PERSPECTIVE

Dredging in the Spratly Islands: Gaining Land but Losing Reefs

Camilo Mora[1]*, Iain R. Caldwell[2], Charles Birkeland[3], John W. McManus[4]

1 Department of Geography, University of Hawaii at Manoa, Honolulu, Hawaii, United States of America, 2 Hawaii Institute of Marine Biology, University of Hawaii at Manoa, Honolulu, Hawaii, United States of America, 3 Department of Biology, University of Hawaii at Manoa, Honolulu, Hawaii, United States of America, 4 Department of Marine Biology and Ecology, Rosenstiel School, University of Miami, Miami, Florida, United States of America

* cmora@hawaii.edu

Abstract

Coral reefs on remote islands and atolls are less exposed to direct human stressors but are becoming increasingly vulnerable because of their development for geopolitical and military purposes. Here we document dredging and filling activities by countries in the South China Sea, where building new islands and channels on atolls is leading to considerable losses of, and perhaps irreversible damages to, unique coral reef ecosystems. Preventing similar damage across other reefs in the region necessitates the urgent development of cooperative management of disputed territories in the South China Sea. We suggest using the Antarctic Treaty as a positive precedent for such international cooperation.

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Coral reefs constitute one of the most diverse, socioeconomically important, and threatened ecosystems in the world [1–3]. Coral reefs harbor thousands of species [4] and provide food and livelihoods for millions of people while safeguarding coastal populations from extreme weather disturbances [2,3]. Unfortunately, the world's coral reefs are rapidly degrading [1–3], with ~19% of the total coral reef area effectively lost [3] and 60% to 75% under direct human pressures [3,5,6]. Climate change aside, this decline has been attributed to threats emerging from widespread human expansion in coastal areas, which has facilitated exploitation of local resources, assisted colonization by invasive species, and led to the loss and degradation of habitats directly and indirectly through fishing and runoff from agriculture and sewage systems [1–3,5–7]. In efforts to protect the world's coral reefs, remote islands and atolls are often seen as reefs of "hope," as their isolation and uninhabitability provide de facto protection against direct human stressors, and may help impacted reefs through replenishment [5,6]. Such isolated reefs may, however, still be vulnerable because of their geopolitical and military importance (e.g., allowing expansion of exclusive economic zones and providing strategic bases for military operations). Here we document patterns of reclamation (here defined as creating new land by filling submerged areas) of atolls in the South China Sea, which have resulted in considerable loss of coral reefs. We show that conditions are ripe for reclamation of more atolls, highlighting the need for international cooperation in the protection of these atolls before more unique and ecologically important biological assets are damaged, potentially irreversibly so.

Studies of past reclamations and reef dredging activities have shown that these operations are highly deleterious to coral reefs [8,9]. First, reef dredging affects large parts of the surrounding reef, not just the dredged areas themselves. For example, 440 ha of reef was completely destroyed by dredging on Johnston Island (United States) in the 1960s, but over 2,800 ha of nearby reefs were also affected [10]. Similarly, at Hay Point (Australia) in 2006 there was a loss of coral cover up to 6 km away from dredging operations [11]. Second, recovery from the direct and indirect effects of dredging is slow at best and nonexistent at worst. In 1939, 29% of the reefs in Kaneohe Bay (United States) were removed by dredging, and none of the patch reefs that were dredged had completely recovered 30 years later [12]. In Castle Harbour (Bermuda), reclamation to build an airfield in the early 1940s led to limited coral recolonization and large quantities of resuspended sediments even 32 years after reclamation [13]; several fish species are claimed extinct as a result of this dredging [14,15]. Such examples and others led Hatcher et al. [8] to conclude that dredging and land clearing, as well as the associated sedimentation, are possibly the most permanent of anthropogenic impacts on coral reefs.

The impacts of dredging for the Spratly Islands are of particular concern because the geographical position of these atolls favors connectivity via stepping stones for reefs over the region [16–19] and because their high biodiversity works as insurance for many species. In an extensive review of the sparse and limited data available for the region, Hughes et al. [20] showed that reefs on offshore atolls in the South China Sea were overall in better condition than near-shore reefs. For instance, by 2004 they reported average coral covers of 64% for the Spratly Islands and 68% for the Paracel Islands. By comparison, coral reefs across the Indo-Pacific region in 2004 had average coral covers below 25% [21]. Reefs on isolated atolls can still be prone to extensive bleaching and mortality due to global climate change [22] and, in the particular case of atolls in the South China Sea, the use of explosives and cyanine [20]. However, the potential for recovery of isolated reefs to such stressors is remarkable. Hughes et al. [20] documented, for instance, how coral cover in several offshore reefs in the region declined from above 80% in the early 1990s to below 6% by 1998 to 2001 (due to a mixture of El Niño and damaging fishing methods that make use of cyanine and explosives) but then recovered to 30% on most reefs and up to 78% in some reefs by 2004–2008. Another important attribute of atolls in the South China Sea is the great diversity of species. Over 6,500 marine species are recorded for these atolls [23], including some 571 reef coral species [24] (more than half of the world's known species of reef-building corals). The relatively better health and high diversity of coral reefs in atolls over the South China Sea highlights the uniqueness of such reefs and the important roles they may play for reefs throughout the entire region. Furthermore, these atolls are safe harbor for some of the last viable populations of highly threatened species (e.g., Bumphead Parrotfish [*Bolbometopon muricatum*] and several species of sawfishes [*Pristis*, *Anoxypristis*]), highlighting how dredging in the South China Sea may threaten not only species with extinction but also the commitment by countries in the region to biodiversity conservation goals such as the Convention of Biological Diversity Aichi Targets and the United Nations Sustainable Development Goals.

Recently available remote sensing data (i.e., Landsat 8 Operational Land Imager and Thermal Infrared Sensors Terrain Corrected images) allow quantification of the sharp contrast between the gain of land and the loss of coral reefs resulting from reclamation in the Spratly Islands (Fig 1). For seven atolls recently reclaimed by China in the Spratly Islands (names provided in Fig 1D, Table 1), we extracted one cloud-free image for each 60-day period from February 2014 to May 2015. In these images, only land above sea level is visible in the short-wave infrared band (i.e., Landsat band 6), while land above sea level and natural reef areas (e.g., coral

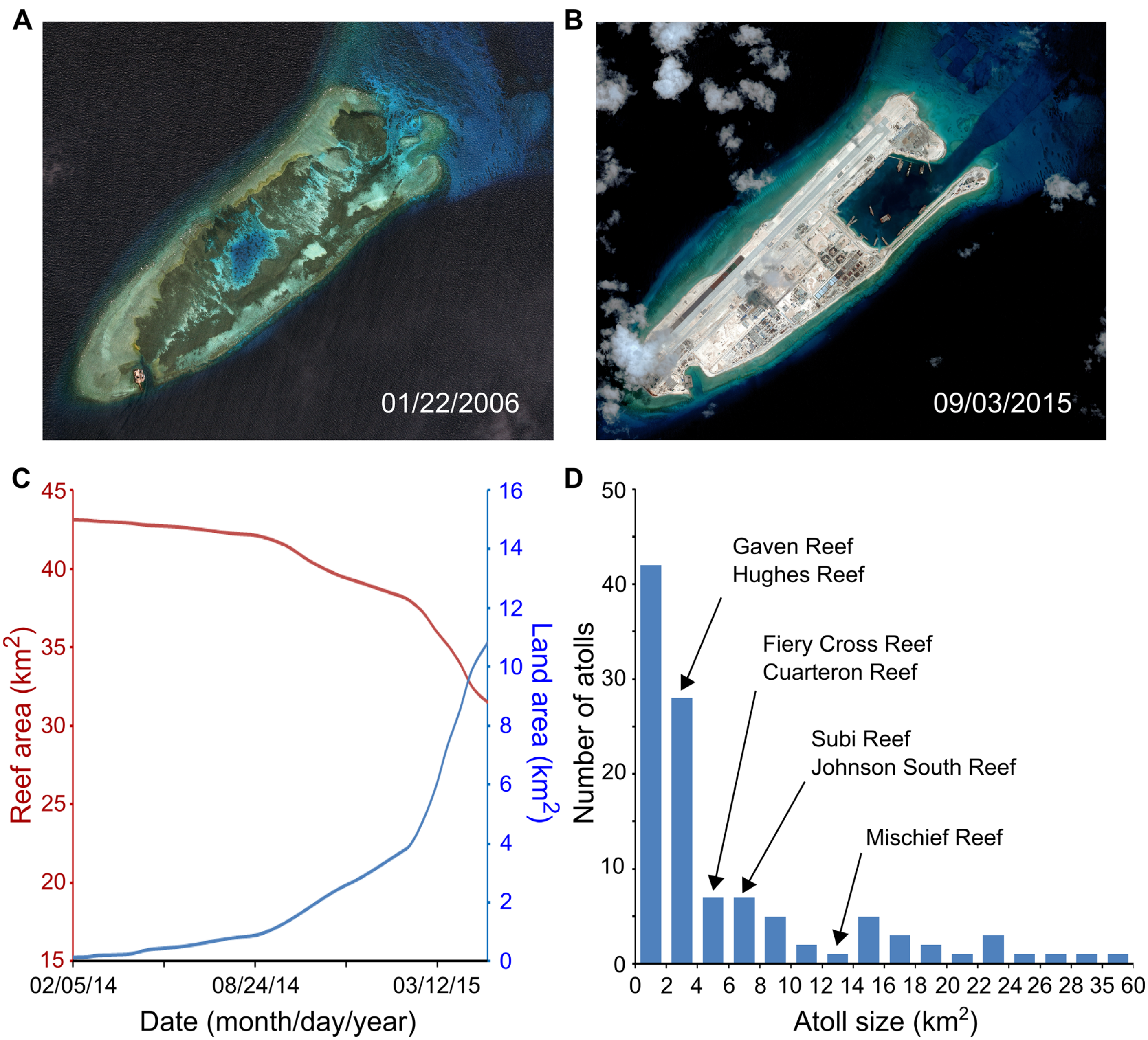

Fig 1. Reclamation leads to gains of land in return for losses of coral reefs: A case example of China's recent reclamation in the Spratly Islands. For display purposes, we show two images of Fiery Cross Reef before (A) and after (B) land reclamation (images courtesy of the Asia Maritime Transparency Initiative from the Center for Strategic and International Studies and Digital Globe). The cumulative reclamation in the seven atolls has resulted in considerable increases in land (blue line, C) but reductions in coral reef area (red line, C). Changes in land and reefs, over time, for the individual atolls are shown in S2 Data. The Spratly Islands, South China Sea, are rich in atolls with similar sizes and characteristics to those already reclaimed (D, China's seven recently reclaimed atolls are highlighted with arrows in their respective size categories). Data for plots C–D are provided in S2–S4 Data. Quantifying similar trends for the reclamation of other atolls by other countries was not possible with available Landsat 8 images because reclamation in many of these atolls had occurred prior to the launching of the Landsat 8 satellite in 2013 and because historically there was land above sea level, which precludes differentiating reclaimed land from natural land.

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reefs and submerged natural sand bars) are both visible in the red optical band (i.e., Landsat band 4). By subtracting the size of visible areas in Landsat band 6 from the size of visible areas in Landsat band 4, we were able to quantify the total size of natural reef areas (see S1 Data for

Table 1. List of reclaimed atolls in the Spratly Islands and the Paracel Islands. Several countries are responsible for the land fillings but are not named to avoid implying ownership.

SPRATLY ISLANDS	Latitude	Longitude
Cuarteron Reef	8°51′39.04″N	112°50′20.52″E
Fiery Cross Reef	9°32′53.33″N	112°53′18.59″E
Gaven Reef	10°12′29.25″N	114°13′22.52″E
Hughes Reef	9°54′51.29″N	114°29′51.57″E
Johnson South Reef	9°43′11.81″N	114°16′56.30″E
Mischief Reef	9°54′8.19″N	115°32′14.22″E
Subi Reef	10°55′31.53″N	114°5′6.03″E
Erica Reef	8°6′27.29″N	114°8′1.88″E
Mariveles Reef	7°58′3.09″N	113°55′13.54″E
Swallow Reef	7°22′28.80″N	113°49′43.79″E
Thitu Island	11°3′13.87″N	114°17′5.89″E
Itu Aba Island	10°22′37.36″N	114°21′56.44″E
Central Reef	8°55′51.13″N	112°21′0.47″E
Namyit Island	10°10′46.13″N	114°21′57.63″E
Pearson Reefs	8°57′28.47″N	113°40′38.21″E
Sand Cay	10°22′28.72″N	114°28′48.63″E
Sin Cowe Island	9°53′7.52″N	114°19′47.29″E
Southwest Cay	11°25′45.36″N	114°19′54.05″E
Spratly Island	8°38′42.03″N	111°55′13.15″E
West Reef	8°51′45.58″N	112°13′29.83″E
PARACEL ISLANDS		
Duncan Island	16°27′6.41″N	111°42′37.06″E
Lincoln Island	16°39′59.93″N	112°43′49.44″E
Money Island	16°26′51.70″N	111°30′25.13″E
Palm Island	16°27′8.01″N	111°42′2.62″E
Pattle Island	16°32′2.76″N	111°36′25.93″E
Rocky Island	16°50′39.71″N	112°20′50.41″E
Triton Island	15°47′6.02″N	111°12′15.13″E
Woody Island	16°50′4.82″N	112°20′15.70″E

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details); the area of reclamation is the size of visible areas in Landsat band 6, as prior to reclamation most of the atolls were submerged, with the exception of small areas occupied by a handful of buildings on piers (note that the amount of land area was near zero at the start of the reclamation; Fig 1C, S1 Data). The seven reclaimed atolls have effectively lost ~11.6 km^2 (26.9%) of their reef area for a gain of ~10.7 km^2 of land (i.e., >75 times increase in land area) from February 2014 to May 2015 (Fig 1C). The area of land gained was smaller than the area of reef lost because reefs were lost not only through land reclamation but also through the deepening of reef lagoons to allow boat access (Fig 1B). Similar quantification of reclamation by other countries in the South China Sea (Table 1) was not possible with available Landsat 8 images because reclamation in many of these atolls has occurred prior to the launching of the Landsat 8 satellite in 2013 and because historically there was land above sea level, which precludes differentiating reclaimed land from natural land.

The impacts of reclamation on coral reefs are likely more severe than simple changes in area, as reclamation is being achieved by means of suction dredging (i.e., cutting and sucking materials from the seafloor and pumping them over land). With this method, reefs are ecologically degraded and denuded of their structural complexity. Dredging and pumping also disturbs the seafloor and can cause runoff from reclaimed land, which generates large clouds of suspended sediment [11] that can lead to coral mortality by overwhelming the corals' capacity to remove sediments and leave corals susceptible to lesions and diseases [7,9,25]. The highly abrasive coralline sands in flowing water can scour away living tissue on a myriad of species and bury many organisms beyond their recovery limits [26]. Such sedimentation also prevents new coral larvae from settling in and around the dredged areas, which is one of the main reasons why dredged areas show no signs of recovery even decades after the initial dredging operations [9,12,13]. Furthermore, degradation of wave-breaking reef crests, which make reclamation in these areas feasible, will result in a further reduction of coral reefs' ability to (1) self-repair and protect against wave abrasion [27,28] (especially in a region characterized by typhoons) and (2) keep up with rising sea levels over the next several decades [29]. This suggests that the new islands would require periodic dredging and filling, that these reefs may face chronic distress and long-term ecological damage, and that reclamation may prove economically expensive and impractical.

The potential for land reclamation on other atolls in the Spratly Islands is high, which necessitates the urgent development of cooperative management of disputed territories in the South China Sea. First, the Spratly Islands are rich in atolls with similar characteristics to those already reclaimed (Fig 1D); second, there are calls for rapid development of disputed territories to gain access to resources and increase sovereignty and military strength [30]; and third, all countries with claims in the Spratly Islands have performed reclamation in this archipelago (Table 1; at least 20 atolls have been reclaimed in the Spratly Islands, and this does not include reclamation activities in the Paracel Islands). In the Spratly Islands, where no country can gain full access to resources without generating international conflict and where the race for development could cause irreversible damage to unique natural assets, novel multinational approaches to conservation are urgently needed [20]. One such possibility is the generation of a multinational marine protected area [16,17]. Such a marine protected area could safeguard an area of high biodiversity and importance to genetic connectivity in the Pacific, in addition to promoting peace in the region (extended justification provided by McManus [16,17]). A positive precedent for the creation of this protected area is that of Antarctica, which was also subject to numerous overlapping claims and where a recently renewed treaty froze national claims, preventing large-scale ecological damage while providing environmental protection and areas for scientific study. Development of such a legal framework for the management of the Spratly Islands could prevent conflict, promote functional ecosystems, and potentially result in larger gains (through spillover, e.g. [31]) for all countries involved.

Supporting Information

S1 Data. Methods used to quantify the area of reefs dredged and filled in the Spratly Islands using Landsat 8 imagery.
(PDF)

S2 Data. Raw and interpolated data from Landsat 8 imagery (as shown in Fig 1C).
(XLSX)

S3 Data. Sizes of atolls in the Spratly Islands (data shown in Fig 1D).
(XLSX)

S4 Data. Compressed folder containing the shapefiles created from Landsat 8 imagery to calculate changes in land and reef areas over time for seven recently reclaimed atolls in the Spratly Islands.
(ZIP)

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