reef use interactions: From impacts to solutions?

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ABSTRACT

The literature on coral reefs and human resource use or fishing is reviewed less from the perspective of summarizing findings but more from the sociological perspective of what scientists chose to study, publish, and cite in journal articles. The motivation was to determine if coral reef science is generating information needed to solve the coral reef climate and fisheries crisis that has been publicized in many of the highest visibility and cited publications. The social-ecological system of coral reefs involves the environment, the ecosystem, human harvesting and social organization and the policies that arise from their interaction. Regardless of the focus and findings of any science investigation on this system, recommendations for management are limited, and include restrictions on space, time of use, effort, gear, species, size, and gender. Evaluating the scientific journal literature in the *Scopus* database on these restrictions indicates a disparity in focus for both publications and citations. The greatest number of scientists and citations are focused on spatial closures and fishing effort, effort seen as the problem and closures the solution. The other restrictions, that represent less extreme forms of management and have lower short-term social costs and trade offs, are not well studied and, when studied, investigated by either a small group of associated colleagues or transient one-publication investigators. When the values, selectivity, and incentives of scientists conflict with resource users desires for knowledge, incentives, and profits the resulting divide can weaken the social relevance and applicability of science and delay real-world problem solving. Societal engagement, acceptance, objectivity, and finding solutions are likely to increase if scientific effort is spread more evenly across this full spectrum of management restrictions and more components of the social-ecological system.

1. Introduction

Readers of the human and reef-interaction coral reef literature will find considerable reason for skepticism about the future of coral reefs (Hoegh-Guldberg et al., 2007; Hughes et al., 2003; Jackson et al., 2001; Pandolfi et al., 2005). There are many problems and coral reef scientists have been busy documenting these problems in some detail. This documenting of human impacts is arguably one of the main normative activities of ecologists that keep them engaged in both science and societal issues. However, because most funding for coral reefs and ecology is public, solving the problems of nature and society is also arguably the other main area of engagement where their intellectual skills are most needed. In principle, there is likely to be an evolution of intellectual activity and scholarship from identifying and studying impacts to developing solutions for those impacts and then moving on to the next and either lesser impacts, emerging impacts, or possibly impacts that are more difficult to solve and require study over longer times and larger social-ecological systems.

There is, however, the possibility that ecologists as a culture can become caught in an impact crater, to use a metaphor, where the continual documentation of impacts is not followed by solutions because the culture of evaluating impacts is entrenched in the discipline. A scientific snowball effect can emerge where investigator values, education, incentives, and citation continually perpetuate and accelerate a monolithic focus that exceeds the laws of diminishing return, reasonable effort, and social relevance. Alternatively, scientists may simply consider the recommendations and solutions part of their science as simplistic, not as intellectually stimulating as investigating the impacts, and therefore relegated to environmental management and engineers rather than scientists. Solutions are, for example, to reduce or eliminate the impacts, reduce human populations and effort, and create no-take marine protected areas (MPAs) and the implementation and consequences of these solutions viewed as unworthy of further investigation. These types of solutions are, however, seldom well investigated nor are the inherent trade offs, particularly social, fully recognized (Christie, 2004). Evaluating the solutions themselves may be complex but possibly seen as the domain of social scientists.

To exemplify this type of selectivity and possible snowballing effect of impact research in applied coral reefs science, I undertook a search of keywords. Searching the words coral reef, fishing, and impact in the title abstract, and keywords of the *Scopus* database produces 250 journal articles (www.scopus.com July 10, 2010), where as replacing impacts with solutions produces 16 journal articles. The most cited of the impacts papers was published in *Science* in 2003, cited 621 times and increasing resilience was stated as the solution to

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climate and human impacts (Hughes et al., 2003). The most cited solutions paper was published in *Ambio* in 1993; cited 113 times, and marine reserves were the stated simple solution to human fishing impacts (Roberts and Polunin, 1993). The eventual blending of these two concepts, or that reserves, remote, and pristine reefs increase resilience to climate change has since then been a common and highly cited contemporary solution (Hughes et al., 2005, 2007; Mumby et al., 2006). The empirical evidence has, however, been ambivalent (Graham et al., 2008; Selig and Bruno, 2010) and there are difficult problems of identifying and measuring a resilience metric(s) over sufficient time and the appropriate scales to have confidence in these conclusions (Holling, 2001).

Since the first solutions paper in 1996, solutions articles have been cited a total 237 times, have an h index of 7 (7 paper cited 7 or more times) and the last full year of the search, 2009, had the most citations when the sum of this body of work was cited 30 times. Solutions papers are notably published in the low to mid-impact journals, the most papers published in a year was four papers in 2003 and there is no author who has published more than one paper with solutions in the title, abstract, or keywords. In contrast, since the first impact paper was published in 1977, the 250 impact papers were cited 4583 times had an h index of 32 and the year with the most citations was 2009, when 959 citations and 33 papers were recorded. The top 6 most cited articles were published in *Science* and there were well over 100 authors with more than one paper published on fishing impacts. Despite the delay from 1977 to 1996 in publishing a solutions paper, there is scant evidence that the impacts papers are giving way to a rise in solutions studies and citations.

The question one has to ask is, if studying impacts is better than studying solutions for a scientific career, is there the possibility that applied science may not move on to solutions because personal career incentives override societal needs? Is good scientific and personal progress, good for coral reef ecosystems or just good for our profession and careers? And, if so, how can personal and societal need be better aligned? This paper is written to briefly address this problem with a brief review of the literature, focusing on where efforts are being focused in terms of publications and citation on impacts and solutions, a call for more solution-oriented research, and discussing some of the potential ideas to increase engagement in societal problem solving.

2. The social-ecological system

The social-ecological system that defines the coral reef resource use environment contains many facets of the environment, the ecosystem, harvesting and associated culture, the interaction or policy environment and the proposed management institutions (Fig. 1). Resource use is complicated because it has environmental, ecological, cultural, economic, sociological, and governance dimensions. Each of these sub-systems is complex and worthy of considerable scientific investigation for both pure and applied reasons, yet those professionals most interested in coral reefs are natural scientists who largely study the environment and ecosystem and less often the three other subcomponents, which may be viewed as multidisciplinary or social science.

Natural scientists are going to study what they are trained to study and know best but the funding will also be influenced by societal problems or issues that need resolution and this can potentially broaden the scope of investigators to social science and multidisciplinarity. Nevertheless, it is not always well appreciated that regardless of the findings of any research, the recommendations for fisheries management are often as simple as restrictions on space, time, effort, gear, species, size, and gender. In coral reefs, habitat management, restoration, and hatcheries are largely not viewed as viable alternatives on a large scale by most practitioners. Socioeconomics, governance, and economic recommendations can be made to improve the functioning of the management system but the end product of these changes will be some combination of these restrictions. Consequently, focusing and sampling from this list of restrictions provides a simple way to evaluate research activities and the state of the global research portfolio on applied coral reef fisheries science (Table 1).

3. Management restrictions

3.1. Spatial restrictions or reserves

The literature on spatial closures is complicated by the terms in use, including closures, reserves, marine protected areas, harvest refuge, and spatial management and usage has varied over time and among different groups of investigators. The word reserves, with fish and coral reefs captures the largest number of papers, with 200 articles published since the first published paper in 1996 and this literature has been cited 6381 times, has an h index of 45, and 17 of these papers have been cited over 100 times. If fish is removed from the search, the number of articles increases to 352. The year with the most number of citations was 1006 in 2009 but the most number of published papers was 23 in 2006. There are more than 100 authors with more than 2 publications in this field and consequently, this is the most attractive and best studied of the various fisheries management restrictions.

Most studies show greater sizes, population density, biomass, and species richness of target species in these reserves (Lester et al., 2009). Reserves have been used as controls for fishing impacts and what was

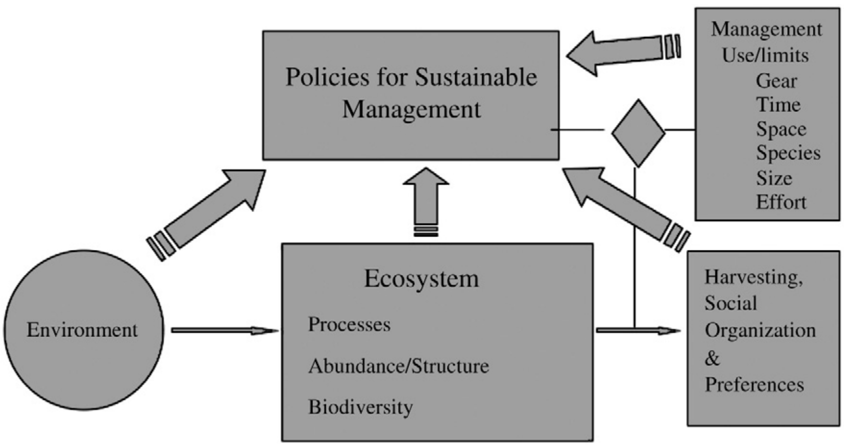

Fig. 1. Interaction diagram of the social–ecological system that describes the main components the coral reef fisheries and management system.

Table 1
Summary statistics of searches for journal articles in *Scopus* (www.scopus.com) on July 10, 2010 for the seven fisheries management restrictions and articles from key areas of social science research. The search had coral reefs, fish or fishing, and the restriction below among the keywords and the title, abstract, and keywords were searched. Titles that appeared to not represent findings of relevance to resource use were searched by reading abstracts and removed if not representative. The output here is based on the search that produced the greatest number of articles after removing those deemed irrelevant to the resource use topic.

Topic	Articles	Total citations	h-index	Authors>1 paper
Restrictions/impacts				
Spatial closure/reserve	200	6381	45	105
Effort	137	1802	20	49
Gear	66	416	16	19
Sex	15	221	7	0
Time, temporal, or seasonal	12	263	7	5
Species restriction	8	40	4	2
Size restriction	5	26	3	0
Social organization				
Economic	94	1246	16	14
Policy	47	1492	10	9
Social	47	906	10	5
Legal	13	140	6	0

natural or pristine is also of considerable interest (Jackson, 2001). The most cited paper is a review of these impacts, which had been cited 493 times at the time of this search (Jennings and Kaiser, 1998). The fishing impact studies have led to a growing and increasingly cited literature on either measured or implied trophic cascades inside closures (Hughes et al., 2007; McClanahan and Shafir, 1990; Mumby et al., 2006). The aspect of larval and adult movement and spillover is also of great interest and among the most highly cited papers (Abesamis and Russ, 2005; Kramer and Chapman, 1999; McClanahan and Kaunda-Arara, 1996; McClanahan and Mangi, 2000; Russ and Alcala, 1996a, 1996b; Swearer et al. 1999). The impact studies have been pooled into a number of meta-analyses studies that have compiled this information and are often cited for evidence of impacts of fishing, but these papers are either global (Cote et al., 2001; Lester et al., 2009; Micheli et al., 2004) or regional (McClanahan et al., 2009a; Russ et al., 2005) and a global evaluation of coral reefs is lacking.

In some cases the influences of habitat, time since closure, closure areas, spillover, buffer zones, and spatial configurations of closures, resource usage and their interactions have been evaluated (Abesamis and Russ, 2005; Acosta, 2002; Friedlander and Parrish, 1998; McClanahan et al., 2007, 2009a) but these aspects are far fewer than the impacts associated with fishing and closure from fishing and the few meta-analysis are based on small sample sizes and include non-coral reef ecosystems (Halpern et al., 2010). These design aspects are critical parts of the solutions aspects of closure, are complex problems that should be attractive to natural scientists, but have received limited attention.

3.2. Effort restrictions

The coral reef fishing effort search found 137 papers since the first paper was published in 1977 and 49 authors have published more than 2 papers on this subject. The total number of articles increases to 251 if the word coral is removed from the search but this only picks up a few additional coral reef studies. The 137 papers have been cited 1802 times, have an h index of 20, and the most number of papers, at 20, and citations, at 332, occurred in 2009. Despite the relatively large literature, many of the papers are calling for reduced fishing effort to avoid ecological changes on specific reef species or functional groups rather than measuring effort and determining the impacts for specific levels of fishing effort (Hughes et al., 2007; McClanahan et al., 1996, 1999). Many of the most cited papers relate fishing effort to aspects of fisheries closures, either in respect to reserve boundaries or fishing in the non-reserve areas (McClanahan and Kaunda-Arara, 1996), the equivalence of effort and reserves (Hastings and Botsford, 1999), or the placement of reserves in relationship to populations sources, sinks, and fishing effort (Crowder et al., 2000). Consequently, fishing effort is often seen as an impact, indirect, secondary, and a poorly quantified consideration to the most cited and studied aspect of the closure restriction.

Investigations that actually measure effort and relate it to reef ecology are far fewer, and the most cited papers were the eight and tenth most cited papers, which present some empirical relationships between fishing effort and fish numbers and communities (Russ and Alcala, 1998a,b) while the fifth most cited paper suggests that large ecological changes can occur in coral reefs with low fishing effort (McClanahan and Muthiga, 1998). There is a notable lack of systematic studies of catch per unit effort and the 32nd most cited paper is the only paper with effort and catch and catch composition data over a well defined and standard per area spatial gradient (McClanahan et al., 2008b). If coral is taken out of the search words, a few other papers such as the study of Fijian customary ownership reefs were identified but these studies use shoreline length as a metric for fishing effort data, but provide some interesting fisheries and ecological relationships that suggest cascading effects of fishing (Dulvy et al., 2004; Jennings and Polunin, 1996). Among the moderately cited papers are concerns about the social drivers of effort and resource extraction (McClanahan et al., 2007; McManus et al., 1997) and the types of management, markets, or social organization that will influence effort (Christie et al., 2002; Cinner and McClanahan, 2006).

3.3. Gear restrictions

Searches of coral reef, fishing and gear produced 66 articles since the first article was published in 1996 and this subject has been cited 416 times, the subject has an h index of 16 and the most citations were 194 in 2009. There are 19 authors that have published more than 1 paper on the subject. Nearly all of these papers evaluated the impacts of gear on coral reef ecology in some way, either on the fish or benthos, quantifying derelict gear (Chiappone et al., 2002; Mangi and Roberts, 2006; McClanahan et al., 1997), or restoration of benthos disturbed by destructive gear (Fox et al., 2005).

The papers that examined gear, catches, and socioeconomics are far fewer and less cited. The 20th most cited paper is the most cited solutions paper and it evaluated the effects of increased mesh size on the fishing power of coral reef fish traps, and had been cited 13 times (Robichaud et al., 1999). The investigators found that large mesh traps caught 51% less fish by weight than the standard commercial traps and they argued that “squeezability” allows fish to escape at larger mesh sizes. The 21st most cited paper is also a solutions paper in that it describes the effects of removing small mesh nets and finds that there are a number of positive benefits to the ecology and CPUE metrics of the fish community but not on total yield (McClanahan et al., 2008b). Knowledge of the catch and overlap in the selectivity of different gears has been suggested as a way to reduce resource competition among gear and suboptimal fishing (McClanahan and Mangi, 2004). There are a number of recent papers since this 2004 paper that have used this concept to evaluate gear-based management as means to influence reef community structure through selectivity in the catch and the potential for maintaining reef ecology and resilience to climate change (Cinner et al., 2009; McClanahan and Cinner, 2008).

3.4. Sex restrictions

The remaining four restrictions have received considerable less scholarship and the impact or management of fishing based on the sex of fish include 15 articles that had been cited 221 times, had an h index of 7, and no author had published more than one article on this subject. The major focus of the most cited papers is spawning aggregations and their vulnerability to and effects of fishing on abundance and sex ratios (Adams et al., 2000; Beets and Friedlander, 1999; Claydon, 2005; Zeller, 1998). Males are usually more vulnerable to fishing because they spend more time at aggregations sites and are sometime the larger and more valuable individuals, particularly in protogynous hermaphroditic species like parrotfish and wrasses and, therefore, males are often the main beneficiaries of fisheries closures (DeMartini et al., 2008; Hawkins and Roberts, 2004; Sadovy et al., 2003). An exception is the yellow tang, an important aquarium species, where the male has higher growth rates than females (Claisse et al., 2009).

3.5. Temporal restrictions

Searches for coral reef fish and temporary closures and their combinations produced no articles. If time and season were replaced for temporary and fish with fishing than then the number of captured papers increased to 12 since the first publication in 1996. These papers have been cited 263 times with an h index of 7 and the largest numbers of citation was 55 in 2009. The top five authors are closely associated colleagues and the only authors who have published more than 1 paper on this subject. The three most cited papers have a solutions focus by studying the rates of recovery of fish in permanent closures (McClanahan et al., 2007; McClanahan and Graham, 2005; Russ and Alcala, 1996b) and the forth studied the effects of closures and gear management on fish catches (McClanahan and Mangi, 2001).

There are a few relevant papers not picked up by the search because of language usage but that studied temporary closure, two empirically and one by modeling. The empirical study evaluated traditional management “taboo” systems in Papua New Guinea where fishing was allowed for only a few days per year and found that some of these periodic closure systems had larger fishes and biomass than permanent government or community closures, which often had low compliance (McClanahan et al., 2006). In contrast, permanently opening an area closured for ~6 years resulted in a quadrupling of effort in the nearby fish landing site and an eventual decline in effort and catch to a stable baseline after only three months of continuous fishing (McClanahan and Mangi, 2000). Referring to temporary restrictions as “dynamic closures” and using a modeling approach, Game et al. (2009) concluded that rotating fishing among a subset of closures increased herbivore biomass and the potential resiliency of the coral reef but not when all closures were rotated.

These few papers imply solutions in the terms of trade offs in times of use and closure and their distribution in space and the desired benefits of resource users and potentially improving the ecology of the coral reef were considered. Two papers have evaluated the social factors that influenced compliance or success of closures on a national level. A study of Papua New Guinea found it was highest in closures with short-term harvests and positively related to the visibility of the reserve and age of management and negatively with resource users integration into fisheries markets, wealth, and population size (McClanahan et al., 2006). In the Philippines, Pollnac et al. (2001) found population size of the community, a perceived crisis in terms of reduced fish populations, successful alternative income projects, high levels of participation in community decision making, continuing advice from the implementing organization and inputs from local government were the main factors that led to community closure success, although only a few of these were temporary. Aswani and Sabetian (2009) also found that urbanization erodes customary tenure and effectiveness of temporal closures in the Solomon Islands.

3.6. Species restrictions

The species restriction search found only 8 papers since the first publication in 2001. The literature has been cited 40 times, has an h index of 4, and the year with the most citations was 2009 with 14. Only two of the 23 authors have published more than one paper on this subject and these are collaborating coauthors. The most cited papers related gear and the species caught (Mangi and Roberts, 2006; Rhodes and Tupper, 2007) and potential to reduce impacts of fishing on reef ecology (McClanahan and Cinner, 2008) or the impacts of climate change (Cinner et al., 2009). Concern about the selectivity of aquarium fishing has not received much citation (Wood, 2001).

There are other papers that have identified species that are considered ecologically important and deserve special restrictions that were not captured by this search, including batfish and a some browsing herbivores that eat late-succession algae (Bellwood et al., 2006; Hoey and Bellwood, 2009), the bumphead parrotfish (Bellwood et al., 2003), triggerfish that eat sea urchins (McClanahan, 1999a, 2000), reef sharks that can control key ecological processes (Bascompte et al., 2005) and most of these studies align themselves conceptually with the trophic cascade literature that is also associated with closures. It is likely that coral reef scientist find the cascade framing more interesting and seductive than the applied aspects of species restrictions.

3.7. Size restrictions

Size restrictions literature includes 5 papers published since the first paper in 2006. The literature has been cited 26 times, has an h index of 3, and the most citations were 12 in 2009. The focus is on fishing gear and size of catch (Mangi and Roberts, 2006) or management and preferences for management systems that might increase fish sizes (Ashworth et al., 2006; Cinner, 2007; McClanahan et al., 2008b). This literature does not produce specific recommendations on the optimal size of fish and how this relates to gear use, although this information can be accessed from generic sources of data compilation such as Fishbase (www.fishbase.org) and these types of papers are often published in management newsletters (i.e. Fishbytes). The role of fishing on size and the ecological consequences were not picked up by this search but studies have shown, for example, that the size of disturbances to the benthos changes with the size of a common grazing parrotfish (Bonaldo and Bellwood, 2008).

4. The natural science focus

Many of the above papers overlap and the total number of papers for these various searches was 525 journal articles published since 1977. This study was not intended to be an exhaustive list but simply a list created by a chosen and competent method of sampling the literature. Supplemental methods will increase the numbers but are not expected to greatly change the observed relative contributions of journal articles and citations. The focus here, however, was not a comprehensive review but rather the choices of study and citation, which is likely to be sufficiently covered by the method.

This review suggests that there is a strong disparity in the types of restrictions that are studied with spatial closures or reserves being the most preferred topic for study and citation, following my effort, gear, temporal closures, species, and size restrictions. Effort restriction is probably overrepresented in the analysis because, as mentioned, it is often cited in abstracts as the impact compared with closures or a recommendation for management changes but less often quantitatively studied and related to specific impacts at specific levels of effort. Quantitative study of reserves and other management restriction subjects are more common when they are cited in the abstract, albeit more frequently as impacts than solutions.

The potential reasons for this disparity are many and probably include logistic feasibility and funding, intellectual interest or challenge (i.e. what is unknown or controversial), and the management values and culture of academic and conservation scientists. Ecology and management have the perpetual challenge of studying processes that unfold in ecological time, months to decades, but where funding, interest, and professional feasibility is often considerably shorter.

Closures provide snap shots in time that can control for many of the human impacts over time and provide an opportunity to make comparisons with a single sampling period. This provides an opportunity to do management relevant science without the costs of repeated surveys. The weaknesses of snap shot science and low spatial replication have been discussed and thoroughly criticized (Sale et al., 2005), but many of these concerns have been addressed by space-for-time substitutions and regional and global meta-analyses and a few decadal length time series at specific sites (Babcock et al., 2010). The question remains, however, if spatial closures have an advantage in terms of logistic feasibility of study compared to other restrictions where snapshot science is also still the main scientific contribution? I believe that the disparity in scholarship is too large and the differences in feasibility too small to conclude that the optimization of the expenditures of time and money produces the very different levels of scientific effort.

Financing remains another possible explanation associated with feasibility in that it may be likely that conservation and management funders associated with closures are more likely to support closure research than fisheries management bodies or that scientists funded by these bodies are more likely to publish their results. The rise of public funds and private foundations is possibly more likely to align with societal needs for closure than fisheries management agenda in tropical countries, but there are considerable societal lobbies for both food and conservation that make this idea seem tenuous and hard to test and conclude. Possibly the food are more applied and less publication oriented than the ecosystem and preservation constituents of society but for the terrestrial equivalent, agriculture versus terrestrial parks, there are massive funds for agriculture and the publication of their results.

The second possibility is that high interest topics such as reserves provoke more intellectual interest in terms of unknowns and controversies. Certainly, the literature is lively in terms of the debates on closures and this lively debate may attract attention and contributions from more scientists (Lester et al., 2009; Sale et al., 2005). Yet, is it sophisticated science to conclude that closing areas to fishing in areas where fishing is heavy leads to larger target fish, more biomass and somewhat more species of fish? It is arguable that a good deal of the closure science is quite basic, possibly pedestrian. The rates at which populations change, the life history characteristics that influence these recovery rates, and the indirect effects on non-target species are more intellectually provocative but, nonetheless, not as well studied, although they do receive citation.

The questions of closure effects on fish size, biomass, and numbers of species have been thoroughly addressed at sites and through meta-analyses but, what I consider more challenging topics, such as how social factors influences these results, how climate disturbances interact with management, and how the age, size, boundaries, buffers, spillover rates, and management surrounding reserves might interact and influence the response are very much understudied. I don't see the same intellectual challenge in what has been thoroughly studied and see more challenge in what has not been well studied, so I find the intellectually seductive explanation unconvincing. I do agree, however, that the study of trophic cascades that are generated by closures and fishing is both intellectually challenging and deserves study and the high citation.

Possibly, many of the basic resource management issues of the other restrictions are considered solved by natural scientists and not intellectually interesting enough to address through their scientific methods possibly seen as a management, engineering, or social science issue with less intellectual intrigue. For example, compilations of the optimal sizes for harvested fish are readily available from websites like FishBase and possibly there is a consensus among scientists and managers, albeit poorly quantified (but see McClanahan et al., 2005a,b), on those gear, species, sizes, and sex restrictions.

This “too mundane” explanation may be partly true, but I also believe that some very key questions remain largely unrecognized, unaddressed, and unanswered in many of these fields of this applied science. For example, how does the size of fish influence their impact on the food web, would achieving the optimal size of fish for harvesting have consequences for their ecological influences and competitiveness, what ratio of males to females in protogynous hermaphrodites results in reproductive and recruitment limitations, can populations of keystone species be maintained by any of the regularly utilized fishing gear and at what levels of effort, is species, size, and sex selectivity a better fisheries solution than proportional harvesting? These are just a few examples of complex and provocative questions that have direct utility to solving fisheries-ecosystem problems and yet they are barely being explored, particularly empirically.

The third possibility is that this focus represents the values and culture of coral reef scientist, which is the explanation I find most convincing. Closures are attractive to biologists because they leave ecological systems largely undisturbed and there are no major sacrifices or trade offs from a natural science point of view (i.e. simple solutions; Roberts and Polunin, 1993). Natural and conservation scientists promote and congratulate themselves when recommending and achieving this goal, even though the vast majority of closures are small, riddled by poor compliance, under siege from their borders and climate change, and seldom critically or scientifically evaluated (McClanahan, 1999b; Wood et al., 2008). In addition, there are considerable social trade offs, if not for the academy, government, or the whole of society in the long-term, there are costs for some sectors of society on the short term (McClanahan, 2010; Hicks et al., 2009). These are either not recognized or evaluated by natural scientists who study and recommend based on a subset of the whole social–ecological system (Christie, 2004).

5. Human use and socio-economic organization

Searching the same keywords, coral reefs, fish or fishing, and social produces 47 papers published since the first paper in 1998 of which five authors published more than one paper, and the most numbers of citations were 134 in 2009 (Table 1). The most cited paper is the Jennings and Kaiser (1998) review, which is an impact paper and is followed in citation by two impact papers, one on marine reserves (Bohnsack, 1998) and the economics of destructive fishing (Cesar et al., 1997). More moderately cited papers include the willingness to pay of divers (Arin and Kramer, 2002), the socioeconomic drivers of overfishing (Cinner and McClanahan, 2006; McClanahan et al., 2008b; Obura, 2001) and impacts of climate change on people (Wilkinson, 1996).

Using economic instead of social increases the number of papers to 94 often because the term socio-economic is frequently used for these types of studies. The total number of citations was 1246 and the most number of citations in a year was 173 in 2009. This search produces similar findings but a few more intermediately cited papers on the economics of fisheries aggregations (Sadovy and Domeier, 2005), destructive fishing in the Philippines (White et al., 2000) and the economic value of coral reefs (Spurgeon, 1992). Consequently, socio-economic papers were largely a subset of the impacts papers, with some interest in social drivers, but also included valuation studies of coral reefs.

There is a larger literature on common-pool resource use that is more solutions oriented in providing social design principles (Ostrom, 1999) and this is only receiving minimal attention in the artisanal coral reef literature (Pauly, 2006). Evaluation of the design principles increases understanding of social organization and identifies elements of social organization that lead societies toward or away from sustainable management (Cinner et al., 2009). The conceptual framework and method can help find weaknesses in social organization and provides ways to investigate either problems or solutions to social organization and may also help better identify acceptable restrictions.

5.1. Policies

Searching the same keywords and policy identifies 47 papers since the first paper was published in 1989. This body of work had a total of 1492 citations of which the most number of citations was 223 in 2009. The most cited papers are those that discuss resilience (Hughes et al., 2003), the effects of fishing (Jennings and Kaiser, 1998), and the effects of yields from reserves (Alcala and Russ, 1990; Russ and Alcala 1999). The more moderately cited papers evaluated various fisheries management options and socioeconomic drivers of overfishing (Cesar et al., 1997; Cinner and McClanahan, 2006; Dalzell, 1998; Finkl and Charlier, 2003; Haley and Clayton, 2003; McClanahan et al., 1996, 1997; Thorburn, 2000), and aquaculture and the trade in live fish food (Pomeroy et al., 2006, 2008). A search of the word legal produces very few papers and the few identified are papers that refer to legal sizes of fish or areas for protection and not legal scholarship focused on the management of coral reef resources.

The total number of identified social, economic, policy, and legal articles in the above three searches was 148 and 100 of these papers are also in the 525 natural science papers. Only 48 articles unique articles were identified and many of these were written by natural scientists. There are a growing number of transdisciplinary scientists and some social scientists that are interested in coral reefs and fisheries socio-economic, but the numbers are not large and are often trained in other subdisciplines.

Integration of social science into coral reef fisheries managed has been poor and it is uncertain and possibly unlikely that they will engage in applied issues, as they likely share the same clique and incentives dilemma as natural scientists. Pauly (2006) argues that when social scientists have engaged in tropical fisheries they have neglected quantitative approaches and failed to propose and test models that are general enough to be applicable for management and policy, emphasizing the local over the general. He argues that biologists and economists have come to monopolize policy because they are willing to develop generalizations even when they lack knowledge of the social consequences of their recommendations. Consequently, I believe many of the recommendations of natural scientists are viable only in special circumstances (McClanahan et al., 2008b) because they lack the interest, training, and methods to fully address social costs, social consequences, and trade offs. Because natural scientists seldom suffer the consequences of their recommendations, they are free of this responsibility and can generalize beyond the specific and propose monolithic visions that they and their peers value.

6. Management values, monoliths, and prudent trade offs

Values, associated education, and economic and social incentives frequently determine the choices scientists make about what to study and what is viewed as important enough to emulate, cite in our own work, and support in our recommendations. The perennial mismatch between personal, societal, and ecological needs means that to solve larger societal and environmental problems, a larger vision and time scale needs to be incorporated into a scientist's personal vision of their chosen work either through their own commitment, education, granting, and other social incentive systems. Failure can result in snowballing monolithic scientific cliques, perennial investigations producing minor nuances on a major theme while ignoring the fuller portfolio of problems. Repeated recommendations can be generated but may never be satisfactorily falsified if natural scientists do not encourage and acknowledge the results of transdisciplinary and social science nor the social and management failures that arise from their recommendations. This can result in a smug and irresponsible monolithic discipline that generate management proposal that cannot solve real problems.

As an example, the focus on closures and limiting effort restrictions often stands in conflict to what resource users see as the most acceptable restrictions, minimum sizes and elimination of destructive gear (McClanahan et al., 2005a, 2005b, 2009b). They see these as acceptable trade offs where as giving up fishing grounds, particularly large areas as unacceptable. Natural scientists infrequently acknowledge social trade offs and therefore a bin of poor compliance closures scatters that globe where they were socially and economically inappropriate. Ironically, communities living around these closures are aware of this and their knowledge of compliance is a good predictor of the natural resources (Pollnac et al., 2010). Yet, this local knowledge is not being acknowledged enough to influence natural science proponents to question their recommendations nor slow the bemoaning of poor progress in achieving global closure goals (Wood et al., 2008).

This lack of correspondence in values creates the possibility that management science is not a societal partner in solving environmental problems with resource users but a special interest group that is promoting the agenda of the natural science intellectuals, which promotes nature while being selective and, at times, callous in recognizing social costs. There are developing methods such as management preference evaluations (McClanahan et al., 2009b) and portfolio modeling (Cheung and Sumaila, 2008) that have the potential to guide the diversification of research that can improve and catalyze better understanding and solutions. Spreading scientific effort more evenly across this spectrum of management restrictions is likely to greatly increase the societal engagement, acceptance, and the objectivity of this science and scientists. More nuanced management frameworks are now available and we need natural and social scientists to test their efficacy and potentially falsify and build the most appropriate and successful recommendations (McClanahan et al., 2008a, 2009c).

7. Conclusions and recommendations

Evidence for an evolution of science from impacts to solutions in coral reef resource use is not evident from this evaluation. Rather, there is a proliferation of science and citation in all areas of restrictive management but the spatial closure field has rapidly developed and far out paces the knowledge generated on other management restrictions, many of which are only being investigated by a small group of researchers or composed of transient investigators that do not persist beyond a single publication. To increase societal relevance, this science needs to move on from issues that have been well established and diversify into areas that interest a broader constituency of coral reef stakeholders. This will require greater engagement with resource users, managers, social scientists, more transdisciplinarity, greater efforts to identify the contexts and social organization issues that lead to success and failure, and to accept evidence for failure. Further, increasing the scientific focus from simple hypothesis testing (i.e. closure vs nonclosure), to gradients, rates of change, biological diversity and its trade offs, units of social relevance (i.e. food and money), multivariate analysis, inferential and deterministic modeling, portfolio analysis and models, risk spreading, and environmental, ecological, and social contexts is likely to provide considerable intellectual stimulus, challenge, and social relevance for our science. There is much to be done, a future for coral reefs requires our engagement, and ~100 million coral reef dependents can potentially benefit from these efforts.

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References

Abesamis, R.A., Russ, G.R., 2005. Density-dependent spillover from a marine reserve: long-term evidence. Ecological Applications 15, 1798–1812.

Acosta, C.A., 2002. Spatially explicit dispersal dynamics and equilibrium population sizes in marine harvest refuges. Journal of Marine Science 59, 458–468.

Adams, S., Mapstone, B.D., Russ, G.R., Davies, C.R., 2000. Geographic variation in the sex ratio, sex specific size, and age structure of *Plectropomus leopardus* (Serranidae) between reefs open and closed to fishing on the Great Barrier Reef. Canadian Journal of Fisheries and Aquatic Sciences 57, 1448–1458.

Alcala, A.C., Russ, G.R., 1990. A direct test of the effects of protective management on abundance and yield of tropical marine resources. Journal du Conseil - Conseil International pour l'Exploration de la Mer 47, 40–47.

Arin, T., Kramer, R.A., 2002. Divers' willingness to pay to visit marine sanctuaries: an exploratory study. Ocean and Coastal Management 45, 171–183.

Ashworth, J.S., Bruce, O.E., El Hellw, M., 2006. Fish assemblages of Red Sea backreef biotopes. Aquatic Conservation: Marine and Freshwater Ecosystems 16, 593–609.

Aswani, S., Sabetian, A., 2009. Implications of urbanization for artisanal parrotfish fisheries in the Western Solomon islands. Conservation Biology 24, 520–530.

Babcock, R., Alcala, A., Barrett, N., Edgar, G., Lafferty, K., McClanahan, T., Russ, G., Shears, N., 2010. Decadal trends in marine reserves: differential rates of change for direct and indirect effects. Proceedings of the National Academy of Science, USA. 107, 18256–18261.

Bascompte, J., Melian, C., Sala, E., 2005. Interaction strength combinations and the overfishing of a marine food web. PNAS 102, 5443–5447.

Beets, J., Friedlander, A., 1999. Evaluation of a conservation strategy: A spawning aggregation closure for red hind, Epinephelus guttatus, in the U.S. Virgin Islands. Environmental Biology of Fishes 55, 91–98.

Bellwood, D., Hoey, S., Choat, J.H., 2003. Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. Ecology Letters 6, 281–285.

Bellwood, D.R., Hughes, T.P., Hoey, A.S., 2006. Sleeping functional group drives coral-reef recovery. Current Biology 16, 2434–2439.

Bohnsack, J.A., 1998. Application of marine reserves to reef fisheries management. Australian Journal of Ecology 23, 298–304.

Bonaldo, R.M., Bellwood, D.R., 2008. Size-dependent variation in the functional role of the parrotfish Scarus rivulatus on the Great Barrier Reef, Australia. Marine Ecology Progress Series 360, 237–244.

Cesar, H., Lundin, C.G., Bettencourt, S., Dixon, J., 1997. Indonesian coral reefs — an economic analysis of a precious but threatened resource. Ambio 26, 345–350.

Cheung, W.W.L., Sumaila, R., 2008. Trade-offs between conservation and socio-economic objectives in managing a tropical marine ecosystem. Ecological Economics 66, 193–210.

Chiappone, M., White, A., Swanson, D.W., Miller, S.L., 2002. Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys. Marine Pollution Bulletin 44, 597–604.

Christie, P., 2004. Marine protected areas as biological successes and social failures in southeast Asia. American Fisheries Society Symposium 42, 155–164.

Christie, P., White, A., Deguit, E., 2002. Starting point or solution? Community-based marine protected areas in the Philippines. Journal of Environmental Management 66, 441–454.

CInner, J.E., 2007. Designing marine reserves to reflect socioeconomic conditions: lessons from long-enduring customary management systems. Coral Reefs 26, 1035–1045.

Cinner, J.E., McClanahan, T.R., 2006. Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea. Environmental Conservation 33, 73–80.

Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Pratchett, M.S., Wilson, S.K., Raina, J.B., 2009. Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. Journal of Applied Ecology 46, 724–732.

Claisse, J.T., Kienzle, M., Bushnell, M.E., Shafer, D.J., Parrish, J.D., 2009. Habitat- and sex-specific life history patterns of yellow tang *Zebrasoma flavescens* in Hawaii, USA. Marine Ecology Progress Series 389, 245–255.

Claydon, J., 2005. Spawning aggregations of coral reef fishes: characteristics, hypotheses, threats and management. Oceanography and Marine Biology 265–301.

Cote, I.M., Mosquera, I., Reynolds, J.D., 2001. Effects of marine reserve characteristics on the protection of fish populations: a meta-analysis. Journal of Fish Biology 59, 178–189.

Crowder, L.B., Lyman, S.J., Figueira, W.F., Priddy, J., 2000. Source-sink population dynamics and the problems of siting marine reserves. Bulletin of Marine Science 66, 799–820.

Dalzell, P., 1998. The role of archaeological and cultural-historical records in long-range coastal fisheries resources management strategies and policies in the Pacific Islands. Ocean and Coastal Management 40, 237–252.

DeMartini, E.E., Friedlander, A.M., Sandin, S.A., Sala, E., 2008. Differences in fish-assemblage structure between fished and unfished atolls in the northern Line Islands, central Pacific. Marine Ecology Progress Series 365, 199–215.

Dulvy, N.K., Freckleton, R.P., Polunin, N.V.C., 2004. Coral reef cascades and the indirect effects of predator removal by exploitation. Ecology Letters 7, 410–416.

Finkl, C.W., Charlier, R.H., 2003. Sustainability of subtropical coastal zones in Southeastern Florida: challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. Journal of Coastal Research 19, 934–943.

Fox, H.E., Mous, P.J., Pet, J.S., Muljadi, A.H., Caldwell, R.L., 2005. Experimental assessment of coral reef rehabilitation following blast fishing. Conservation Biology 19, 98–107.

Friedlander, A.M., Parrish, J.D., 1998. Habitat characteristics affecting fish assembalges on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224, 1–30.

Game, E.T., Bode, M., McDonald-Madden, E., Grantham, H.S., Possingham, H.P., 2009. Dynamic marine protected areas can improve the resilience of coral reef systems. Ecology Letters 12, 1336–1345.

Graham, N.A.J., McClanahan, T.R., MacNeil, M.A., Wilson, S.K., Polunin, N.V.C., Jennings, S., Chabanet, P., Clark, S., Spalding, M.D., Letourneur, Y., Bigot, L., Galzin, R., Öhman, M.C., Garpe, K.C., Edwards, A.J., Sheppard, C.R.C., 2008. Climate warming, marine protected areas and the ocean-scale integrity of coral reef ecosystems. PloS One 3.

Haley, M., Clayton, A., 2003. The role of NGOs in environmental policy failures in a developing country: the mismanagement of Jamaica's coral reefs. Environmental Values 12, 29–54.

Halpern, B.S., Lester, S.E., Kellner, J.B., 2010. Spillover from marine reserves and the replenishment of fished stocks. Environmental Conservation 36, 268–276.

Hastings, A., Botsford, L.W., 1999. Equivalence in yield from marine reserves and traditional fisheries management. Science 284, 1537–1541.

Hawkins, J.P., Roberts, C.M., 2004. Effects of fishing on sex-changing Caribbean parrotfishes. Biological Conservation 115, 213–226.

Hicks, C.C., McClanahan, T.R., Cinner, J.E., Hills, J.M., 2009. Trade-offs in values assigned to ecological goods and services associated with different coral reef management strategies. Ecology and Society 14, 10 http://www.ecologyandsociety.org/vol14/iss1/art10/.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatziolos, M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318, 1737–1742.

Hoey, A.S., Bellwood, D.R., 2009. Limited functional redundancy in a high diversity system: single species dominates key ecological process on coral reefs. Ecosystems 1–13.

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4, 390–405.

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nystrom, M., Palumbi, S., Pandolfi, J.M., Rosen, B., Rougharden, J., 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301, 929–933.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., Wilson, J., 2005. New paradigms for supporting the resilience of marine ecosystems. Trends in Ecology & Evolution 20.

Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh Guldberg, O., McCook, L., Moltschaniwskyl, N., Pratchett, M.S., Steneck, R.S., Willis, B., 2007. Phase shifts, herbivory, and resilience of coral reefs to climate change. Current Biology 17, 360–365.

Jackson, J.B.C., 2001. What was natural in the coastal oceans? Proceedings of the National Academy of Sciences of the United States of America 98, 5411–5418.

Jackson, J.B.C., Kirby, M.X., Berger, W.A., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–638.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Advances in Marine Biology 201–352.

Jennings, S., Polunin, N.V.C., 1996. Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef fish communities. Journal of Applied Ecology 33, 400–412.

Kramer, D.L., Chapman, M.R., 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes 55, 65–79.

Lester, S.E., Halpern, B.S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D., Airame, S., Warner, R.R., 2009. Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384, 33–46.

Mangi, S.C., Roberts, C.M., 2006. Quantifying the environmental impacts of artisanal fishing gear on Kenya's coral reef ecosystems. Marine Pollution Bulletin 52, 1646–1660.

McClanahan, T.R., 1999a. Predation and the control of the sea urchin *Echinometra viridis* and fleshy algae in the path reefs of Glovers Reef, Belize. Ecosystems 2, 511–523.

McClanahan, T.R., 1999b. Is there a future for coral reef parks in poor tropical countries? Coral Reefs 18, 321–325.

McClanahan, T.R., 2000. Recovery of the coral reef keystone predator, *Balistapus undulatus*, in East African marine parks. Biological Conservation 94, 191–198.

McClanahan, T.R., 2010. Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. Conserv. Biol 24, 1519–1528.

McClanahan, T.R., Cinner, J.E., 2008. A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. Aquatic Conservation: Marine and Freshwater Ecosystems 18, 493–507.

McClanahan, T.R., Cinner, J.E., Graham, N.A.J., Daw, T.M., Maina, J., Stead, S.M., Wamukota, A., Brown, K., Venus, V., Polunin, N.V.C., 2009a. Identifying reefs of hope and hopeful actions: contextualizing environmental, ecological, and social parameters to respond effectively to climate change. Conservation Biology 23, 662–671.

McClanahan, T.R., Cinner, J.E., Kamukuru, A.T., Abunge, C., Ndagala, J., 2009b. Management preferences, perceived benefits and conflicts among resource users and managers in the Mafia Island Marine Park, Tanzania. Environmental Conservation 35, 340–350.

McClanahan, T.R., Cinner, J.E., Maina, J., Graham, N.A.J., Daw, T.M., Stead, S.M., Wamukota, A., Brown, K., Ateweberhan, M., Venus, V., Polunin, N.V.C., 2008a. Conservation action in a changing climate. Conservation Letters 1, 53–59.

McClanahan, T.R., Davies, J., Maina, J., 2005a. Factors influencing resource users and managers' perceptions towards marine protected area management in Kenya. Environmental Conservation 32, 42–49.

McClanahan, T.R., Glaesel, H., Rubens, J., Kiambo, R., 1997. The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. Environmental Conservation 24, 105–120.
McClanahan, T.R., Graham, N.A.J., 2005. Recovery trajectories of coral reef fish assemblages within Kenyan marine protected areas. Marine Ecology Progress Series 294, 241–248.
McClanahan, T.R., Graham, N.A.J., Calnan, J.M., MacNeil, M.A., 2007. Toward pristine biomass: reef fish recovery in coral reef marine protected areas in Kenya. Ecological Applications 17, 1055–1067.
McClanahan, T.R., Graham, N.A.J., Wilson, S.K., Letourneur, Y., Fisher, R., 2009c. Effects of fisheries closure size, age, and history of compliance on coral reef fish communities in the western Indian Ocean. Marine Ecology Progress Series 396, 99–109.
McClanahan, T.R., Hicks, C.C., Darling, E.S., 2008b. Malthusian overfishing and efforts to overcome it on Kenyan coral reefs. Ecological Applications 18, 1516–1529.
McClanahan, T.R., Kamukuru, A.T., Muthiga, N.A., Yebio, M.G., Obura, D., 1996. Effect of sea urchin reductions on algae, coral, and fish populations. Conservation Biology 10, 136–154.
McClanahan, T.R., Kaunda-Arara, B., 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10, 1187–1199.
McClanahan, T.R., Maina, J., Davies, J., 2005b. Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. Fisheries Management and Ecology 12, 105–112.
McClanahan, T.R., Mangi, S., 2000. Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. Ecological Applications 10, 1792–1805.
McClanahan, T.R., Mangi, S., 2001. The effect of a closed area and beach seine exclusion on coral reef fish catches. Fisheries Management and Ecology 8, 107–121.
McClanahan, T.R., Mangi, S.C., 2004. Gear-based management of a tropical artisanal fishery based on species selectivity and capture size. Fisheries Management and Ecology 11, 51–60.
McClanahan, T.R., Marnane, M.J., Cinner, J.E., Kiene, W.E., 2006. A comparison of marine protected areas and alternative approaches to coral-reef management. Current Biology 16, 1408–1413.
McClanahan, T.R., Muthiga, N.A., 1998. An ecological shift in a remote coral atoll of Belize over 25 years. Environmental Conservation 25, 122–130.
McClanahan, T.R., Muthiga, N.A., Kamukuru, A.T., Machano, H., Kiambo, R.W., 1999. The effects of marine parks and fishing on coral reefs of northern Tanzania. Biological Conservation 89, 161–182.
McClanahan, T.R., Shafir, S.H., 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 83, 362–370.
McManus, J.W., Reyes Jr., R.B., Nanola Jr., C.L., 1997. Effects of some destructive fishing methods on coral cover and potential rates of recovery. Environmental Management 21, 69–78.
Micheli, F., Halpern, B.S., Botsford, L.W., Warner, R.R., 2004. Trajectories and correlates of community change in no-take marine reserves. Ecological Applications 14, 1709–1723.
Mumby, P.J., Dahlgren, C.P., Harborne, A.R., Kappel, C.V., Micheli, F., Brumbaugh, D.R., Holmes, K.E., Mendes, J., Broad, K., Sanchirico, J.N., Buch, K., Box, S., Stoffle, R.W., Gill, A.B., 2006. Fishing, trophic cascades, and the process of grazing on coral reefs. Science 311, 98–101.
Obura, D.O., 2001. Kenya. Marine Pollution Bulletin 42, 1264–1278.
Ostrom, E., 1999. Coping with tragedies of the commons. Annual Review of Political Science 2, 493–535.
Pandolfi, J.M., Jackson, J.B.C., Baron, N., Bradbury, R.H., Guzman, H.M., Hughes, T.P., Kappel, C.V., Micheli, F., Ogden, J.C., Possingham, H.P., Sala, E., 2005. Are U.S. coral reefs on the slippery slope to slime? Science 307, 1725–1726.
Pauly, D., 2006. Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. MAST 4, 7–22.
Pollnac, R., Christie, P., Cinner, J.E., Dalton, T., Daw, T.M., Forrester, G.E., Graham, N.A.J., McClanahan, T.R., 2010. Marine reserves as linked social–ecological systems. Proceedings of the National Academy of Sciences, U.S.A. 107, 18262–18265.
Pollnac, R.B., Crawford, B.R., Gorospe, M.L.G., 2001. Discovering factors that influence the success of community-based marine protected areas in the Visayas. Philippines Ocean Coast Management 44, 683–710.
Pomeroy, R.S., Parks, J.E., Balboa, C.M., 2006. Farming the reef: is aquaculture a solution for reducing fishing pressure on coral reefs? Marine Policy 30, 111–130.
Pomeroy, R.S., Pido, M.D., Pontillas, J.F.A., Francisco, B.S., White, A.T., Ponce De Leon, E.M.C., Silvestre, G.T., 2008. Evaluation of policy options for the live reef food fish trade in the province of Palawan, Western Philippines. Marine Policy 32, 55–65.
Rhodes, K.L., Tupper, M.H., 2007. A preliminary market-based analysis of the Pohnpei, Micronesia, grouper (Serranidae: Epinephelinae) fishery reveals unsustainable fishing practices. Coral Reefs 26, 335–344.
Roberts, C.M., Polunin, N.V.C., 1993. Marine reserves: simple solutions to managing complex fisheries? Ambio 22, 363–368.
Robichaud, D., Hunte, W., Oxenford, H.A., 1999. Effects of increased mesh size on catch and fishing power of coral reef fish traps. Fisheries Research 39, 275–294.
Russ, G.R., Alcala, A.C., 1996a. Do marine reserves export adult fish biomass? Evidence from Apo Island, Central Philippines. Marine Ecology Progress Series 132, 1–9.
Russ, G.R., Alcala, A.C., 1996b. Marine reserves: rates and patterns of recovery and decline of large predatory fish. Ecological Applications 6, 947–961.
Russ, G.R., Alcala, A.C., 1998a. Natural fishing experiments in marine reserves 1983–1993: roles of life history and fishing intensity in family responses. Coral Reefs 17, 399–416.
Russ, G.R., Alcala, A.C., 1998b. Natural fishing experiments in marine reserves 1983–1993: community and trophic responses. Coral Reefs 17, 383–397.
Russ, G.R., Alcala, A.C., 1999. Management histories of Sumilon and Apo Marine Reserves, Philippines, and their influence on national marine resource policy. Coral Reef 18, 307–319.
Russ, G.R., Stockwell, B., Alcala, A.C., 2005. Inferring versus measuring rates of recovery in no-take marine reserves. Marine Ecology Progress Series 292, 1–12.
Sadovy, Y., Domeier, M., 2005. Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. Coral Reefs 24, 254–262.
Sadovy, Y., Kulbicki, M., Labrosse, P., Letourneur, Y., Lokani, P., Donaldson, T.J., 2003. The humphead wrasse, *Cheilinus undulatus*: synopsis of a threatened and poorly known giant coral reef fish. Reviews in Fish Biology and Fisheries 13, 327–364.
Sale, P.F., Cowen, R.K., Danilowicz, B.S., Jones, G.P., Kritzer, J.P., Lindeman, K.C., Planes, S., Polunin, N.V.C., Russ, G.R., Sadovy, Y.J., Steneck, R.S., 2005. Critical science gaps impede use of no-take fishery reserves. Trends in Ecology & Evolution 20, 74–80.
Selig, E.R., Bruno, J.F., 2010. A global analysis of the effectiveness of marine protected areas in preventing coral loss. PloS One 5, e9278.
Spurgeon, J.P.G., 1992. The economic valuation of coral reefs. Marine Pollution Bulletin 24, 529–536.
Swearer, S.E., Caselel, J.E., Lea, D.E., Warner, R.R., 1999. Larval retention and recruitment in an island population of a coral-reef fish. Nature 402, 799–802.
Thorburn, C.C., 2000. Changing customary marine resource management practice and institutions: the case of Sasi Lola in the Kei Islands, Indonesia. World Development 28, 1461–1479.
White, A.T., Vogt, H.P., Arin, T., 2000. Philippine coral reefs under threat: the economic losses caused by reef destruction. Marine Pollution Bulletin 40, 598–605.
Wilkinson, C.R., 1996. Global change and coral reefs: impacts on reefs, economies and human cultures. Global Change Biology 2, 547–558.
Wood, E., 2001. Global advances in conservation and management of marine ornamental resources. Aquarium Sciences and Conservation 3, 65–77.
Wood, L., Fish, L., Laughren, J., Pauly, D., 2008. Assessing progress towards global marine protection targets: shortfalls in information and action. Fauna & Flora International, Oryx 42, 340–351.
Zeller, D.C., 1998. Spawning aggregations: patterns of movement of the coral trout *Plectropomus leopardus* (Serranidae) as determined by ultrasonic telemetry. Marine Ecology Progress Series 162, 253–263.