Literature Review and Gap Analysis on the Sources and Effects of Non-extractive Stressors on Coral Reef Ecosystems

Revisión de la Literatura y el Análisis de las Deficiencias en las Fuentes y los Efectos de los Factores de Estrés No Extractivos en los Ecosistemas de Arrecifes de Coral

Revue de la Littérature et Analyse de L'écart sur les Sources et les Effets des Facteurs de Stress Non Extractives sur les Écosystèmes des Récifs Coralliens

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ABSTRACT

This study reviews literature as it relates to non-extractive activities and their impacts on coral reef ecosystems, including tourism-related acitivites such as trampling, snorkeling and diving, and boating and coastal development-related effects such as sedimentation, habitat alteration and nutrient enrichment. The study then utilizes Geographic Information Systems to conduct a gap analysis as it relates to areas/regions, stressors and trends, thereby identifying areas/regions that may be under-represented in non-extractive activities studies and lacking in appropriate management actions and listing the stressors that may be yet poorly understood and thus warranting greter research and management efforts.

KEY WORDS: Coral reefs, non-extractive activities, recreation, gap analysis, coral reef management

INTRODUCTION

Coral reefs ecosystems provide important ecological goods and services, such as tourism, fisheries and coastal protection (Moberg and Folke 1999). Globally the net benefits of coral reefs are valued at nearly $30 billion annually (Cesar et al. 2003). Yet coral reef ecosystems around the world are in rapid decline under pressure from a multitude of human threats. It is estimated that almost half of all the world's coral reef ecosystems face medium high to very high anthropogenic impact (Halpern et al. 2008) and the resulting effects are deleterious. Coral reefs in the Indo-Pacific are believed to have lost 50% of their coral cover in the past four decades, with almost three-thirds of this decline occurring in just seven years between 1995 and 2002 (Bruno and Selig 2007). In the Caribbean, coral cover decreased by 80% in only three decades (Gardner et al. 2003). Global climate change, overfishing (and destructive fishing), tourism, pollution, and nutrient and sediment run-off from coastal development endanger the long-term sustainability of coral reefs. These ecosystems often suffer from multiple anthropogenic stressors at a time (Bellwood et al. 2004), reducing their resilience and ability to recover from single perturbations, such as tropical storms (Hughs and Connell 1999) or coral bleaching events (Carilli et al. 2007).

While global warming and extractive uses such as overfishing are often discussed as being the most detrimental stressors to coral reef ecosystems, local non-extractive stressors, such as impacts from recreational activities, vessels, nutrient enrichment and sedimentation should not be overlooked. Non-extractive stressors are the usually unintentionally deleterious effects of recreational activities or the result of activities far from the reefs themselves. Direct impacts generally occur from tourism or recreational activities. Throughout this paper, recreational impacts are considered those caused by activities such as trampling or reef-walking, SCUBA diving, snorkeling, and wildlife interactions. Vessel-based impacts result from damage caused by vessels anchoring, groundings, scarring, and heavy metal contamination. Indirect non-extractive stressors often originate from land-based activities, such as coastal construction or farming, and include sedimentation and nutrient enrichment.

The world's population continues to grow and coastal populations are booming with approximately a tenth of the global population now living within 100 kilometers of coral reefs (Donner and Potere 2007). Marine and coastal tourism have become leading industries in coastal communities and ones that are often encouraged as an alternative to the continued harvesting of overexploited marine resources. Yet, these tourism activities depend on resources that they often inadvertently damage. Additionally, they regularly occur within marine protected areas with none or few restrictions or guidelines for sustainable use (Medio et al. 1997). Therefore, to enable proper management of coral reef ecosystems, there is a necessity to study and understand non-extractive anthropogenic stressors and their effects.

From mid-2006 to late 2007, Shivlani compiled and synthesized the available literature for a report submitted to the Florida Department of Environmental Protection's Southeast Florida Coral Reef Initiative. His focus was primarily on direct impacts caused by anthropogenic stressors, only briefly discussing indirect impacts such as sedimentation or nutrient enrichment. This study integrated and built on Shivlani's original work by adding a geographic analysis of the studies to determine knowledge gaps in non-extractive coral reef stressor research, in addition to updating and expanding the database. It is not a typical literature review or meta-analysis, but implements a combination of a literature review and spatial and

temporal analyses with the use of Geographic Information Systems (GIS) to provide a broader qualitative and quantitative picture of non-extractive stressors on coral reef ecosystems. Based on the updated database, this paper presents and analyses the the temporal, thematic and geographic trends of research on tourism-related non-extractive stressors of coral reef ecosystems on a global scale. Finally, conclusions and recommendations are made as to how researchers and reef managers should allocate their future efforts to ensure the most effective management of our global coral reef ecosystems.

METHODS

Between mid-2006 to September 2007, Manoj Shivlani surveyed various literature databases (such as the Aquatic Science and Fisheries Abstracts, Web of Science and others), United Nations publications and non-governmental organizations online resources for research conducted on non-extractive stressors on coral reefs. He developed a Microsoft Excel worksheet summarizing 223 peer-reviewed literature and other technical documents published between 1977 and 2007, mainly focused on the direct impacts caused by anthropogenic stressors (i.e. recreational and vessel-base impacts).

In the summer of 2013, I created a Microsoft Access database to enable basic information on publications and their geographic details to be easily associated and organized. This program was chosen over Microsoft Excel because several geographic coordinates could be associated with each publication record, without repetitive data collection. The data previously collected by Shivlani was integrated into this database before additional literature was added.

Over approximately three months, relevant literature was collected through the use of Google Scholar. Google Scholar was selected over the more commonly used literature database Web of Science because while having indexed the majority of the articles contained within the latter database, it also includes conference proceedings, books and non-English publications (Mikki 2009; de Winter et al. 2013). Therefore, Google Scholar allowed for a wider coverage of literature, as desired in this analysis.

Literature searches were done using the term 'coral' followed by various coral reef stressor terms, for example, "recreation", "scuba" or "snorkel", and "sedimentation", "sediment" or "turbidity".

For the purpose of this project, studies on these topics had to be relatable to human impacts. For example, studies on the creation of coral reef structures over centuries through sedimentation were neglected. With the assumption that Shivlani had a complete collection of direct impact stressors prior to 2007, searches on those terms were limited to publications after 2006. As the focus of the search was on primary research, opinions and essays were excluded. Due to time considerations, the topics of global warming and invasive species were also purposefully excluded from this project to limit its scope. Both of these topics are booming areas of research and could not be properly investigated in this timeframe. Additionally, the GIS aspect of this project emphasizes place-based studies. Many global warming studies are theoretical and not site-specific, while apart from the recent Caribbean lionfish invasion, most marine invasive studies document large regions that were not ideal for this type of study.

Upon finding new material, electronic full-text copies were stored for reference when available and then a summary of each publication was inputted into the Microsoft Access database. Each record included publication information, such as title, authors, date of publication and publication body, the abstract, key words, the type and length of the study and geographic coordinates for each study site. Each publication was categorized by major stressor: recreational impacts (trampling, diving, snorkeling, wildlife viewing/interactions), vessel-based impacts (anchoring, grounding, shading, discharges), nutrient enrichment, and sedimentation; and by major coral reef regions of the world, as per Burke et al. (2011), with the ability to select multiple stressors or regions for each publication. When exact coordinates were not provided but a map or diagram of the study sites was available, the location was estimated using Google Maps with a notation included with the record indicating that the coordinates were an estimate. If research was performed in a laboratory, rather than in the field, the location of the samples used in the experiment was recorded instead of a field site location.

At the end of data collection, summaries and analyses of the complete dataset were completed. Various combinations of literature attributes were exported from the Microsoft Access database and imported into ESRI's ArcGIS 10.1, a spatial-analysis software, to visually represent geographic trends. A single mean location was calculated for each study, except for those which took place in several countries, whereby a single mean location was determined for the sites in each country to provide an accurate representation of the geographic variability of the studies.

RESULTS

Over 120 publications on direct non-extractive stressors (i.e. recreational and vessel-based impacts) and their effects on coral reef ecosystems were added.

Additionally, over 120 publications on indirect stressors, mainly nutrient enrichment, were added. The total database to date documents 452 publications. The database represents the majority of literature on direct non-extractive stressors to coral reefs, but unfortunately, due to time constraints, it only provides a small representation of the available literature on indirect stressors (nutrient enrichment and sedimentation). Since I was not able to collect the majority of the available literature on indirect non-extractive stressors, the focus of this report is on therefore on recreational and vessel-based stressors on

coral reefs, for which 342 publications were documented.

Half of the literature on direct non-extractive stressors to date is related to the impacts of snorkeling and SCUBA diving, and almost three quarters of the literature was related to recreational impacts versus vessel-based impacts (Figure 1). Of vessel-based impacts studied, the most common topics are that of antifouling paint and other hard metal contamination, often related to the shipping industry (Figure 1).

Of the total 369 records (including nutrient enrichment and sedimentation) with available geographic information on study sites, specific coordinates for every research site were geocoded for 188 publications (54%). Of these publications, only 28% (51 publications) provided exact coordinates for every research site, whereas the remaining coordinates were estimated based on maps or descriptions within the publication. Due to time constraints, the remaining publications were geocoded with a single estimated position based on information from the title and abstract of the study. During this secondary process, estimated coordinates were repetitively used for recurring locations, therefore causing a recognized geographic bias. This effect can be especially perceived for the Great Barrier Reef, where the same coordinates were geocoded for twenty publications of the 36 undertaken in Australia causing an exaggerated hot spot in the central Great Barrier Reef (Figure 2).

Geographically, research on non-extractive stressors was very clustered by area and major coral region. Over a third of the direct non-extractive stressor studies have occurred within the Atlantic, while this area only accounts for 10% of the world's coral reefs (Figure 3). On the other hand, the Pacific and Southeast Asia regions which together encompass over 50% of the world's coral reefs, were the site of study for less than a quarter of all publications (Figure 3). Recreational impact studies, while occurring around the world's coral ecosystems, are extensively based in the northern Red Sea (Figure 2A).

On the other hand, vessel-based impacts are not only less frequent (Figure 1), but are highly clustered in the Florida Keys, with secondary hotspots in the Puerto Rico and US Virgin Islands area and the Great Barrier Reef (Fig. 2B).

A research-to-reef area ratio shows research effort in the Atlantic and Middle East is approximately ten times greater than in Southeast Asia (Table 1). Table 1 also shows the percentage of reefs considered 'threatened' by local threats contained within each region. While these values are calculated including threats other than the recreational and vessel-based ones investigated in this report (e.g. overfishing and watershed based impacts), they illustrate that research effort is not correlated to the actual threat level faced by regional reefs.

The first two studies related to this area of research were published in 1977 on the impacts of anchoring and human trampling respectively (Davis 1977; Woodland and Hooper 1977). Very few studies were then published in this field until the 1990s, where recreational impacts on coral reefs began to be studied more often (Figure 4). Non-extractive studies boomed in the new millennium with over 120 publications in the first decade.

A timelapse of the locations of non-extractive research shows that the first two studies occurred in the Florida Keys and Great Barrier Reef, soon followed by others in Hawaii and the Caribbean (Figure 5). It is interesting to note that while the Red Sea is a hotspot for recreational impacts research, studies in this region did not occur until the 1990s, and apart from a single study reporting on heavy metals levels in sedimentation from coastal areas in Singapore in 1997, there was no research conducted on non-extractive stressors in the Indo-Pacific until the 2000s.

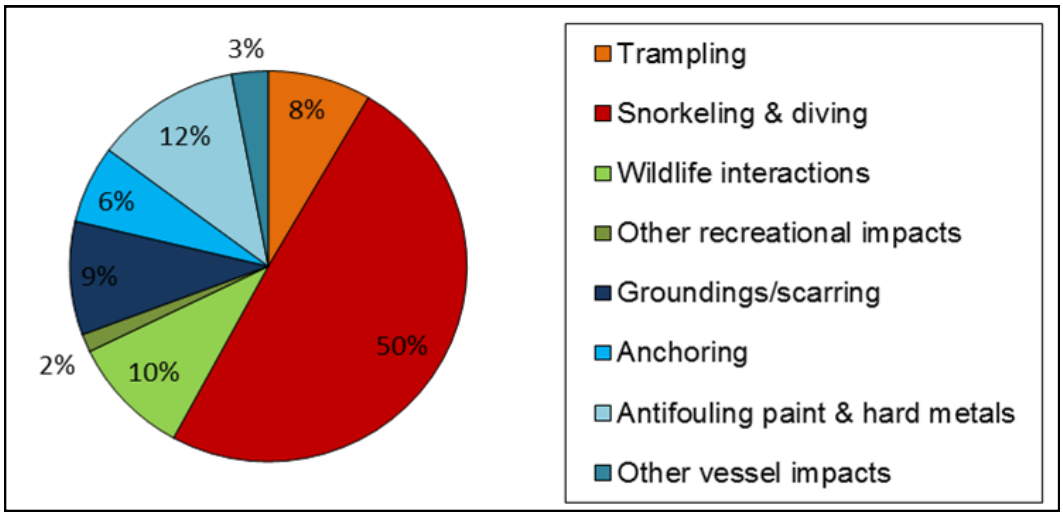

Figure 1. Breakdown of specific stressors studied in peer-reviewed literature (not including reviews) on direct non-extractive stressors and their effects on coral reef ecosystems. Other recreational impacts include effects of platoons and beach-goers. Other vessels impacts include effects of oil and oil spills, cruise ships, kayaks, vessel noise, and animal interactions with vessels.

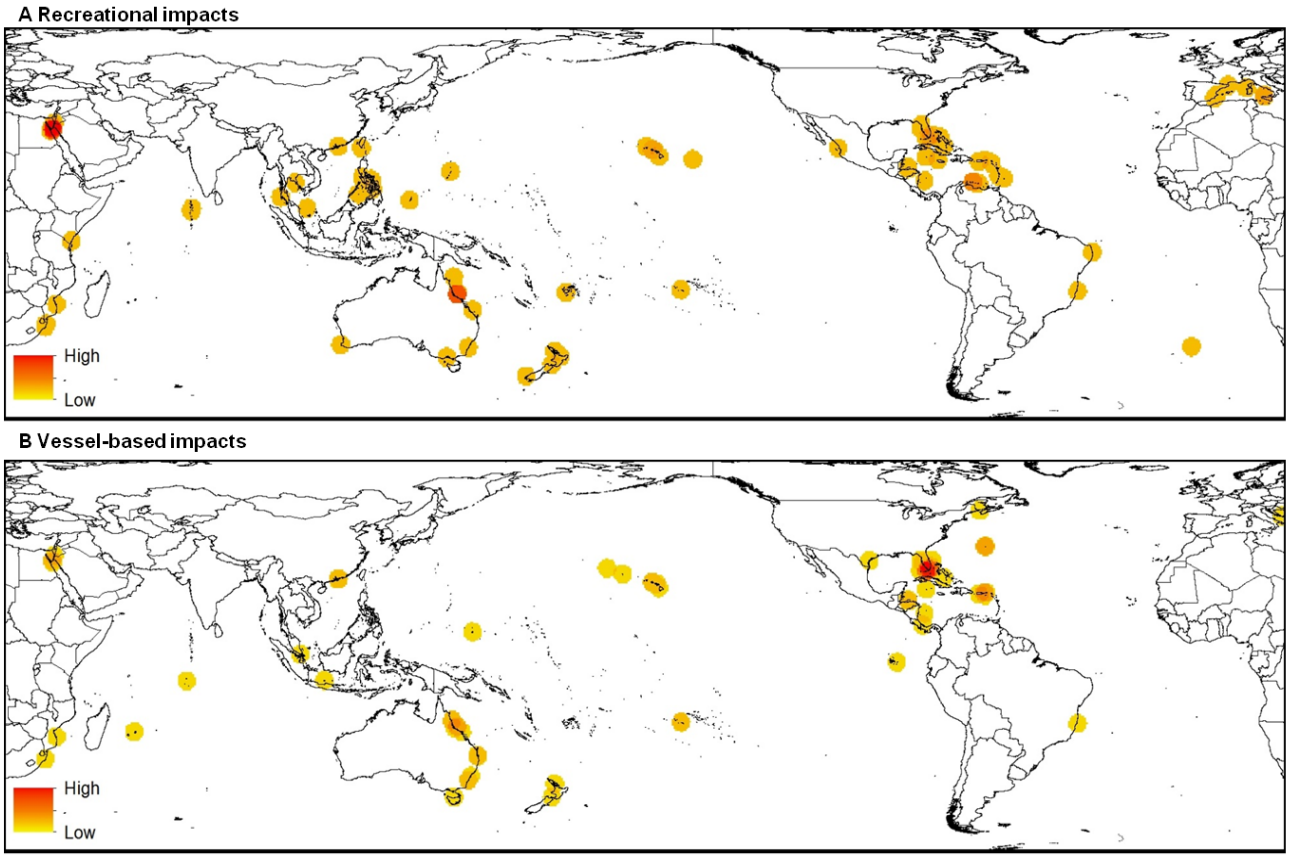

Figure 2. Point density distribution of studies on direct non-extractive coral reef stressors and their effects (A: recreational impact and B: vessel-based impacts), indicating hot spots in these topics of research. Darker shades of red indicate greater research effort.

Table 1. Research-to-reef area ratio and coral reef threat by major coral reef region. Percentage regional reef threatened values courtesy of Burke et al. (2011), and local threats were calculated approximating the impacts of overfishing and destructive fishing, coastal development, watershed-based pollution and marine-based pollution and damage.

Region	Research-to-reef area ratio	% Regional reef threatened (from local threats)	Reef threatened as % of global
Atlantic	3.47	75	12
Middle East	3.10	65	6
Australia	1.06	14	4
Pacific	0.58	48	20
Indian Ocean	0.35	66	14
Southeast Asia	0.32	94	43
Global	1.00	61	100

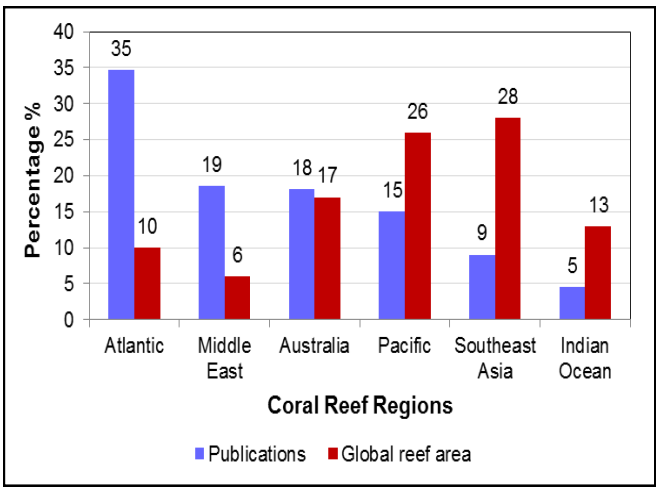

Figure 3. Percentage of publications on direct non-extractive stressors and their effects on coral reef ecosystems by coral reef region in comparison to the region's portion of global coral reef area. Studies located in the Mediterranean were included within the Middle East region. Global reef area percentage values courtesy of Burke et al. (2011).

DISCUSSION

This study through the use of an extensive literature review and Geographic Information Systems spatial analysis illustrates the current state of research on the sources and effects of direct and local non-extractive stressors on coral reef ecosystems around the world. It is clear that coral reef ecosystems are facing a difficult future with over half of all coral reefs estimated to be seriously threatened with disappearance within the next forty years (Wilkinson et al. 2008) and more recent reports claiming that sixty percent of reefs are currently threatened by local stressors, such as overfishing, coastal development and pollution (Burke et al. 2011). Coral reefs are affected by multiple stressors locally, but also globally with rising impacts associated with global warming, and these are having deleterious effects. Yet local direct non-extractive stressors, such as the recreational and tourism-related activities investigated in this report, are often easier to manage. Therefore, it is important to continue research in this area, as well as understand its trends and any under-represented regions or topics as to allow for the most effective management and conservation of the world's coral reef ecosystems.

Studying anthropogenic impacts on coral reefs though was largely overlooked until the mid-1990s and then only occurred in small areas of the Caribbean, the Great Barrier Reef and the northern Red Sea. While these regions are closest to the major marine biology institutions, they were also where marine tourism and recreation were booming, and therefore where worries over possible damage by these activities developed. In fact, the earliest study on direct non-extractive stressors on coral reefs suggested that natural stressors, such a wave action and hurricanes, were having much greater negative impacts on coral reefs than recreational diving (Tilmant & Schmahl 1981). In the new millennium, with the increase in marine and coastal activities and the increasing evidence of damage caused by them, came a dramatic increase in the study of their impacts, particularly in the Indo-Pacific region.

It has been suggested that research effort on coral reefs should be based on their level of threat (Fisher et al. 2011) or specifically, level of species richness with the basis that these areas are of highest value to global biodiversity (Vernon et al. 2009). As seen with Fisher and his colleagues (2011), this does not seem to be the case. While I was not able to specifically analyze correlations between these factors and study locations, research effort is clearly highly clustered in regions that are not facing the highest threats nor are the most biodiverse. Approximately ten times more research has been published on sites in the Atlantic and Middle East than in Southeast Asia, although this latter region is estimated to contain over forty percent of the world's threatened reefs (Burke et al. 2011).

Only a quarter of non-extractive coral reef stressor research occurred in the Pacific and Southeast Asia while these two regions account for over half of the world's coral reefs. Preliminary examinations of publication data suggests that research is often conducted at locations that are the most convenient. Study sites are often correlated to their proximity to the primary author's institution; hence the overwhelming number of publications based in the Caribbean, Red Sea and Australia where the majority of tropical marine biology research institutions are located. Additionally, the accessibility and infrastructure of nations also appears to dictate study location, for example probably explaining the complete lack of studies in the Dominican Republic and Cuba, even though they are the two Caribbean nations undergoing the largest growth in tourism.

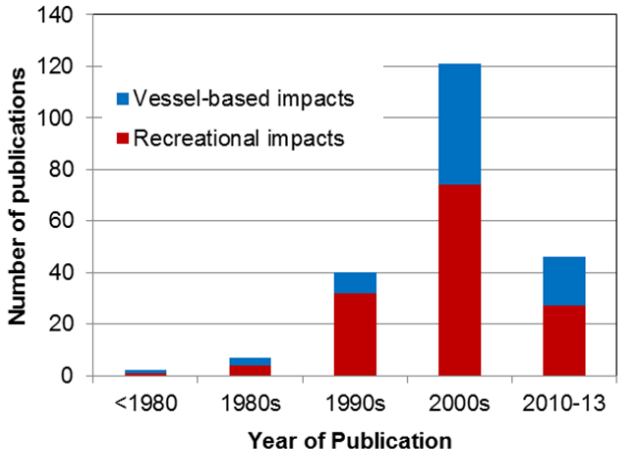

Figure 4. Number of publications on direct non-extractive stressors and their effects on coral reef ecosystems by decade.

It should be noted though that other factors may be influencing these geographic findings, notably the language of publication. The regions seen with the highest number of publications are also those with research institutions that operate largely in English, including the Red Sea region due to its historical and current American and British influences and connections. This is not the case for research institutions in other regions. With most major scientific journals publishing only in English and the strong competition to be published by these, researchers who are not fluent in written English face a significant barrier to their research being internationally indexed. Hence, it is likely that much more research has occurred in some of these regions than I was able to access. Regardless, there is still a need for increased research on non-extractive stressors in under-represented countries, especially the Dominican Republic, Cuba, Indonesia and Thailand.

Certain topics are also under-represented in this field of research. While there is a vast amount of information on the direct physical impacts of snorkelers and divers, there is a need to further investigate secondary effects of these activities on coral disease, parasites and predation in coral reef communities. Additionally, the ecological and biological effectiveness of certain management strategies, such as the creation of artificial reefs, underwater trails and plat-

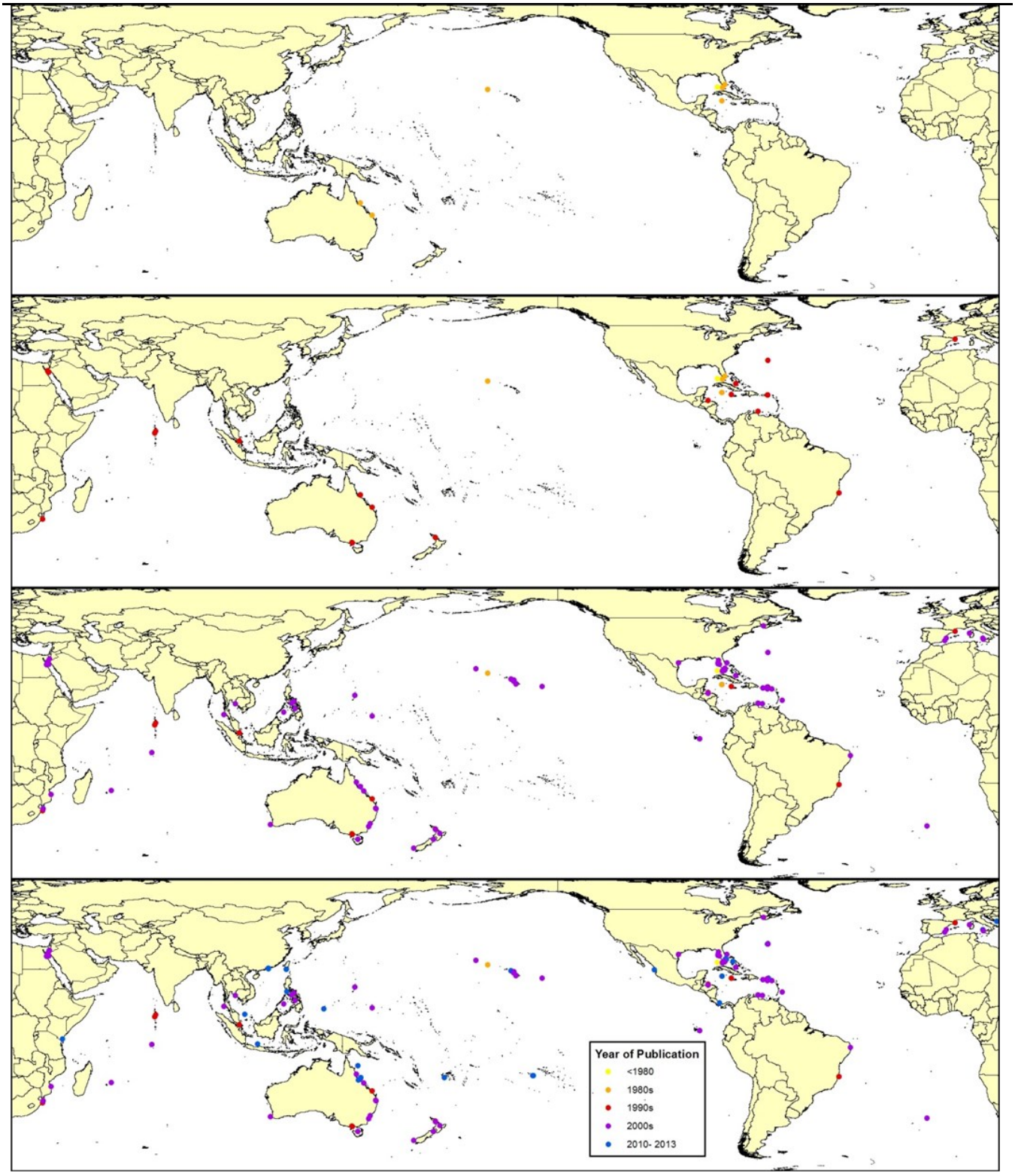

Figure 5. Temporal progresson of specific geographic locations of studies on direct non-extractive stressors and their

forms, need to be properly assessed to determine whether they are efficient uses of management resources. Socioeconomic aspects of these strategies also need to be investigated. For example, while artificial reefs are hyped as being an effective strategy to reduce recreational pressures on natural coral reefs, I did not find any studies that examined users' willingness to shift their activity to these structures, particularly smaller, abstract structures such as ball reefs, rather than historical shipwrecks or structurally interesting decommissioned oil production platforms. Also lacking is studies on the effects of the removal or management of recreational activities within marine protected areas (MPAs) or through marine spatial planning. This though is probably due to few MPAs strongly regulating recreational activities and the relative novelty of marine spatial planning.

Beyond specific topics being under-represented, there is a need for more studies on the synergistic effects of several stressors. From a management perspective, these studies are very important in that by identifying the most important stressors in a disturbed ecosystem they enable managers to determine the most effective and cost-effective strategies for coral reef conservation. Models used to evaluate direct non-extractive stressors need to additionally consider the effects of indirect land-based stressors, such as nutrient enrichment, sedimentation and pollution from coastal development, and global impacts, such as global warming and ocean acidification. These indirect stressors are often much more difficult to regulate and therefore while direct stressors may be controlled or minimized (for example by improving diver skills, installing mooring balls, etc), coral reef health may not improve significantly due to underestimation indirect stressor effects.

Finally, there is a need for direct non-extractive stressors on coral reef ecosystems to be studied over the long-term. Most studies occur over only a few months, with only two studies in this report monitoring sites for over five years (Epstein et al. 1999, Hawkins et al. 2005). Long-term monitoring allows for meaningful, trend-based information that can detect precise changes within a community that may otherwise be missed in 'snapshot' studies. For example, Hawkins and her colleagues' (2005) nine year monitoring of Saba in the Netherland Antilles provided insight into the combined effects of periodic, natural events and continuous anthropogenic use, information which does not exist for other areas, particularly those with higher use. Additionally, long-term research is particularly important in this area of research as little to no baseline data exists for shorter studies to refer to.

On a related side note, due the lack of long-term monitoring and funding for it, there is a desperate need for studies to publish accurate geographic information on their study sites. It is surprising that in our technological age only slightly more than a quarter of publications analyzed in this study published exact coordinates for every research site. Accurate geographic coordinates would allow subsequent studies to build on previous work and still be able to determine trends without baseline studies or resource intensive long-term monitoring. A historical comparison conducted by Jameson and his colleagues (2007) was able to demonstrate dramatic changes over nine years in the hard coral and algal cover at a highly used diving site in the Red Sea with data previously published, but due to the lack of accurate information, the possibility of other such comparisons would currently be difficult. Accurate geographic coordinates need to be published, even if only as online supplements, to allow for greater findings to be made in this field of research.

This project has successfully updated and expanded the original database documenting research on direct non-extractive stressors and their effects on coral reef ecosystems, both in content and structure, but this endeavor should be continued and expanded further. Due to time constraints, the collection of literature on sedimentation and nutrient enrichment was not completed, but would yield a much needed complete picture of the state of research on all non-extractive stressors, both direct and indirect. Additional geospatial analyses could further support the conclusions of this report. By manipulating currently available data on local threat levels for coral reefs around the world (Burke et al. 2011), relationships between study locations and the level of local threat faced by reefs could be determined. The suggestion that the clustering of studies in certain regions is mostly dictated by convenience for researchers could also be quantified by determining the relationship between site locations and their distance from the primary author's institution; an analysis which I was unable to complete during this project.

As our coastal populations continue to boom and marine-based tourism becomes increasingly popular, the threats of non-extractive stressors on coral reef ecosystems will soon be a greater problem than those currently presented by overfishing and other extractive activities. Hence, it is critical to monitor the trends and gaps in the research being conducted in this emerging field to enable the best possible research to be conducted for the effective conservation and management of global coral reef ecosystems.

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LITERATURE CITED

Bellwood, D.R., T.P. Hughes, C. Folke, and M. Nyström. 2004. Confronting the coral reef crisis. *Nature* **429**:827-833.

Bruno, J.F. and E.R. Selig. 2007).Regional decline of coral cover in the indo-pacific: Timing, extent, and subregional comparisons. PloS One 2:e711.

Burke, L., K. Reytar, M. Spalding, and A. Perry. 2011. *Reefs at Risk Revisited*. World Resources Institute, Washington, 130 pp.

Carilli, J.E., R.D. Norris, B.A. Black, S.M. Walsh, and M. McField. 2009. Local stressors reduce coral resilience to bleaching. PloS One 4:e6324.

Cesar, H., L. Burke, and L. Pet-Soede. 2003. *The Economics of Worldwide Coral Reef Degradation*. Cesar Environmental Economics Consulting 4-23. Arnhem, The Netherlands.

de Winter, J.C.F., A.A. Zadpoor, and D. Dimitra Dodou. 2014. The expansion of Google Scholar versus Web of Science: a longitudinal study. *Scientometrics* **98**(2):1547-1565.

Donner, S.D. and D. Potere. 2007. The inequity of the global threat to coral reefs. *Bioscience* **57**:214-215.

Epstein, N., R.P.M. Bak, and B. Rinkevich. 1999. Implementation of a small-scale ''no-use zone'' policy in a reef ecosystem: Eilat's reef lagoon six years later. *Coral Reefs* **18**:327-332.

Fisher, R., B.T. Radford, N. Knowlton, R.E. Brainard, and F.B. Michaelis. 2011. Global mismatch between effort and conservation needs of tropical coral reefs. Publications, Agencies and Staff of the U.S. Department of Commerce. Paper 262.

Halpern, B.S., H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck, and others. 2008. A global map of human impact on marine ecosystems. *Science* **319**:948-952.

Hughes, T. and J. Connell. 1999. Multiple stressors on coral reefs: A long -term perspective. *Limnology and Oceanography* **44**:932-940.

Jameson, S.C., M.S.A. Ammar, E. Saadala, H.M. Mostafa, and B. Riegl. 2007. A quantitative ecological assessment of diving sites in the Egyptian Red Sea during a period of severe anchor damage: A baseline for restoration and sustainable tourism management. *Journal of Sustainable Tourism* **15**(3):309-323.

Medio, D., R.F.G. Ormond, and M. Pearson. 1997. Effect of briefings on rates of damage to corals by scuba divers. *Biological Conservation* **79**:91-95.

Mikki, S. 2009. Google Scholar compared to Web of Science: A literature review. *Nordic Journal of Information Literacy in Higher Education* **1**(1):41-51.

Moberg, F. and C. Folke. 1999. Ecological goods and services of coral reef ecosystems. *Ecological Economics* **29**:215-233.

Tilmant, J.T. and G.P. Schmahl. 1982. A comparative analysis of coral damage on recreationally used reefs within Biscayne National Park, Florida. *Proceedings of the International Coral Reef Symposium* **1**:187-192.

Vernon, J.E.N., L.M. Devantier, E. Turak, A.L. Green, S. Kininmonth, M. Stafford-Smith, and N. Peterson. 2009. Delineating the coral triangle. *Galaxea Journal of Coral Reef Studies* **11**:91-100.

Wilkinson, C. 2008. *Status of Coral Reefs of the World: 2008*. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia. 296 pp.