

Republic of the Philippines
Office of the Solicitor General

26 April 2016

Ms. Judith Levine
Registrar
Permanent Court of Arbitration
Peace Palace
Carnegieplein 2
2517 KJ The Hague
The Netherlands

Re: *PCA Case No. 2013-19: The Republic of the Philippines v. The People's Republic of China*

Dear Ms. Levine:

I write in response to your letter dated 1 April 2016 (PH-CN 166245) inviting the Philippines to seek clarification from Professor John W. McManus concerning what proportion of his estimates on the extent of reef area that has been damaged he would confidently assign to dredging versus claim shell extraction.

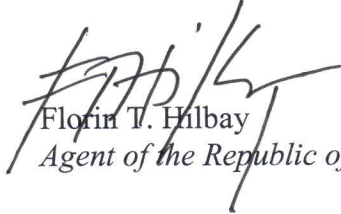
The Philippines has obtained the requested clarification from Professor McManus. It is explained in a letter from him and in its accompanying revised version of his 2015 report, *Offshore Coral Reef Damage, Overfishing and Paths to Peace in the South China Sea*. Professor McManus has asked the Philippines to transmit these documents to the Tribunal on his behalf. Both are included herewith.

Since, as the Tribunal noted in its 1 April 2016 letter, Professor Carpenter relied on the earlier version of Professor McManus' report in his response to the Tribunal's questions during the merits hearings, Professor Carpenter has requested the opportunity to comment upon Professor McManus' clarification. This is presented in a short declaration that is also included with this letter. Please note that Professor Carpenter's declaration references a recently published peer-reviewed article that describes the impact of China's artificial island-building programme. That article is included among the provisional annexes that counsel for the Philippines filed for consideration by the Tribunal on 25 April 2016, as Annex 893.

The Philippines is grateful to the Tribunal for the opportunity to present these materials, and hopes that they will prove useful to the Tribunal and its experts. Please do not hesitate to let me know should you have any questions or concerns.

Please accept the renewed assurances of my highest consideration.

Sincerely,

A handwritten signature in black ink, appearing to read 'F. Hilbay', with a long horizontal flourish extending to the right.

Florin T. Hilbay
Agent of the Republic of the Philippines



April 22, 2016

Honorable Members of the Permanent Court of Arbitration:

I am honored to enclose herein a newly revised draft of my unpublished paper, *Offshore Coral Reef Damage, Overfishing, and Paths to Peace in the South China Sea*.

Much of the analysis which has gone into this paper has necessarily been done using available free imagery from Google Earth Pro (GEP). A key, unnatural feature identifiable in these images which indicates severe damage to coral reefs is the presence of arc-like structures, often associated with streams of flowing sand and silt. Until very recently, the only process known to create such arcs was suction dredging (including cutter-suction dredging), where it indicates the alternating use of pulley systems to swing the suction pipe, or stern-mounted, large, spike-like spuds to 'walk' the dredger forward in swinging arcs. In January, 2016, Victor Robert Lee published a paper in which he convincingly argued that the arcs were actually made by 'cutter' boats from the People's Republic of China (PRC), being used to gather highly valuable giant clam shells for carving and other processing. He based this on a combination of purchased imagery which was of higher resolution than available on GEP, along with images of giant clam operations he found on PRC websites. These boats are anchored on long stern lines and swung laterally with the propeller turning so as to dig up giant clams in the substrate. They can be found by the hundreds in images of reefs across the Spratly area. He acknowledged that some dredgers do make such arcs, but suggested that the dredgers used by PRC have drafts too deep to operate in these shallow areas. This appears to be the first published report of this unusual and destructive harvesting practice, other than a short article and piece of video collected by a BBC reporter from a reef near Thitu (Pag-asa) Island in December 2015.

In February, 2016, I volunteered to accompany a film crew, which had gained rare approvals from the Philippines to enter the area. This afforded me the opportunity to conduct swimming surveys of two of the reefs in question – Teishi Reef and an apparently unnamed reef east of Thitu Island, which I refer to as 'checkmark reef' due to its shape. The latter reef is also the site that the BBC reporter had visited.

I confirmed both that the affected areas were very shallow (generally 1-3 m deep) and that the presence of masses of dead broken branching coral, as well as abundant sand on one of the reefs, ruled out dredging as a cause. The thoroughness of the damage to marine life exceeded anything I had previously seen in four decades of investigating coral reef degradation. Interviews with local fishers, officials and military personnel indicated that this highly destructive PRC harvesting practice was now very widespread across the Spratly area. I later confirmed via an extensive search for information on various websites that the dredgers generally used by PRC for the island building have drafts too deep for such areas, though not for deep lagoons such as those

at the PRC-occupied Fiery Cross, Subi and Mischief reefs where such damage is evidenced in satellite imagery of active operations. I also found imagery for four reefs occupied by Vietnam which clearly show a more common form of shallow dredging, resulting in long rectangular cuts, conducted with smaller dredging systems on reef flats.

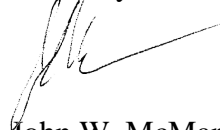
In light of this new evidence and the availability of newer imagery for some reefs, and encouraged by your recent request for clarifications, I redid my quantifications of damage to reefs in the South China Sea. The revised draft of my paper is enclosed. The new information has been incorporated into a revised table of area measurements and into the text. The graphics have not changed from the original.

The new results indicate that the People's Republic of China (PRC) is responsible for at least 39 km² of damage from shallow dredging and 69 km² of damage from giant clam harvest using propellers to dig up the bottom within the Greater Spratly Islands, which includes Scarborough Reef (a ratio of 0.57:1 shallow dredging to clam harvest damage). Vietnam is responsible for shallow dredging covering approximately 0.26 km². The overall damage to coral reefs within the Greater Spratly Islands covers at least 124 km², of which PRC is responsible for 99%.

It must be emphasized that these are underestimates of the damage from shallow dredging and destructive clam harvesting. The PRC dredgers have gathered materials in waters just below the depths wherein the impacts can be easily seen on Google Earth Imagery. Fishers on the boat in which I rode out of the area indicated that several reefs I thought would be nearly pristine now have very little living coral in shallow areas due to clam harvesting. Philippine marines on Thitu Island informed me that they had been ordered to avoid arrests and confiscations of boats following the Scarborough Reef incident in 2012. Thus, it seems that the only shallow reefs which are safe from the giant clam operations are those occupied by Vietnam, Malaysia, and Taiwan, none of which show such damage on available imagery, and possibly the reefs at Thitu and Second Thomas Shoal (Ayungan) where the Philippines has particularly strong presences. There is already abundant evidence of such damage adjacent to the Philippine base at Commodore (Rizal) Reef, which the fishers attributed to PRC giant clam operations – adding that the base there was powerless to stop any illegal activities by anyone.

Please disregard my previous draft, which was based on information which has become obsolete. As you will see in the updated text, the situation is much worse than the previous draft indicated, in terms of severity of damage, area of damage, and the prospects for yet unquantified damage which may exist now or occur in the very near future. I continue to search for funds which I hope to use to conduct more thorough analyses of environmentally destructive activities within the South China Sea.

Sincerely,



John W. McManus, PhD
Professor

Reference:

V.R. Lee, 'Satellite Imagery Shows Ecocide in the South China Sea: Poaching of giant clam shells is causing massive scarring of coral reefs' (2016) *The Diplomat*. Available at: <http://thediplomat.com/2016/01/satellite-images-show-ecocide-in-the-south-china-sea/>; accessed 9 February 2016.

Offshore Coral Reef Damage, Overfishing and Paths to Peace in the South China Sea

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Offshore Coral Reef Damage, Overfishing, and Paths to Peace in the South China Sea

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Abstract

Offshore coral reefs of the South China Sea are subject to complex overlapping sovereignty claims by up to six regional nations. Escalating tensions have led to widespread structural reinforcement of military outposts on many reefs via dredging and filling. Satellite images indicated at least 160 km² of coral reef damage, including 17 km² in essentially permanent damage from filling and channel/harbor dredging, and 143 km² of decadal-scale damage from dredging for building materials and giant clam harvesting. This damage will exacerbate the growing regional overfishing problem. Options to lessen tensions include (1) the establishment of a Greater Spratly Islands Peace Park, and (2) the collaborative management of fisheries, the environment and mineral resources across the entire Sea. Both options require freezes on extant claims and activities in support of claims. No matter how it is achieved, regional peace would greatly enhance fisheries stability and economic growth among all claimant nations.

Keywords

coral reef atolls; Spratly Islands; Paracel Islands; Scarborough Reef; tying hands signaling

* This paper is based in part on a presentation prepared for the conference 'The South China Sea: An International Law Perspective', held on 6 March, 2015, in Brussels, Belgium. The author is grateful for helpful advice on the social, political, economic and ecological situation in the South China Sea from Dr. Liana Talaue McManus.

Introduction

Offshore coral reefs in the South China Sea (SCS), here defined as beyond 50 km from major land masses, include Pratas and Scarborough atolls, and numerous reefs within the Spratly and Paracel island groups (Figure 1). Each of these reef systems is subject to overlapping sovereignty claims by two or more of the regional coastal nations, including the People's Republic of China (PRC), Republic of China (Taiwan), the Philippines, Brunei, Malaysia and Vietnam. Other offshore coral reefs include many that do not rise to within 5-10 m of the surface, including many poorly known reefs scattered across the numerous banks and continental shelf areas.¹

Rising tensions in the South China Sea have led to the reinforcement of substrates supporting military outposts on many of the offshore coral reefs which have features near, at, or above tidal levels². The dredging and filling operations conducted in support of this have raised concerns over potential damage to important ecosystems and associated fisheries. These concerns have in turn escalated regional tensions³.

Much of the tension recently has been associated with activities by the PRC, including the construction and military buildup of seven sand islets⁴. One response has been a diplomatic unification of the Philippines and Vietnam against PRC⁵, joined to a limited degree by Malaysia⁶, and supported by Japan, the United States, and other extra-regional nations⁷. In July, 2015, hearings began at the Permanent Court of Arbitration on a case filed by the Philippines to invalidate the claims by the PRC to areas of the Spratly Islands and Scarborough Reef claimed by the Philippines⁸. The PRC refused to participate in those hearings, which concluded on 30 November 2015 with a final decision anticipated during 2016. This indicates that no resolution is currently possible in the form of a division of sovereignty. Thus, there is a need to consider other options which do not involve such a division. For any of these options, compliance – and preferably initiation – by PRC is crucial. This paper will consider a broad range of factors associated with the regional tensions, leading to suggestions for steps toward their easement.

¹ J.W. McManus, 'Coral reefs of the ASEAN Region: status and management' (1988) 17(3) *Ambio* 189-193.

² Island Tracker, Asia Maritime Transparency Initiative. Available at <http://amti.csis.org/island-tracker/>; accessed 11 August 2015.

³ Anon., 'PH tells UN: South China Sea disputes of global concern' (2015) *InterAksion*. Available at <http://www.interaksyon.com/article/112369/ph-tells-un-south-china-sea-disputes-of-global-concern>; accessed 11 August 2015.

⁴ D. Watkins, 'What China Has Been Building in the South China Sea' (2015) *The New York Times*. Available at http://www.nytimes.com/interactive/2015/07/30/world/asia/what-china-has-been-building-in-the-south-china-sea.html?_r=0; accessed 11 August 2015.

⁵ C. Thayer, 'The Philippines and Vietnam Forge a Strategic Partnership' (2015) *The Diplomat*. Available at <http://thediplomat.com/2015/03/the-philippines-and-vietnam-forge-a-strategic-partnership/>; accessed 11 August 2015.

⁶ J. NG and T. Moss, 'Malaysia Toughens Stance with Beijing Over South China Sea' (2015) *The Wall Street Journal*. Available at <file:///C:/Users/John/Documents/Websites/Malaysia%20Toughens%20Stance%20With%20Beijing%20Over%20South%20China%20Sea%20-%20WSJ.html>; accessed 11 August 2015.

⁷ O. Holmes, 'We have short memories': Japan unites with former foes to resist China's empire of sand' (2015) *The Guardian*. Available at <http://www.theguardian.com/world/2015/jun/26/we-have-short-memories-japan-unites-with-former-foes-to-resist-chinas-empire-of-sand>; accessed 11 August 2015.

⁸ G. Poling, 'The Philippines-China Arbitration: What Next?' (2015) *The Diplomat*. Available at <http://thediplomat.com/2015/08/the-philippines-china-arbitration-what-next/>; accessed 11 August 2015.

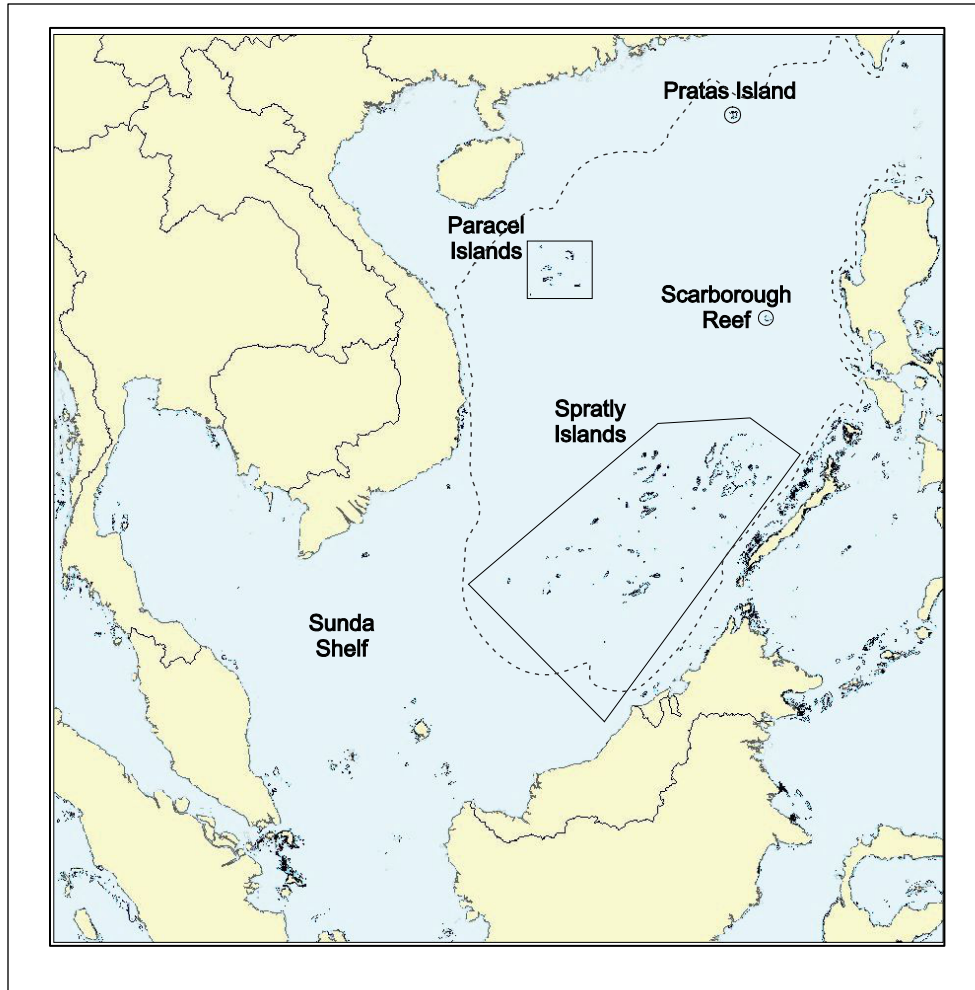


Figure 1. Map of offshore near-surface coral reefs in the South China Sea. Not shown are numerous coral reefs which are several meters below the surface such as those on the Macclesfield Bank and Truro Shoal between the Paracels and Scarborough, the Reed Bank north of the Spratly area, and numerous reefs scattered across the Sunda Shelf. Dashed line indicates shelf areas. (Map modified from one generated by ReefBase.org, by the WorldFish Center, UNEP, WCMC and the Institute for Marine Remote Sensing).

Some General Economic Factors

Shipping

The area between the Spratly Islands and PRC serves as a vital shipping route. Approximately USD 5.3 trillion worth of international trade passes through each year, including up to half of the world's oil shipments⁹. This includes approximately 80% of the shipping trade with PRC¹⁰ and a large part of the shipping trade connecting Europe, Africa and Asia with Japan, Hawaii and the Americas. Serious armed conflict in this area could temporarily close down or delay this shipping, potentially creating losses on the order of USD 14.5 billion dollars per day¹¹, while ships are redirected around the large island of Borneo or elsewhere. This could have a substantial impact on the world economy, and particularly on that of PRC.

Trade and investment relationships

A clear national priority of each claimant country is economic growth. This is particularly important to policy in the PRC, which is taking steps to establish itself as a leading economic power. One major national goal is the establishment of a 'Maritime Silk Road' involving enhanced trade among nations, including those along a route linking its heavy investments in Africa to mainland China¹². Despite some successes with the establishment of a new international bank and other related actions¹³, the tensions in the South China Sea continue to work against these economic goals. As this is being written, China is experiencing a major fall in the stock market¹⁴. The expensive building of islands in the Spratly area and associated military buildup to defend its claims represents a considerable direct economic loss, and the tensions it has inflated add further to instability in the economy and growth of China.

Fisheries

The waters of the South China Sea are heavily overfished. Figure 2 shows a simple Gordon-Schaefer bioeconomic model which illustrates some basic principles. As fishing effort (e.g. number of boats, total tonnage of fishing craft, etc.) in a new fishery increases over time, the yield and gross income from the fishery initially climbs and then falls as parent fish become too scarce to replace previous losses. In an unrealistically ideal ecosystem with a constant environment and level of natural predation, the theoretical maximum for yield vs. fishing effort is the top of the curve, known as the 'maximum sustainable yield (MSY)'. In the real world,

⁹ T.M. Cronk, 'Pacom Chief: China's Land Reclamation Has Broad Consequences' (2015) *U.S. Department of Defense News*. Available at <http://www.defense.gov/news/newsarticle.aspx?id=129348>; accessed 11 August 2015.

¹⁰ W. Englund, 'How the South China Sea could help Beijing level the nuclear playing field' (2015) *The Washington Post*. Available at <https://www.washingtonpost.com/news/worldviews/wp/2015/05/14/how-the-south-china-sea-could-be-beijings-path-to-greater-dominance-in-the-pacific/>; accessed 11 August 2015.

¹¹ Calculated as 5.3 trillion divided by 365 days

¹² W. Yale, 'China's maritime silk road' (2015) *The Diplomat*. Available at <http://thediplomat.com/2015/04/chinas-maritime-silk-road-gamble/>; accessed 12 August 2015.

¹³ Y. Sun, 'How the International Community Changed China's Asian Infrastructure Investment Bank' (2015) *The Diplomat*. Available at <http://thediplomat.com/2015/07/how-the-international-community-changed-chinas-asian-infrastructure-investment-bank/>; accessed 12 August 2015.

¹⁴ P. Sweeney and L. Jianxin, 'China lets yuan fall further, fuels fears of 'currency war'' (2015) *Reuters*. Available at <http://www.reuters.com/article/2015/08/12/us-china-markets-yuan-idUSKCN0QG04U20150812>; accessed 12 August 2015.

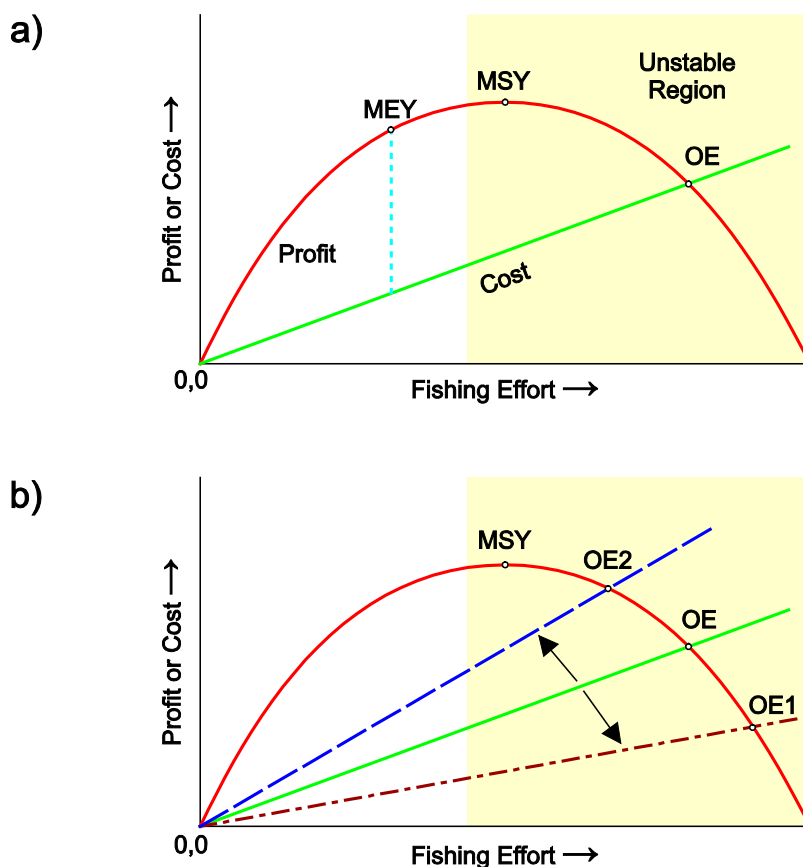


Figure 2. Gordon-Schaefer bioeconomic model. As fishing effort increases along the x-axis, the total cost of the effort increases roughly linearly (straight line). Profits initially increase and then decrease as fish stocks become too sparse to maintain healthy populations (curved line). Shaded areas indicate increasingly unstable stocks as effort increases. MSY at the top of the curve is the traditional ‘maximum sustainable yield’ point which, due to unpredictability in various factors, is unstable. OE is the ‘open-access equilibrium’, the point at which the average fisher makes no net income. In the absence of controls and alternative incomes, people tend to enter a fishery (adding effort) up to this point. In (a), MEY represents the greatest net profit to society (dotted line), which is a target point for fishery management. In (b), the cost of fishing can be lowered by means such as blast-fishing or subsidies, making the equilibrium drop (OE1), decreasing societal profit and further destabilizing stocks. Increasing the costs of fishing, such as via taxes or increasing opportunity costs, raises the equilibrium (OE2), improving overall production and helping to stabilize stocks.

variability makes the region in the vicinity of MSY unstable for fish stocks. The further to the right of MSY the level of fishing becomes (increasing fishing effort), the more likely a fishing collapse will occur – a wild fluctuation leading to extremely low abundances or local extinction. This is true both for single species fisheries and those with many species¹⁵.

We illustrate the total cost of fishing by the fishing society as a line which increases as fishing effort increases. The difference vertically from this ‘loss’ line to the gross income curve represents net income. The cost line includes both the direct costs associated with gear, fuel, boat-maintenance, salaries, etc., as well as taxes, payments to investors, and any opportunity costs of spending time fishing as opposed to earning salaries from other jobs. For example, a fisher who is giving up working at a job paying ten dollars per hour has an additional cost to go fishing of ten dollars per hour. In an ‘open access’ fishery, people increasingly enter the fishery, provided they can meet the necessary start-up costs, until the average person or boat is making no net profit. This point, the ‘scramble point’, ‘bionomic equilibrium’ or ‘open-access equilibrium’ is the only equilibrium point in most unregulated fisheries. It is achieved at the cost of driving fish stocks to where they are greatly reduced in the wild and often very likely to collapse unexpectedly¹⁶. Thus, fisheries must always be regulated in order to be sustainable.

In unregulated fisheries with low entry costs (e.g. small boats) in areas of coastal crowding and widespread poverty (near zero opportunity costs), the overfishing tends to rapidly progress from population level overfishing (beyond optimal) to ecosystem overfishing (causing unfavorable ecological shifts among local species), to Malthusian overfishing. In the latter condition, a state of desperation and heavy competition with compatriots and outsiders leads to increasing use of fishing gear types that are dangerous, such as air-hose based ‘hookah’ diving, and destructive to the fishery, such as poisoning and blast-fishing¹⁷. Often, the MSY point is used as a ‘limit reference point’, a point at which one should take strong action to reduce fishing pressure. An appropriate ‘target reference point’ is the ‘Maximum Economic Yield (MEY)’ point¹⁸. At this point, society is getting the optimal net profit from a fishery, and the effort is low enough to keep the fish stocks healthy.

Once a fishery is at the open access equilibrium point, the goal should be to reduce fishing effort until the MEY level is achieved. In the unrealistically ideal case, that would entail a reduction of the fishing effort by 50%. In the real world, because of natural variability and unsymmetrical yield (profit) curves, the reduction goal should be set at 60%¹⁹. However, there are very few cases in which such reductions have been possible.

The state of Malthusian overfishing is often easy to recognize. People living at near-zero net income tend to have extremely poor housing, few possessions, and often relatives in menial jobs in distant cities sending funds home. Fish in village markets tend to be small – often with a

¹⁵ J.W. McManus, C. Nañola, R. Reyes, and K. Kesner, *Resource Ecology of the Bolinao Coral Reef System* (ICLARM Studies and Reviews 22, 1992) 50-56. Available (free with registration) at http://www.reefbase.org/resource_center/publication/pub_19712.aspx; accessed 12 August 2015.

¹⁶ *Ibid*

¹⁷ *Ibid*; D. Pauly, 'On Malthusian overfishing' (1990) 13(1) *Naga, ICLARM Quarterly* 3–4. Available at http://aquaticcommons.org/9417/1/na_2839.pdf; accessed 12 August 2015.

¹⁸ J.F. Caddy and R. Mahon, *Reference points for fisheries management* (FAO Fisheries Technical Paper. No. 347. Rome, FAO, 1995) Chapter 2. Available at www.fao.org/docrep/003/v8400e/v8400e00.HTM; accessed 12 August 2015.

¹⁹ McManus *et al.*, *op. cit.* ref. 15.

median fish length of 8-25 cm or so²⁰. This describes the condition along most of the coastline of the South China Sea. Exceptions include the small coastlines of Taiwan and Brunei, where truly poor fishing populations are limited. Thus, it is reasonable to infer that, in general, the coastlines of the South China Sea are fished at more than twice the level at which they should be. This helps to explain why fishers in areas such as the Philippines and Vietnam will often risk going to distant offshore reefs in unsafe craft, often loaded with blasting fishing devices so as to make the risk as worthy as possible.

The Gordon-Schaefer model roughly describes the dynamics of more modern fishing fleets as well. For larger vessels, a means to push the open access equilibrium to the left is to impose taxes, often justified as covering the cost of enforcing fishing regulations. This raises the cost of fishing, and moves the equilibrium appropriately. However, for small-scale fishing, taxation is often impractical. For these situations, the emphasis is often on the development of alternative livelihoods, thereby raising the opportunity cost of fishing. In such fisheries, the use of destructive fishing methods is a way to lower the cost. This moves the equilibrium point to the right, where fish stocks become even more unstable – particularly with the added instabilities associated with damaged fish habitat. In the general case, the cost is lowered via the introduction of more efficient fishing gear, fish-tracking sonar, etc., or via government subsidies such as low-cost loans or subsidized fuel. All of these push the equilibrium to the right, further reducing wild fish stocks to dangerously low levels. Fishing regulation is generally crucial to maintaining sustainability, whereas fishing subsidies generally reduce sustainability.

A 2002 study of the major commercial fisheries of the South China Sea, focused primarily on offshore fishing, indicated that fish stocks at trophic levels three and above, such as tuna, mackerel, jacks, and sharks, underwent a reduction of more than 50% from 1960 to 2000. The exception was Brunei, where fishing is prohibited around the numerous oil rigs and interconnecting pipes which act as no-fishing reserves. This demonstrates the effectiveness of large marine protected areas in this region²¹.

PRC has attempted to unilaterally impose regulations on South China Sea fisheries, including seasonal closures²² and a mandate for non-PRC fishers to request permission to fish in the Sea²³, presumably aimed at reducing fishing effort. While these regulations are entirely valid means to improve fishery sustainability, their unilaterally imposed nature has caused them to backfire. Both Vietnam and the Philippines have responded by encouraging their fishers to increase their fishing effort in protest, and as a means to reinforce claims of national

²⁰ J.W. McManus, L.A.B. Meñez, K.N. Kesner-Reyes, S.G. Vergara, and M.C. Ablan, 'Coral reef fishing and coral-algal phase shifts: implications for global reef status' (2000) 57(3) *ICES Journal of Marine Science* 572–578.

²¹ V. Christensen, L. R. Garces, G.T. Silvestre and D. Pauly, 'Fisheries Impact on the South China Sea Large Marine Ecosystem: A Preliminary Analysis using Spatially-Explicit Methodology' in G. Silvestre, L. Garces, I. Stobutzki, M. Ahmed, R.A. Valmonte-Santos, C. Luna, L. Lachica-Aliño, P. Munro, V. Christensen and D. Pauly (eds), *Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries* (WorldFish Center Conference Proceedings (67) 51-62. Available at <http://www1.worldfishcenter.org/trawl2/publications/assessment/pdf/Chapter-03-FA.pdf>; accessed 13 August 2015.

²² C. Xieyuan (ed), 'South China Sea Fishing Ban Lifted' (2015) *CRIEnglish.com News*. Available at <http://english.cri.cn/12394/2015/08/01/4161s889863.htm>; accessed 13 August 2015.

²³ G. Cabacungan, R.D. Anda, T. Quismundo, 'Kalayaan mayor urges PH fishers to defy China' (2014) *Inquirer.net*. Available at <http://globalnation.inquirer.net/96275/kalayaan-mayor-urges-ph-fishers-to-defy-china>; accessed 14 August 2015.

sovereignty²⁴. For its part, China has outfitted approximately 50,000 of its marine fishing fleet with location and communications devices to keep them in touch with their military when needed, and is subsidizing fuel for long distance travel²⁵. Vietnam is also subsidizing its fishers by funding the construction of improved vessels²⁶. This combination of fisheries effort enhancement and subsidy are driving the regional fisheries into a much worse state than the poor state that market forces alone would have induced. Additionally, the occasional arrests of fishers from PRC by the Philippines for harvesting protected species such as sea turtles²⁷, and the harassment of fishers from the Philippines²⁸ and Vietnam²⁹ by PRC, continue to keep regional tensions high.

There have been various proposals to convert portions of the Spratly Island area into protected areas³⁰. Others have proposed that the whole of the Spratly Islands be converted to a single international protected area or peace park³¹. During a seven-year intensive study of the coral reef fisheries of Bolinao, Philippines, on the South China Sea, it was noted that heavy Malthusian overfishing tended to drive many species to local rarity or extinction³². Every few years, however, the stocks would be temporarily rejuvenated. Because the coastline in both directions for hundreds of miles was likely to be overfished to the same extreme levels, as predicted by the open access equilibrium, attention turned to offshore reefs as a potential source of fish larvae. A compilation of known larval drift times for coral reef fish indicated that the average fish was likely to drift with ocean currents for about a month prior to settling out on a reef. A set of six vector current charts created from records of ship drift were obtained, each representing current patterns typical of a given alternate month. In an early form of particle tracking inter-reef connectivity, hypothetical larvae were initiated within the Spratly Island area, and their likely motions were tracked from vector to vector – accounting for direction, speed and the passage of time. Because of the reversing monsoons and other weather factors, the currents of the South China Sea vary radically over the year, sometimes reversing directions. Thus, the tracking in each alternate monthly case provided different results. At times, the fish could resupply much of the western Philippines, Taiwan and southeastern PRC. At others, they could supply parts of Brunei and Malaysia. They could also resupply the Paracel Island area and

²⁴ *Ibid*; A. Dien, 'Vietnam lambastes China for fishermen harassment, island building' (2015) *Thanh Nien News*. Available at <http://www.thanhniennews.com/politics/vietnam-lambastes-china-for-fishermen-harassment-island-building-47155.html>; accessed 14 August 2015.

²⁵ H.J. Kazianis, 'China's 50,000 Secret Weapons in the South China Sea' (2015) *The National Interest*. Available at <http://nationalinterest.org/feature/china%E2%80%99s-50000-secret-weapons-the-south-china-sea-10973>; accessed 14 August 2015.

²⁶ A. Dien, *op. cit.* ref. 24.

²⁷ Anon., 'Philippines orders nine Chinese fishermen freed after poaching conviction in disputed Spratlys' 9 June 2015 *South China Morning Post*. Available at <http://www.scmp.com/news/asia/diplomacy/article/1819283/philippines-orders-nine-chinese-fishermen-freed-after-poaching>; accessed 14 August 2015.

²⁸ S. Lannin, 'South China Sea: Escalating tensions threatening livelihoods of local fishermen' 3 June 2015 *ABC News Online* (Australia). Available at <http://www.abc.net.au/news/2015-06-02/fishermen-say-south-china-sea-dispute-threatening-their-livelihood/6516138>; accessed 14 August 2015.

²⁹ A. Dien *op. cit.* ref. 24.

³⁰ A. White, 'Priority areas for marine resource management' in J.P. Morgan and M.J. Valencia (eds), *Atlas for Marine Policy in Southeast Asian Seas* (University of California Press, Berkeley, 1983); M.J. Valencia, J.M. Van Dyke, and N.A. Ludwig, *Sharing the Resources of the South China Sea* (University of Hawaii Press, 1999) 187-190.

³¹ J.W. McManus, 'The Spratly Islands: a marine park alternative' (1992) 15(3) *Naga, ICLARM Quarterly* 4-8; J.W. McManus, 'The Spratly Islands: A Marine Park?' (1994) 23(3) *Ambio* 181-186.

³² McManus *et al.*, *op. cit.* ref. 15.

Scarborough Reef, from where a second generation of fish could reach much of Vietnam and the rest of southern PRC. It was shown that this dense group of offshore reefs could explain why targeted fish species along all of these coastlines do not go extinct amidst the heavy levels of overfishing. This result led to the suggestion in 1992 and 1994 for a Spratly Island International Marine Park³³. This concept was expanded on in 1995³⁴, 1997³⁵ and again in 2010³⁶, the latter paper using the term Peace Park. The results of the simple initial connectivity study were largely confirmed in terms of the prevention of local extinction by a team in 2011 employing state-of-the-art computer models³⁷. Region-wide genetic studies of three reef fish species (the false Moorish idol *Heniochus acuminatus*, the six bar wrasse *Thallasoma hardwickii*, and the threespot dascyllus *Dascyllus trimaculatus*) confirmed that South China Sea connectivity was very high, but indicated that there seem to be some population differences among north-central, western, and southern subareas. The results suggested that the divisions may be anchored within portions of the Spratly area subject to differing current patterns³⁸.

At the Philippines-Vietnam Joint Permanent Working Group on Maritime and Ocean Concerns (JPWG-MOC), held in Vietnam in 2007³⁹, representatives from the Philippines proposed that the Spratly Islands area be converted to a transboundary peace park. This suggestion was reiterated the following year by participants in the Conference on the Results of the Philippines-Vietnam JOMSRE-SCS (JOMSRE I to IV), also in Vietnam⁴⁰. Philippine Ambassador Alberto Encomienda also called for a similar action in 2008 as an implementation of Part IX of the United Nations Convention on the Law of the Sea. This was strongly supported by former Philippine Secretary of the Environment Angel Alcala in 2011⁴¹. The call for a Spratly Island Peace Park has been supported among the discussions and conclusions in several other

³³ McManus 1992 and 1994, *op. cit.* ref. 31.

³⁴ J.W. McManus, 'Large and Small-Scale Marine Protected Areas — Planning, Investment and Intergenerational Quality of Life' in A.J. Hooten and M.E. Hatzios (eds), *Sustainable Financing Mechanisms for Coral Reef Conservation: Proceedings of a Workshop. Environmentally Sustainable Development Proceedings Series No. 9* (World Bank, Washington D.C., 1995) 60-71.

³⁵ J.W. McManus and L.A.B. Meñez, 'The proposed Spratly Island international marine park: biological considerations'. Proceedings of the 8th International Coral Reef Symposium, Volume 2 (1997) 1943-1948.

³⁶ J.W. McManus, K.T. Shao, S.Y. Lin, 'Toward establishing a Spratly Islands International Marine Peace Park: ecological importance and supportive collaborative activities with an emphasis on the role of Taiwan' (2010) 41 *Ocean Development and International Law* 270-280. The term 'Peace Park' was used in this context the previous year by the authors in a presentation at the International Conference on Issues in the South China Sea, 19-20 August 2009 in Taipei, Taiwan, on which the paper was based.

³⁷ J.T. Kool, C.B. Paris, P.H. Barber, and R.K. Cowen, 'Connectivity and the development of population genetic structure in Indo-West Pacific coral reef communities' (2011) 20 *Global Ecology and Biogeography* 695-706.

³⁸ M.C.A. Ablan, J.W. McManus, C.A. Chen, K.T. Shao, J.D. Bell, A.S. Cabanban, V.S. Tuan and I.W. Arthana, 'Meso-scale transboundary units for the management of coral reefs in the South China Sea Area' (2002) 25(3-4) *NAGA, The WorldFish Center Quarterly* 4-9; C.A. Chen, M.C.A. Ablan, J.W. McManus, J.D. Bell, V.S. Tuan, A.S. Cabanban and K.T. Shao, (2004) 'Population structure and genetic variability of six bar wrasse (*Thallasoma hardwickii*) in northern South China Sea revealed by mitochondrial control region sequences' *Marine Biotechnology* 6 (4): 312-326.

³⁹ Y.H. Song, 'A marine biodiversity project in the South China Sea: joint efforts made in the SCS Workshop Process' (2011) 26 *The International Journal of Marine and Coastal Law* 119-149.

⁴⁰ *Ibid.*

⁴¹ A.C. Alcala, 'A transboundary Peace Park in the Spratlys' (2011) *Dumaguete Metro Post*. Available at <http://dumaguete-metropost.com/a-transboundary-peace-park-in-the-spratlys-p1743-98.htm>; accessed 18 August 2015.

scientific papers, including at least one with a PRC co-author⁴² and one from a team of PRC scientists⁴³.

Biodiversity

The South China Sea is a region of very high marine species diversity. Despite a recent emphasis on surveys by the Philippines, Vietnam, PRC and Taiwan, no up-to-date compilation of known species yet exists. Some preliminary species numbers are found in a 2010 compilation of multiple biodiversity surveys⁴⁴. In general, the Philippines and adjacent areas have species numbers which are roughly five to ten times those in a given biotic group to those found in the Caribbean or Hawaii. For example, the Caribbean has approximately 61 species of reef-building corals, while the Philippines and neighbors to the south have more than 600 such coral species. While Hawaii has approximately 420 species of reef fish, the Philippines and southern neighbors have more than 2,200 species (37% of the world's reef fish species)⁴⁵. A recent study has indicated that coral reefs globally may have roughly 830,000 multicellular species, of which 620,000 (about 75%) have yet to be identified⁴⁶. The biogeographic gradient in invertebrate species tends to be higher than that of fish. However, via conservative first order estimation, 37% of the 830,000 reef species globally would lead us to expect that the southern reefs of the South China Sea to hold more than 307,000 multicellular coral reef species. Given the sparse nature of studies in the area, coupled with the isolation of some portions, it would be reasonable to expect that the majority of these have yet to be identified, and a large number of them will be new to science. This indicates that the potential for new medical 'drugs from the sea' from these offshore reefs is particularly high.

Parts of the South China Sea are encompassed within the boundaries of the 'Coral Triangle', a region of anomalously high marine species diversity extending from the Solomon Islands to eastern Java, Indonesia and northwards to encompass the Philippines. This area is the focus of a major biodiversity conservation effort, the Coral Triangle Initiative. The latter is a partnership among the Philippines, Malaysia, Indonesia, Timor-Leste, Papua New Guinea, and the Solomon Islands, aimed at protecting and managing coral reefs and tuna, and concurrently at helping to alleviate coastal poverty. It has been endorsed and funded by Australia, the United States, the Asia Development Bank, the Global Environment Facility, the Nature Conservancy, the World Wildlife Fund, and others⁴⁷. The actual center of highest marine species diversity is located in the Central Philippines, nearly adjacent to the South China Sea⁴⁸. Based on connectivity studies⁴⁹, as well as of migration routes of wide-ranging fish including tuna⁵⁰, the

⁴² T.P. Hughes, H. Huang, M.A.L. Young, 'The wicked problem of China's disappearing coral reefs' (2013) 27 *Conservation Biology* 261–269.

⁴³ M.X. Zhao, K.F. Yu, Q. Shi, T.R. Chen, H.L. Zhang, and T.G. Chen, 'Coral communities of the remote atoll reefs in the Nansha Islands, southern South China Sea' (2013) 185(9) *Environmental monitoring and assessment* 7381-7392.

⁴⁴ See McManus *et al.*, *op. cit.* ref. 36.

⁴⁵ The Coral Triangle Atlas online at <http://ctatlas.reefbase.org/coraltriangle.aspx>; accessed 14 August 2015.

⁴⁶ R. Fisher, R.A. O'Leary, S. Low-Choy, K. Mengersen, N. Knowlton, R.E. Brainard, and M.J. Caley, 'Species richness on coral reefs and the pursuit of convergent global estimates' 25 *Current Biology* 500–505.

⁴⁷ The Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF). Available at <http://www.coraltriangleinitiative.org/>; accessed 16 August 2015.

⁴⁸ K.E. Carpenter and V.G. Springer, 'The center of the center of shore fish biodiversity : The Philippine Islands' (2005) 72 *Environmental Biology of Fishes* 467-480.

⁴⁹ McManus (1992) *op. cit.*, ref. 31; Kool *et al.*, *op. cit.* ref. 37.

Spratly Island area may improve the sustainability of fisheries in the Philippines and those as far south as Indonesia. Clearly, environmental damage to the Spratly Islands is inconsistent with this major international cooperative effort. Additionally, this damage works specifically against regional environmental protection agreements such as Agenda 21 and the Biodiversity Convention, and regional efforts associated with international organizations including the Association of South East Asian Nations, the Southeast Asian Fisheries Development Center, the Coordinating Body for the Seas of Southeast Asia, the World Fish Center, the World Bank, the United Nations Environment Programme, the United Nations Development Programme, the United Nations Food and Agriculture Organization, and other United Nations organizations with coastal activities in the area.

Tourist Potential

There are at least a hundred surface and subsurface coral reefs in the Greater Spratly Islands, and another twenty or so amid the Paracel Islands that would offer world class tourist diving if a peaceful climate were to prevail. In past decades, there had been visits to the Spratly Islands by muro-ami ships⁵¹, in which hundreds of fishers would damage coral while driving fish into nets with weighted ropes⁵². However, this practice has nearly died out. Fishers using blasting devices⁵³ and poisons still show up in arrests by various claimant countries. However, these methods are rarely used in waters below ten meters of depth, lest many of the fish sink or drift away because of the increasingly difficult task of collecting them in deepening waters. A single blast of a typical 'bottle bomb' typically kills coral within a 0.5-1.5 m radius⁵⁴, leaving coral in that spot to recover over roughly a 5-10 year period. The near absence of organic pollutants of these far off-shore reefs (except near potentially polluting military outposts) will lead to relatively rapid recovery rates compared to those alongside major land masses, because populated coastlines tend to release excessive nutrients which make seaweed more likely to outcompete coral following a disturbance⁵⁵. Levels of damage by destructive fishing devices tend to be less in situations where fish are very abundant, because boats become quickly loaded with fish. This means that one need not damage as much habitat to reach one's harvesting capacity. Given that surface and near surface coral reefs in the Spratly area cover roughly 1,150

⁵⁰ Valencia *et al. op. cit.* ref. 30 pg. 265.

⁵¹ C.R. Wilkinson and R.W. Buddemeier, 'Global Climate Change and Coral Reefs: Implications for People and Reefs' *Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on the Implications of Climate Change on Coral Reefs*, (IUCN, Gland, Switzerland, 1994) 77. Available at <https://cmsdata.iucn.org/downloads/climchnng.pdf>; accessed 18 August 2015.

⁵² J.W. McManus, 'Social and economic aspects of reef fisheries and their management' in N. Polunin and C. Roberts (eds.), *Coral Reef Fisheries*. (Chapman and Hall, London, 1996) 249-181.

⁵³ J. Akamine 'Who is to be blamed? Socio-cultural notes on blast fishing in the Spratly Islands' in Proceedings of the 10th International Coral Reef Symposium (Okinawa, International Society for Reef Studies, 2006) 1427-1433. Available at http://www.reefbase.org/resource_center/publication/icrs.aspx; accessed 18 August, 2015.

⁵⁴ J.W. McManus, C.L. Nañola, and R.B. Reyes, 'Effects of some destructive fishing methods on coral cover and potential rates of recovery' (1997) 21(1) *Environmental Management* 69-78; S.B. Saila, L.J. Kocic and J.W. McManus, 'Modelling the effects of destructive fishing practices on tropical coral reefs' (1993) 94 *Marine Ecology Progress Series* 51-60.

⁵⁵ J.W. McManus and J.F. Polsenberg, 'Coral-Algal Phase-Shifts on Coral Reefs: Ecological and Environmental Aspects' (2004) 60 *Progress in Oceanography* 263-279.

square kilometers⁵⁶, and the fact that fishing by all gears on those reefs is orders of magnitude sparser than along the coastlines of major regional landmasses, one can be confident that nearly pristine reefs are easily found. Exceptions will include the areas near to the more than 50 military outposts, in which the troops and associated people will fish quite heavily so as to minimize fuel costs. Additionally, the reefs from which sand has been dredged or stirred up during giant clam harvesting, or on which new islets or islet extensions rest, will be severely damaged. Because of their high value, certain easily captured, shallow water species will likely be largely absent across the region, such as certain species of giant clams⁵⁷. Sea turtles, sharks, large groupers and wrasses have been specifically targeted, especially for markets in PRC, and so their populations are likely much lower now than they were a few decades ago. For example, the nine fishermen from PRC recently released from custody by the Philippines were arrested at Half Moon Shoal with a harvest of 555 sea turtles⁵⁸.

Fortunately, recovery for local extinctions of such species is often possible. For instance, giant clams have been restored to many regional reefs⁵⁹. Sea turtle populations in the Hainan are being restored via rescue and release practices⁶⁰. Large predatory fish have been shown to recover quite well when fishing pressures on them are alleviated for long periods of time⁶¹.

An excellent example of such recovery has been within the very similar coral reef atolls of the Tubbataha Reefs World Heritage Site, directly south of the Spratly area near the center of the Sulu Sea. Two decades ago, they were in a state similar to many of the Spratly reefs most readily accessible shore – low on sharks and other high trophic level species. Now, after more than a decade of protection by rangers living in a structure on pilings on one of the reefs, these fish populations are unusually high⁶². Ecologists have come to understand that most truly pristine reefs in past centuries had more biomass in predatory fish than in their prey, such as herbivorous and planktivorous fish. This currently very rare situation was enabled by the fact that the prey fish tend to have much higher rates of turn-over than the predators. By 2015, it had become apparent that a near-pristine state was being approached at Tubbataha. Amidst the massive schools of jacks and other species of predators, there are currently relatively dense populations of sharks, including tiger sharks⁶³ which are particularly high in the trophic web.

If the existing military outposts of the Spratly and Paracel areas were to support trained park rangers, a substantial amount of natural reef restoration would be possible. Giant clams and other

⁵⁶ M. Spalding, C. Ravilious, and E.P. Green, *World Atlas of Coral Reefs* (University of California Press, Berkeley, CA, 2001).

⁵⁷ E.D. Gomez, 'Destroyed reefs, vanishing giant clams'. (2015) *Philippine Daily Inquirer*. Available at <http://opinion.inquirer.net/84595/destroyed-reefs-vanishing-giant-clams>; accessed 20 August, 2015.

⁵⁸ Associated Press in Manila op. cit. ref. 27.

⁵⁹ E.D. Gomez, S. Mingo-Licuanan, 'Achievements and lessons learned in restocking giant clams in the Philippines' (2006) 80(1) *Fisheries Research* 46-52.

⁶⁰ A. Ruggeri, 'The unlikely sea turtle saviour' (2015) *BBC Travel*. Available at <http://www.bbc.com/travel/story/20150521-in-china-saving-sea-turtles-from-soup>; accessed 27 August 2015.

⁶¹ G.R. Russ and A.C. Alcala, 'Marine reserves: long-term protection is required for full recovery of predatory fish populations' (2004) 138(4) *Oecologia* 622-627.

⁶² M. Dygico, C. Salao, A.B. Honasan, *Tubbataha Reefs: A marine protected area that works* (WWF-Philippines, Quezon City, Philippines, 2006).

⁶³ B. Gacard, 'Expedition Shark: Why we need to protect these predators: A team of scientists from the Philippines, Europe, and America conduct a 10-day expedition in the Tubbataha Reef' (2015) *Rappler*. Available at: <http://www.rappler.com/science-nature/environment/98766-expedition-shark-tubbataha-lamave-marine-conservation>; accessed 29 August, 2015.

absent shallow water species could be restored via transplantation. At present, the only tourist resort in the Spratly area is the Malaysian resort at Swallow Reef. Part of its economic success is undoubtedly due to its environmental protection and location in the relatively peaceful southwest, away from the threat of intervention by other claimant nations. The PRC base of Sansha (Woody Island) in the Paracels and the Taiwanese-occupied islands of Taiping (Itu Aba Island) in the northern Spratlys and the Dongsha Islands are being prepared for increasing tourism – with much planning concentrated on protecting the environment⁶⁴. Taiping is notable for its solar power conversion initiative⁶⁵, setting the stage for similar ecologically friendly developments among other Spratly Island bases. However, one can achieve much less impact by limiting visitors to live-aboard vessels, as is being done at Tubbataha. Some of the costs of securing the reefs in that case come from entry fees⁶⁶. However, the total economic impact includes the income received at airports from tourists flying in, at the hotels where they stay, at the taxis, shops and restaurants they use, at the dive tour operators, and so forth. A peaceful South China Sea would greatly enhance tourist income across the region. Additionally, it would be a boost to the yacht building and maintenance industry. China ranks eighth among the world's superyacht builders. However, most of the yachts are purchased to be used in other parts of the world⁶⁷. Easing unrest in the region would lead to a rise of the yachting industry – another means to boost the regional economy.

Coral Reef Wave Protection and Sea Level Rise

The offshore shallow coral reef atolls of the South China Sea often have a characteristic zonation which includes a wave-breaking reef crest (Figure 3). In areas such as this wherein major typhoons are common, the protection afforded by the reefs from large waves is the major reason why construction of any kind is possible, including military outposts built on pilings. All of the islets in the area are protected by wave-breaking reef structures such as crests or long rows of shallow reef spurs, and none would be likely to exist without them.

Surface breaking coral reefs tend to reduce wave energy by 97%. Of this, 86% is attributed to the wave crest alone, and of what remains, 65% is dissipated along the reef flats behind the crest⁶⁸. The crest is generally about the height of the tides, while usually staying slightly underwater at normal high tides⁶⁹. In this region, the tides range generally to a meter in height or less, except during full and new moons whereat they may gain another half meter or so. Thus, the most significant part of the reef for many purposes is a small elongated 'bump' of a crest, about meter high. Upon these bumps rest not only the futures of any islets and manmade

⁶⁴ Han Bin, 'Sansha: youngest Chinese city fast developing' (2015) *CCTV com English*. Accessible at <http://english.cntv.cn/2015/07/23/VIDE1437637923545130.shtml>; accessed 29 August 2015.

⁶⁵ R. Jennings, 'Taiwan's eco-friendly islet in troubled South China Sea: someone big is watching' (2015) *Forbes*. Accessible at <http://www.forbes.com/sites/ralphjennings/2015/07/19/taiwans-eco-friendly-islet-in-troubled-south-china-sea-someone-big-is-watching/>; accessed 29 August 2015.

⁶⁶ R.F. Subade, 'Mechanisms to capture economic values of marine biodiversity: the case of Tubbataha Reefs UNESCO World Heritage Site, Philippines' (2007) 31 *Marine Policy* 135-142.

⁶⁷ T.L. Wilkinson, 'Why China's ultra-rich haven't warmed to superyachts' (2015) *Fortune*. Accessible at <http://fortune.com/2015/02/10/chinas-ultra-rich-superyachts/>; accessed 29 August 2015.

⁶⁸ F. Ferrario, M.W. Beck, C.D. Storlazzi, F. Micheli, C.C. Shepard and L. Airoidi, 'The effectiveness of coral reefs for coastal hazard risk reduction and adaptation' (2013) 5 (3794) *Nature Communications*. Available at <http://www.nature.com/ncomms/2014/140513/ncomms4794/abs/ncomms4794.html>; accessed 29 August 2015.

⁶⁹ H.J. Wiens, *Atoll environment and ecology* (Yale University Press, New Haven, Connecticut, 1962) 57-58.

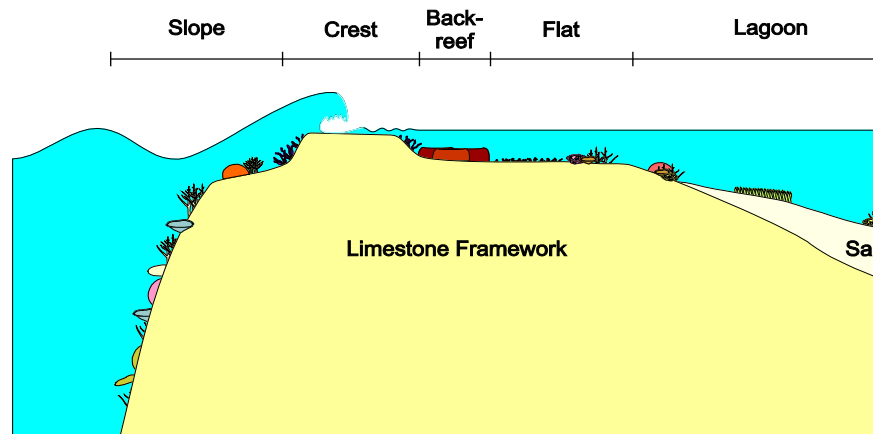


Figure 3. Zones of a typical atoll. Approaching from deep waters, one often encounters a reef slope with prominent coral colonies, a wave-breaking reef crest flanked and covered with various types of algae, a back-reef zone with truncated boulder-shaped corals ('microatolls'), and a reef flat and lagoon with patches of algae, coral, and seagrass amid a plethora of sand-dwelling species such as giant clams and sea cucumbers. All of these habitats support dense assemblages of fish in their natural states. The reef crest is generally the height of the normal tidal range, which is often less than a meter in the South China Sea.

structures in the South China Sea, but also the futures of many coastal populations throughout the tropical and subtropical world. Remarkably little is understood about how these structures grow and maintain themselves amid the constant forces of wave erosion and breakdown by organisms living within the crests. The shallow, wave impacted portions of a geomorphologically significant coral reef grow together as a unit – a highly efficient self-assembling machine which converts wave energy into relatively horizontal water currents, in the process directing these mechanical sources of energy and sunlight into the conversion of oceanic plankton into the most biodiverse ecosystems on Earth. Any significant interference with these processes, particularly involving changes in water flow, runs the risk of disabling the wave protection capacity of the reef. Even in the case that the effects are not visible within a decade or two, they will certainly become important as sea-level rise accelerates within the coming half century or so.

The development of an offshore atoll can take many millions of years. The calcium carbonate reef limestone has built up gradually over time, suffering through periods of exposure to air, rain and land vegetation during low stands of sea level, but generally keeping up (or catching up) with local sea level during periods of rapid rise and/or subsiding sea floors⁷⁰. The Spratly area is replete with examples of reef structures that failed to keep up – the subsurface reef systems. Many groups of shallow atolls in the area sit upon much larger subsurface atolls as small sections that kept up while the rest fell behind, reforming into small atolls. Although many subsurface reef sections are visible through the clear offshore waters on satellite imagery, such as that on Google Earth, these ‘losing’ reefs may be tens of meters deep at their shallowest. Other subsurface reefs are scattered along the large regional shelf areas, including the Sunda Shelf north of Borneo⁷¹. Still others probably exist which fell behind in deeper areas below sufficient light levels to grow with reasonable speed and became ‘give-up’ reefs⁷² or even dropped into areas with scarce or absent sunlight and became devoid of characteristic shallow coral reef life as ‘drowned reefs’⁷³.

The development of a typical atoll is illustrated in Figure 4. An oceanic mountain (or mountainous ridge) becomes surrounded by coral and associated organisms, many of whose calcareous parts coalesce as they die and become covered with new organisms, eventually forming a fringing reef. As the mountain ‘sinks’ due to subsidence and/or rising sea level, the reef tends to grow straight upwards. The outer portions of the reef are very efficient at using up plankton and oxygen flowing inwards, and so reef development lags behind generally a few hundred meters behind the wave-breaking reef crest. As this inner area deepens, a barrier reef is formed around the remaining mountain. Calcareous sand and gravel produced by reef organisms collect within the lagoon, with deeper layers slowly turning into hard reef substrate via complex processes. Once the mountain has disappeared, a ring-shaped coral reef atoll remains, with a

⁷⁰ J.W. McManus, 'Coral Reefs' in J.H. Steele, S.A. Thorpe and K.K. Turekian (eds), *Encyclopedia of Ocean Sciences* (Academic Press, London, 2001) 524-534.

⁷¹ J.W. McManus, 'Coral reefs of the ASEAN Region: status and management' (1988) 17(3) *Ambio* 189-193; J.W. McManus, 'Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia' (1997) 16 Suppl. *Coral Reefs* S121-S127 (especially Fig. 3).

⁷² A.C. Neumann and I. Macintyre, 'Reef response to sea level rise: keep-up, catch-up or give-up' in C. Gabrie, J.L. Toffart and B. Salvat (eds), *Proceedings of the 5th International Coral Reef Congress, Volume 3: Symposia and Seminars A*. (Antenne Museum-Ephe, Moorea, French Polynesia, 1985) 105–110. Available at http://www.reefbase.org/resource_center/publication/pub_24184.aspx; accessed 30 August 2015.

⁷³ P. Blanchon and D. Blakeway, 'Are catch-up reefs an artefact of coring?' (2003) 50 *Sedimentology* 1271–1282.

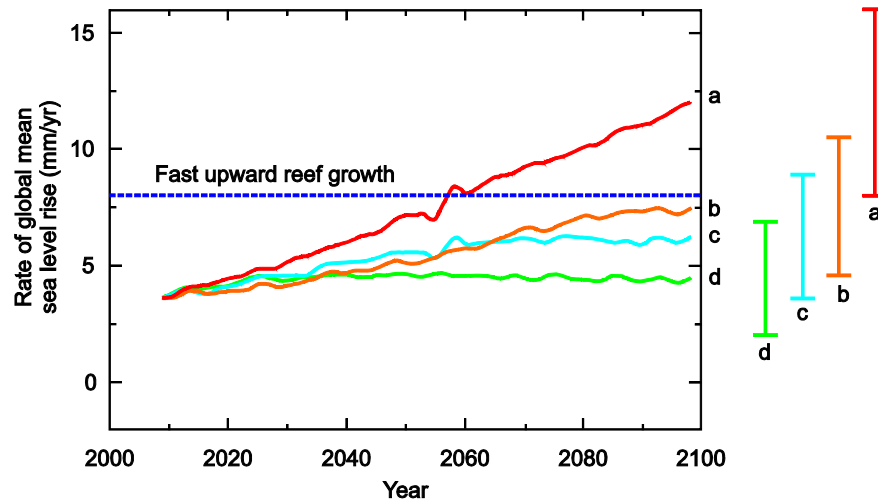


Figure 5. Graphs of projected rates of sea-level rise and vertical reef growth against time. The horizontal dashed line indicates an unusually fast-growing coral reef from fossil records (7.89 mm/y). The highest curve indicates anticipated rates of sea-level rise in the absence of global action to reduce emissions – the ‘business-as-usual’ scenario. Other curves indicate projections from various degrees of emission reduction. The uncertainty of each projection at 2100 is represented on the right. In the absence of global action, most reefs will fall below sea level in coming decades. However, under any of the scenarios of global action, particularly healthy reef crests may remain at the surface. Reefs with substantial functional disruption will generally fall behind.

lagoon over a sand floor supported by reef limestone⁷⁴. Figure 4 (j) shows how waves are transformed into currents, which flow across the reef zones and out through channels. Figure 4 (f-g) shows a hypothetical case wherein an artificial island interferes with these patterns of interacting waves, currents and ecological growth. This interference reduces the ratio of substrate growth to erosion, reducing the capacity of the wave-breaking portions of the reef to keep up with rising sea level. For example, the removal of hard corals from the wave-striking side of the reef crest may reduce its wave-buffering capacity⁷⁵. Additionally, sediment can inhibit the growth of crustose coralline algae and various components of the micro-ecosystem of the reef crest, which are crucial to its accretionary processes. Once the reef crest is no longer primarily intertidal, wave erosion increases, along with various ecological shifts which further result in a breakdown of the reef crest and other shallow reef zones⁷⁶. This breakdown is likely to continue at least until the reef is safely below the range of heavy impact of most storm waves, which can be 10 or more meters deep⁷⁷. Because reef growth rates decline at depth due to reduced light levels (required to fuel symbiotic algae in calcium carbonate producing corals, giant clams and foraminiferans), the reef may fall further behind rising sea levels.

We are in a period of rapidly accelerating sea-level rise. The Intergovernmental Panel on Climate Change (IPCC) in 2013 published anticipated rates of this acceleration under four potential scenarios⁷⁸. Figure 5 shows these accelerating rates in contrast to a relatively fast rate of coral reef growth of 6.7 mm/yr⁷⁹. Each curve is subject to considerable uncertainty, and those associated with the year 2100 are indicated at the right for each scenario. Under the worst case scenario, known as the 'business as usual' scenario, even the most undisturbed coral reefs are likely to fall behind sea level rise substantially prior to 2100. In this case, interference with reef processes by humans is likely only to accelerate the subsequent tear-down processes. However, under any of the scenarios in which effective action is taken to reduce global emissions, many healthy coral reefs may be able to keep up. This assumes that some processes of concern, such as increasing frequencies of coral bleaching (loss of symbiotic algae due to abnormally high water temperatures), intensification of cyclonic storms and the increasing acidity of the ocean do not substantially slow down reef growth – issues now under widespread investigation and debate.

⁷⁴ P. Blanchon, M. Granados-Corea, E. Abbey, J.C. Braga, C. Braithwaite, D.M. Kennedy, T. Spencer, J.M. Webster and C.D. Woodroffe, 'Postglacial Fringing-Reef to Barrier-Reef conversion on Tahiti links Darwin's reef types' (2014) 4(4997) *Scientific Reports*. Available at <http://www.nature.com/articles/srep04997>; accessed 30 August 2015.

⁷⁵ C. Sheppard, D.J. Dixon, M. Gourlay, A. Sheppard, and R. Payet, 'Coral mortality increases wave energy reaching shores protected by reef flats: examples from the Seychelles' (2005) 64 *Estuarine, Coastal and Shelf Science* 223–234.

⁷⁶ R.R. Graus and I.G. MacIntyre, 'Global warming and the future of Caribbean coral reefs' (1998) 13(1) *Carbonates & Evaporites* 43-47.

⁷⁷ This author observed in the late 1980's that concrete blocks used to mark study sites on the Bolinao fringing reef along northwestern Luzon, Philippines weighing approximately 260 kg each at depths up to 20 m sometimes moved horizontally a meter or more during strong typhoons.

⁷⁸ J.A. Church, P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 'Sea Level Change' in T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013) 1137-1216, at p. 1181.

⁷⁹ D. Hubbard, E. Gischler, P. Davies, L. Montaggioni, G. Camoin, W.-C. Dullo, C. Storlazzi, M. Field, C. Fletcher, E. Grossman, C. Sheppard, H. Lescinsky, D. Fenner, J.W. McManus and S. Scheffers, 'Island outlook: Warm and swampy' (2014) 345(6203) *Science* 1461.

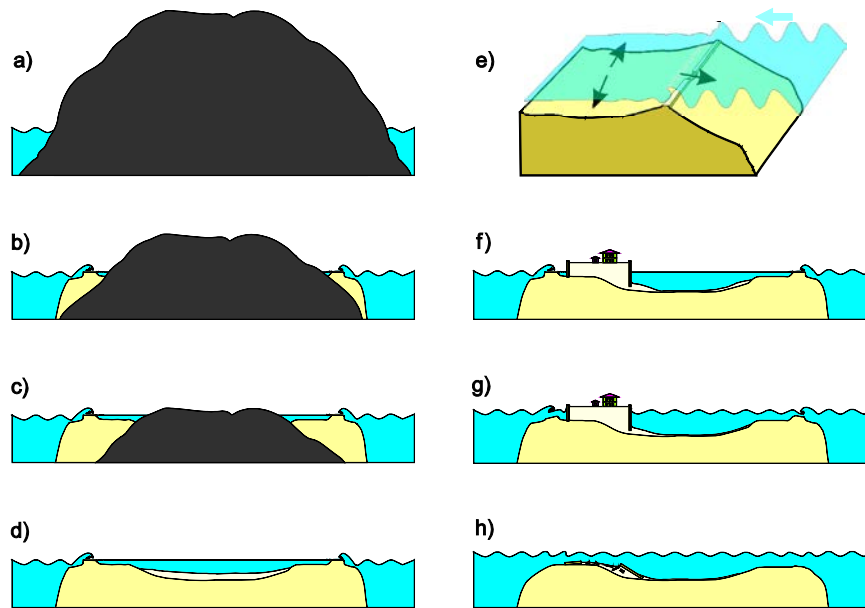


Figure 4. Cross-section diagrams of an atoll showing its origins as fringing reefs around a mountain (a, b). As the mountain sinks and/or sea level rises, the reef often grows vertically forming lagoons within a barrier reef (c), and finally an atoll with a sand-filled lagoon (d). The upper reef slope, crest, back-reef and flat areas together forms a highly efficient 'machine' which converts on average 97% of wave energy into horizontal currents, of which approximately 87% is due to the reef crest (e). Human-built structures are often well-protected by healthy reef crests (f). However, reef crests which are damaged enough to result in net erosion or are unable to keep up with sea-level rise or seafloor sinking are likely to break down (g), ultimately losing their ability to protect human structures from storm waves.

Ideally, well-protected reefs may permit continued human habitation in reef-protected areas around the world, at least in cases where not all land has been submerged. Clearly, however, any anthropogenic activities which substantially and chronically damage reef processes will almost certainly lead to a loss of reef protection from waves.

Damage Assessment of Offshore Reefs in the South China Sea

A great deal of concern has been raised concerning the building of artificial islands on coral reefs in the South China Sea. This concern is well-justified – the loss of regional reef area to burial within a few years of construction activities constitutes the most rapid nearly permanent loss of coral reef area in human history. The near-permanence here must be emphasized. Most coral reef degradation around the world has been characterized by a loss of hard coral covering the substrate due to coral death from unusually high seawater temperatures, disease, thin layers of sediment, or the replacement of corals by seaweed because of excessive nutrients and/or a reduction of herbivores by overfishing or disease⁸⁰. In those cases, there is usually a reasonable chance that some years after the disturbance has been alleviated, the coral will return to its former dominance⁸¹ -- especially for reefs in the Indo-Pacific Region (as opposed to the less resilient Caribbean reefs)⁸². However, once a portion of a coral reef has been buried under tons of sand and gravel, that portion will be devoid of coral reef species for as long as the sediment rests upon it. These are not temporary islands, but rather intended to remain in place for generations. As discussed above, the combined effects of reduction in wave-breaking capacity, negative impacts of climate change on coral reefs generally and accelerating sea level rise may make it impossible to maintain these islands against strengthening typhoons within a few decades. Even then, the vast quantities of piled-up sand and gravel are likely to continue to prevent growth for long periods even once the areas have sunk below sea level, and to spread out to damage other areas of the reefs. The damage from these artificial islands is thus essentially permanent, within the time range of many decades.

Island-building has been by no means the only form of destruction carried out within the offshore reefs of the South China Sea. The most widespread issue has been overfishing, which, by favoring the growth of fleshy algae over calcareous species of plants and animals, has likely reduced the growth capacities of some of the reefs, particularly those adjacent to inhabited islands or structures and thus generally subject to abundant nutrient inputs⁸³. This problem continues to grow, and will do so until a proper management and enforcement plan is in place. Given proper management actions, this problem is theoretically reversible. However, the presence of the extended and new islands will undoubtedly lead to increased fishing pressure in their vicinities as settled fishing populations increase and transient fishers stay nearby for safety reasons.

⁸⁰ L. Burke, K. Reytar, M. Spalding, A. Perry, *Reefs at Risk Revisited* (World Resources Institute, Washington, DC, 2011) 3.

⁸¹ P.J. Mumby, R.S. Steneck, and A. Hastings 'Evidence for and against the existence of alternate attractors on coral reefs' (2013) 122 *Oikos* 481–491.

⁸² G. Roff and P.J. Mumby 'Global disparity in the resilience of coral reefs' (2012) 27 *Trends in Ecology and Evolution* 404–413.

⁸³ J.W. McManus, L.A.B. Meñez, K.N.K Reyes, S.G. Vergara and M.C. Ablan, 'Coral reef fishing and coral-algal phase shifts: implications for global reef status' (2000) 57(3) *ICES Journal of Marine Science* 572–578.

A more recent and very widespread problem which has been largely unidentified to date is that of shallow-water dredging. The channels and harbors that have been dredged in conjunction with the island building and extension, here referred to as ‘deep dredging’, have not produced enough material to create the new land masses. Because of this, widespread dredging of calcareous sand and gravel (the latter from living and dead hard corals) has occurred on reef flats and lagoons on some reef systems. This ‘shallow dredging’, while not causing quite as permanent and catastrophic a loss as the filling operations, is still far more devastating over a term of a decade or longer than overfishing or destructive fishing in the area has been – as elucidated below.

Figure 6 shows Google Earth satellite images with arc-like marks indicating damage to a reef flat and lagoon (top) and island building with deep dredging of a harbor (bottom). Shallow dredging has been known to produce arc-like patterns. However, the visible arcs tend to be in waters too shallow for the operation of the large cutter suction dredgers known to be involved with the island construction, which generally have drafts of 3.5 to 5.5 m. Rather, shallow dredging can be determined on these reefs only in cases where dredgers appear in available imagery, or where large rectangular box-like cut marks appear on reef flats. As of January, 2016, it has been demonstrated that most of the arcs have been made (and sediment stirred up) by numerous small PRC boats which can be anchored and swung laterally to uncover giant clams via propeller action⁸⁴. These clams are then used for products such as expensive carved decorative shells⁸⁵. Although fishers from the Philippines and Vietnam are known to have harvested wild giant clams in the past, only fishers from PRC have been known to use this method of digging up the bottom with boat propellers. Indeed, the small Philippine outrigger boats (bankas) would be unstable if pulled laterally, and no evidence could be found of the arcs on any reef presently guarded by Vietnam. The fact that the arcs can be found on historical imagery for each of the new PRC islands prior to island construction may explain why PRC has frequently claimed that the islands were built on areas of “dead coral”.

Note that in all cases of clamming, dredging and filling (in the absence of fine mesh turbidity curtains, whose characteristic buoys which do not appear in available imagery), large plumes of sand and silt are created, which coat nearby sections of coral reef. Both shallow and deep dredging directly remove reef flat, lagoon, and in some cases reef crest and fore-reef ecosystems, while causing drastic changes to the geomorphology and hydrodynamic regimes. The deep dredging cuts through thousands of years of reef limestone. Because of the draughts of the military and civilian ships (typically 3.5 to 12 m) for which the dredging has been done, as well as a depth safety factor, the final depth will in most cases be 5 to 10 meters beyond existing natural depths. The resulting areas will likely have to be dredged out regularly to keep them from filling in. These basins and channels are not part of the naturally self-assembling machine of the reef, and so will generally be subject to sediment deposition. The changes in currents and new openings for waves to enter unimpeded will have complex consequences for the ecological communities across the reef. The periodic dredging to clear built-up sediments will prevent most

⁸⁴ V.R. Lee, ‘Satellite Imagery Shows Ecocide in the South China Sea: Poaching of giant clam shells is causing massive scarring of coral reefs’ (2016) *The Diplomat*. Available at: <http://thediplomat.com/2016/01/satellite-images-show-ecocide-in-the-south-china-sea/>; accessed 9 February 2016. The results of this paper, based on satellite imagery and searches of websites, were confirmed by this author (JWM) in a field study of two reefs heavily damaged by these giant clamming operations as described further below.

⁸⁵ *Ibid.*

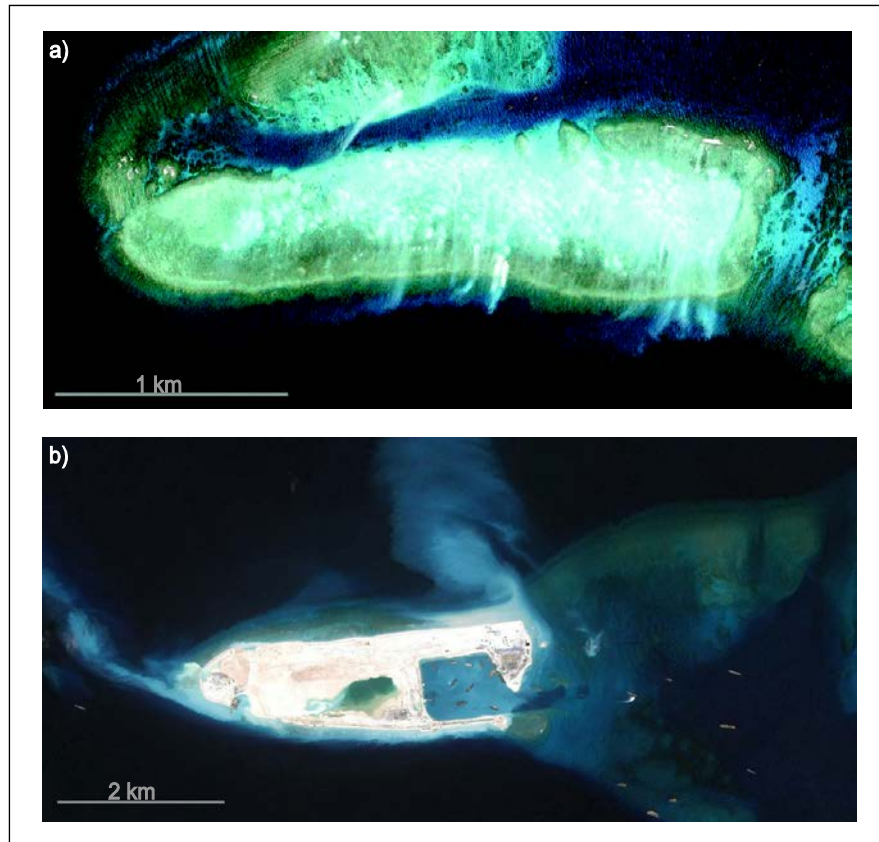


Figure 6. Two satellite images from the Spratly area. a) Two partial atolls rising above a larger subsurface atoll, and subject to shallow dredging to extract sand for island building. The resulting plumes of sand spread out from the lagoons to other reef zones. Dredging and transport vessels are seen at right-center. b) Fiery Cross Reef with all shallow portions of the atoll now buried by sand except for a dredged harbor. Subsurface portions of a larger underlying atoll are visible on the right. Large dredging ships exceeding 100m in length are accompanied by various transport vessels.

reef organisms from settling, and will likely create a chronic problem of sand and silt plumes for surrounding marine ecological zones.

The shallow dredging of calcareous sand and gravel will have both long-term (many decades) and medium-term (a few years or decades) impacts. In the case of non-chronic dredging, many of the lagoon and reef flat ecosystems will gradually return to a near natural state, though with differences because of different depths and, in some cases for reef flats, a loss of semi-consolidated and patchy hard substrate in return for sand from other areas. A few meters in depth of both lagoon sands and reef flat substrate represent a thousand years or more of production by the reef⁸⁶.

Although sand and silt production are natural processes within a reef, misplacement of these materials due to dredging and construction activities can have serious consequences for the zones on which they land⁸⁷. Many benthic (bottom-dwelling) organisms will be simply buried and die. Resuspension of this displaced material by waves or propellers can keep the silt-sized materials in the water column long enough to deprive light to reef-building encrusting algae and a myriad of other reef organisms. These sediments are particularly hazardous to soft and hard corals. They can reduce growth rates, cause lesions, and inhibit sexual reproduction⁸⁸. The weakened corals may become susceptible to diseases⁸⁹. As sand is picked up by waves and fast currents, it can scour living tissue from corals⁹⁰. If the damage is not chronic, the relatively resilient Indo-Pacific reefs may recover all but the larger coral colonies within a few decades to half a century, although substantial changes in species composition may result⁹¹. This relatively rapid recovery is especially the case with reefs constantly washed over with clear, oligotrophic waters, such as with most of the offshore reefs in this region. However near inhabited islands and military structures, the combination of organic pollution and over-fishing for herbivorous fish can result in a post-damage phase shift toward dominance by fleshy algae, delaying recovery for long periods of time depending on the chronic nature and intensity of this pollution and over-fishing⁹². As storms damage the newly filled areas of artificial islands and island extensions, further shallow dredging will likely be necessary to obtain replacement materials. Thus, in some areas the shallow dredging itself may become as chronic a problem as that of the filled areas and deep dredged areas. While the damage associated with the shallow dredging is on average of less concern than the filling and deep dredging, some areas of the shallow dredging subject to periodic repetition will be damaged for just as long -- near-permanently. Because these

⁸⁶ K.-F. Yu, J.-X. Zhao, P.-X. Wang, Q. Shi, Q.-S. Meng, K.D. Collerson, T.-S. Liue, 'High-precision TIMS U-series and AMS 14C dating of a coral reef lagoon sediment core from southern South China Sea' (2006) 25 *Quaternary Science Reviews* 25.

⁸⁷ X.-B. Li, H. Huang, J.-S. Lian, S. Liu, L.-M. Huang, J.-H. Yang, 'Spatial and temporal variations in sediment accumulation and their impacts on coral communities in the Sanya Coral Reef Reserve, Hainan, China' (2013) 96 *Deep-Sea Research II* 88–96.

⁸⁸ P.L.A. Erftemeijer, B. Riegl, B.W. Hoeksema, P.A. Todd, 'Environmental impacts of dredging and other sediment disturbances on corals: a review' (2012) 64 *Marine Pollution Bulletin* 1737-1765.

⁸⁹ F.J. Pollock, J.B. Lamb, S.N. Field, S.F. Heron, B. Schaffelke B, G. Shedrawi, D.G. Bourne, B.L. Willis, 'Sediment and Turbidity Associated with Offshore Dredging Increase Coral Disease Prevalence on Nearby Reefs' (2014) 9(7) *PLoS ONE* e102498. doi:10.1371/journal.pone.0102498.

⁹⁰ Wiens *op. cit.* ref. 69 p. 128; R.C. Highsmith, A.C. Riggs and C.M. D'Antonio, 'Survival of Hurricane-Generated Coral Fragments and a Disturbance Model of Reef Calcification/Growth Rates' (1980) 46(3) *Oecologia* 322-329.

⁹¹ M.X. Zhao, K. F. Yu, Q. M. Zhang, Q. Shi, G. Roff, 'Age structure of massive *Porites lutea* corals at Luhuitou fringing reef (northern South China Sea) indicates recovery following severe anthropogenic disturbance' (2014) 33 *Coral Reefs* 39–44.

⁹² McManus and Polsenberg *op. cit.* ref. 55.

disruptions will tend to inhibit the reef from keeping up with sea level, the affected reefs will likely be submerged within a few decades. This will alter the reef permanently, removing wave-protected reef flat and lagoon habitats, and thus result in further permanent damage.

A preliminary compilation of areas of shallow offshore reefs impacted by filling, deep dredging, shallow dredging and destructive giant clam harvesting across the South China Sea was conducted primarily using satellite images available online on Google Earth Pro as of March 2016. Areas of damage were identified on current or historical satellite images based on a combination of comparisons with historical or neighboring images, in conjunction with experience from several decades of coral reef field and image analyses by this author. This author validated the image analyses via ground-truth surveys (swimming transects exceeding 1.3 km each, with at least 10 m visual range, from NNE to SSW or the reverse direction across the reefs) of the giant clam gathering damage on two reefs east of Thitu island – Teishi Reef on February 22 and the ‘checkmark’ shaped reef (Figure 6a) on February 23, 2016. These surveys indicated that the method kills off most visible bottom-dwelling invertebrates and destabilizes the substrate so as to delay full coral recovery by many years.

Quantification on imagery was done with the use of the area estimation tool in Google Earth Pro. Giant clam harvest areas were identified by nested arching patterns in the sediments characteristic of the impact of anchored small boats being swung laterally to uncover giant clams with their propellers. Shallow dredging damage was inferred from large rectangular pockets which had been cut out of the reef flat adjacent to filled areas at Vietnamese bases on Central Reef, Pearson Reef, Sand Cay, and Sin Cowe East Island, and from the presence of dredgers and plumes they created within lagoons at the PRC bases at Fiery Cross Reef, Subi Reef and Mischief Reef. Deep dredging and filling areas were determined by obviously anthropogenic alterations, confirmed where possible via pre-damage imagery on Google Earth Pro. More than 90 offshore shallow reef sites were investigated across the region. English reef names were gathered from Valencia *et. al.*⁹³ and plotted on Google Earth Pro, with corrections to locations based on matching descriptions of reefs to images. Although nearly all of these named shallow reef sites were represented in images from within the last year or so, and many unnamed sites were located and analyzed, an additional ten or so sites with primarily unnamed reefs were represented only in low-resolution imagery or not at all (based on numerous charts), and so were not properly analyzed. Thus, the quantification is in terms of ‘at least’ this much damage.

For the seven artificial islands rapidly constructed in the Spratly area by China, it was important to use very current information. Because the Asia Maritime Transparency Initiative (AMTI) website of the CSIS Think Tank had better access to current imagery than the author, their island estimates were used herein. Additionally, a recent letter from the head of U.S. Intelligence to Senator John McCain⁹⁴ indicated that an additional 100 acres (404,686 m²) had been added to the Subi and Mischief islands later in 2015 than the AMTI measurements had been made – and this was incorporated in the current analyses. The author measured each new island based on older imagery with some corrections for subsequent changes visible in later images from the AMTI website other sources. However, they were close enough to the published AMTI

⁹³ Valencia *et al.*, *op. cit.* ref. 30 Appendix 1 227-234.

⁹⁴ J. Clapper, ‘Document: DNI Clapper Assessment of South China Sea’ (2016) Available at <https://news.usni.org/2016/03/08/document-dni-assessment-of-chinese-militarization-reclamation-in-south-china-sea>; accessed 17 April 2016.

website to serve as validation, and the more precise AMTI values were used. The deep dredging was completed early enough that Google Earth Imagery was useable directly.

Each occupied feature was identified as to claimant nation by reference to Valencia et al.⁹⁵ and various news sources, and closely examined as to building style to validate that the occupation information was current. Fortunately, each claimant had employed a limited range of very characteristic military base construction styles. Interviews conducted with Philippine military personnel and others in February 2016 confirmed that these troops were generally unable to stop activities by PRC clam boats in their areas because of orders to minimize such arrests.

The results of this analysis are shown in Table 1. More than 160 square kilometers of coral reef area showed serious signs of damage from clam harvest, dredging and/or filling. No obvious damage to coral reef area was visible for Taiwan-occupied Pratas Reef (Dongsha). With total filling covering 14.9 km² of reef ecosystem, and another 2.5 km² of channel and harbor dredging, it is apparent that the world had lost at least 17 km² of its more highly diverse and fishery productive coral reefs, essentially permanently. While not as permanent and severe, the additional clam harvesting and shallow dredging of reef flats and lagoons for building materials had seriously disrupted 143 km² of important ecosystems within these valuable reefs, with impacts that may last for decades. The PRC is responsible for approximately 99% of the overall damage from these activities among offshore coral reefs in the South China Sea.

In the Spratly area per se (excluding Scarborough Reef), unlike within the Parcels, there is a clear and distinct difference between the shallow surface-breaking reefs and deeper subsurface reefs, wherein no part of the reef extends to near the surface. The satellite-derived and empirically measured validation depths published by Hu et al. for North Danger Reefs suggest that these subsurface reefs are generally at about 8 - 20 m or so in depth⁹⁶, and so are not among the reefs known widely as mesophotic reefs (where light is considerably reduced), nor the true deep reefs (below the photic zone). The total area of shallow reefs (at or near the surface) in the Spratly area is approximately 1,150 km². When visible deeper reefs are included, the total becomes 3,821 km²⁹⁷. The 124 km² of damaged shallow reef in the Spratly area represents approximately 10% of the total shallow reef area, and roughly 3% of the total reef area at depths visible to areal and satellite images. Within the Paracels, the 37 km² of damage represents about 8% of the total area of reef of 481 km²⁹⁸.

It is noted that additional, as yet unquantified filling operations have been reported within the Paracels as of February 2016. The likelihood of much greater damage by giant clam harvesting than measured from the available Google Earth imagery is indicated by the fact that fishers interviewed by this author on 24 February, 2016 claimed that these operations had killed most of the shallow coral on other reefs (First Thomas Shoal, Half Moon Shoal, and others) near to Palawan which were not included in the current quantification. Beyond the 35 Spratly reefs with giant clamming damage quantified here, there are at least 10 other shallow reefs within the

⁹⁵ Valencia *et al.*, *op. cit.* ref. 30 Appendix 1 227-234.

⁹⁶ L. Hu, Z. Liu, Zh. Liu, C. Hu, and M.-X. Hea, 'Mapping bottom depth and albedo in coastal waters of the South China Sea islands and reefs using Landsat TM and ETM+ data' (2014) 35(11-12) *International Journal of Remote Sensing* 4156-4172.

⁹⁷ M.D. Spalding, *op. cit.* ref. 56.

⁹⁸ Area estimate from personal communication from Mark Spalding, Senior Marine Scientist, Global Marine Team, The Nature Conservancy (University of Cambridge, UK), based on measurements by the Marine Science Institute of the University of the Philippines as part of regional reef area assessments in Burke *et al.*, *op. cit.* ref. 56.

Table 1. Areas of damage to shallow coral reefs in the South China Sea in square kilometers. The Greater Spratly Islands (GSI) includes Scarborough Reef. These are minimal values, as they are based on available satellite imagery on Google Earth Pro (GEP) as of March 2016, and a few reefs and/or new island expansions may not have been visible. Based on an open US intelligence letter to Sen. John McCain, an additional 404,686 m² of filling for Subi Reef and Mischief Reef in the GSI, not yet in GEP imagery, has been added for PRC. Known island expansion in the Paracels in late 2015 has not been included due to a lack of area estimates and of imagery on GE. Accuracy is believed to exceed 90%. Giant clamming refers to the digging up of giant clams using propellers on anchored boats pulled laterally.

	Filling	Dredging		Giant Clamming	Row Sums	% of Total GSI
		Channel	Shallow			
Greater Spratly islands (GSI)						
People's Republic of China	13.23	1.38	39.30	68.75	122.66	99%
Vietnam	0.27	0.21	0.26	---	0.74	< 1%
Malaysia	0.37	0.05	---	---	0.42	< 1%
Taiwan	0.04	0.04	---	---	0.08	< 1%
Philippines	0.06	---	---	---	0.06	< 1%
Total, GSI	13.91	1.68	39.56	68.75	123.95	
Percent of GSI Damage by PRC	95%	82%	> 99%	100%	99%	
Paracel Islands						
People's Republic of China	1.01	0.86	0.00	35.02	36.89	
Total, South China Sea	14.92	2.54	39.56	103.77	160.84	
Percent of All Damage by PRC	95%	88%	>99%	100%	99%	

Spratly area which had not yet shown damage on their outdated images on Google Earth, are not occupied by Vietnam, Taiwan or Malaysia, are not well-protected by the Philippines, and are thus likely to be damaged soon if they have not been already.

There are some differences in species composition between the shallow and subsurface reefs in the Spratly area, so a loss of shallow water reef area may reduce populations of certain species not found in deeper areas. Many species of oceanic migratory fish (including tuna, jacks, mackerel, etc.) swim through reef areas to feed on dense schools of reef fishes, often in shallow waters. The loss of 8-10% of the shallow reef area in these two reef groups may have a significant impact on regional fisheries, both in terms of direct reef fisheries and migratory oceanic fish harvests. Demonstrating this impact would require multiple years of data, because fish stocks vary annually due to many factors. However, the further expansion of dredged reef area, especially in conjunction with continued overfishing and environmentally damaging giant clam harvest, would clearly pose an increasingly serious problem for regional fisheries sustainability.

Fossil Fuel and Hydrates Issues

In the early 1990's when the idea of an International Spratly Islands International Marine Park was proposed⁹⁹, much of the opposition to it was centered on the possibility of substantial amounts of fossil fuels being present¹⁰⁰. Although it is conceivable that licenses to drill for oil and gas could be issued by a park management organization, there was the concern that the park status would inhibit exploration and development of these reserves. However, in 2013, the U.S. Energy Administration Agency published a map on its website which indicated that there are likely to be no significant oil reserves in the Spratly area outside of the Sunda Shelf, and that gas reserves in the Spratly area are much lower per area than on many surrounding shelf areas. Reserves of these fossil fuels are similarly low at Scarborough Reef and within the Paracel Islands. There are, however, likely to be very significant reserves in areas adjacent to the Paracel Islands¹⁰¹. There are also likely to be substantial methane hydrate reserves within the deep waters between the atolls of the Spratly Island area¹⁰², but the means to safely exploit this highly explosive, greenhouse gas producing, potential energy source have yet to be developed¹⁰³.

⁹⁹ McManus *et al.*, *op. cit.* ref. 31.

¹⁰⁰ M.J. Valencia, 'Oil and the lack of it in the South China Sea.(includes reply)(response to article by Ian Townsend-Gault, Contemporary Southeast Asia, vol 20, no 2, Aug 1998)' (1999) 21(1) *Contemporary Southeast Asia* 153-154.

¹⁰¹ Anon., 'Contested areas of South China Sea likely have few conventional oil and gas resources' (2013) *Independent Statics and Analysis, U.S. Energy Administration Agency*. Available at: <http://www.eia.gov/todayinenergy/detail.cfm?id=10651#>; accessed 10 September 2015.

¹⁰² N.N. Trung, 'The gas hydrate potential in the South China Sea' (2012) 88-89 *Journal of Petroleum Science and Engineering* 41-47; H. Liu, Y. Yao, and H. Deng, 'Geological and Geophysical Conditions for Potential Natural Gas Hydrate Resources in Southern South China Sea Waters' (2011) 22(6) *Journal of Earth Science* 718-725.

¹⁰³ W. Pentland, 'Energy's Most Dangerous Game' (2008) *Forbes*. Available at http://www.forbes.com/2008/08/29/energy-methane-hydrates-biz-energy-cx_wp_0902gashydrates.html; accessed 10 September 2015.

National Aspirations and Precedents

The building of artificial islands has unified the Philippines and Vietnam in opposition to the PRC's actions in the South China Sea¹⁰⁴. They appear to be largely supported in this by many extra-regional nations, including the United States, Japan¹⁰⁵, Australia¹⁰⁶, the United Kingdom¹⁰⁷ and others. In an effort to ease regional tensions, Taiwan has called for an expansion of joint scientific research and environmental protection of the Sea¹⁰⁸. Previous presidents of both Taiwan and the Philippines have spoken in favor of the establishment of a Peace Park or similar designation within the Spratly Islands¹⁰⁹. Clearly, the most important factor in any such natural resource protective strategy would be support from the PRC.

There are precedents involving the PRC which may be helpful. In 2007, the World Conservation Monitoring Center and the International Union for the Conservation of Nature published a list of transboundary protected areas¹¹⁰. Of 227 such areas, the PRC was shown to be a partner in 17, including one which involved three other nations. While these all involved borders on land, they demonstrate that such cooperation is not beyond the realm of consideration by the PRC. There is also a significant marine-based transboundary fisheries management agreement between Vietnam and the PRC, governing the fisheries of the Gulf of Tonkin¹¹¹. While there have been issues with its implementation, particularly with the perception of lack of bilateral equity in decision-making¹¹², it clearly represents a step forward.

¹⁰⁴ N.P. Calleja, 'Philippines, Vietnam close to signing cooperation pact on South China Sea' (2015) *Inquirer.net*. Available at <http://globalnation.inquirer.net/128054/philippines-vietnam-close-to-signing-cooperation-pact-on-south-china-sea>; accessed 10 September 2015.

¹⁰⁵ Y. Hayashi and C. Tsuneoka, 'Japan open to joining U.S. in South China Sea patrols' (2015) *The Wall Street Journal*. Available at <http://www.wsj.com/articles/japan-may-join-u-s-in-south-china-sea-patrols-1435149493>; accessed 10 September 2015.

¹⁰⁶ R. Taylor, 'Australia to Continue Military Patrols in South China Sea' (2015) *The Wall Street Journal*. Available at <http://www.wsj.com/articles/australia-to-continue-patrolling-south-china-sea-1433046154>; accessed 10 September 2015.

¹⁰⁷ M. Martina, 'Britain calls for freedom of navigation in South China Sea' (2015) *Reuters World*. Available at <http://uk.reuters.com/article/2015/08/12/uk-southchinasea-china-britain-idUKKCN0QH1HO20150812>; accessed 10 September 2015.

¹⁰⁸ Anon., 'South China Sea Peace Initiative' *Ministry of Foreign Affairs, Republic of China (Taiwan)* (2015). Available at http://www.mofa.gov.tw/News_Content.aspx?n=604CBAA3DB3DDA11&sms=69594088D2AB9C50&s=4589151C339E71C5; accessed 10 September 2015.

¹⁰⁹ McManus *et al.*, *op. cit.* ref. 36.

¹¹⁰ I. Lysenko, C. Besançon, and C. Savy, *2007 UNEP-WCMC Global List of Transboundary Protected Areas* (United Nations Environment Programme and World Conservation Monitoring Center, Cambridge, U.K., 2007). Available at: http://www.tbpa.net/docs/78_Transboundary_PAs_database_2007_WCMC_tbpa.net.pdf; accessed 12 September 2015.

¹¹¹ L. Jianwei and C. Pingping, 'China-Vietnam fishery cooperation in the gulf of tonkin revisited' (2011) Second International Workshop, November 2010, East Sea (South China Sea) Studies (Ho Chi Minh City, Vietnam, EastSeaStudies.org, 2011). Available at <http://nghiencuubiendong.vn/en/conferences-and-seminars-/second-international-workshop/594-china-vietnam-fishery-cooperation-in-the-gulf-of-tonkin-revisited-by-li-jianwei-a-chen-pingping>; accessed 12 September 2015.

¹¹² M. Lerner, 'Outcry over China's global fishing practices' (2015) *Blouin News*. Available at <http://blogs.blouinnews.com/blouinbeatbusiness/2015/05/20/outcry-over-chinas-global-fishing-practices/>; accessed 12 September 2015.

The 'Tied-Hands' Dilemma

In political science theory, a nation which expects to be taken seriously in a stand-off must find an effective means with which to signal that it will not back down¹¹³. These signals are often most effective when they involve substantial investment of one type or another, which will lead to a major loss if the nation was to capitulate. Signaling may be most effective when these losses are likely to lead to the populace forcing a major change in government. Fearon classified these signaling investments as either 'sunk costs' or 'tied hands'¹¹⁴. In a recent analysis of the Spratly Islands tension within this framework, Haotian Qi showed that sunk costs would include military buildup and the recent development of artificial islands. Of at least equal concern, however, is the ubiquitous tied hands strategy in play across the region¹¹⁵. Each major claimant nation, but particularly the PRC, the Philippines and Vietnam, have conducted major information campaigns primarily aimed at ensuring that the general populace within each country strongly believes that its claims are the only legal and justified ones. An example is the recent three-part series, shown on television in the Philippines and available on the Internet, entitled 'Kalayaan, Karapatan sa Karagatan'¹¹⁶. Kalayaan is the name for the Philippine claim in the Spratly Islands, and the rest of the title refers to ocean rights. This well-produced series makes the PRC in particular seem like it is hoarding valuable resources away from their rightful owners, the Philippines. It is clear that if any of these three nations were to concede territory to the others, the periodic street demonstrations already happening in some of these countries would intensify considerably, potentially leading to the ouster of the extant government. Indeed, this threat of ouster is an important part of the signaling via the tied hands investment.

It is becoming increasingly unlikely that the nations involved in overlapping claims in the South China Sea will agree to any settlement which leads to a reduction of perceived sovereignty. Thus, any potential path to peace must maintain each nation's claims as they currently stand.

Steps toward Peace

General

It is widely understood that the nonbinding Declaration of a Code of Conduct adopted by the Foreign Ministers of ASEAN and the People's Republic of China at the 8th ASEAN Summit in Cambodia in 2002 was insufficient to protect the region's natural resources and ensure political stability. Thus, there are moves to develop a new, binding Code of Conduct¹¹⁷. In this process, it must be clearly understood that regional stability is indivisibly bound to sustainable fisheries

¹¹³ J.D. Fearon, 'Signaling Foreign Policy Interests: tying hands versus sinking costs' (1997) 41(1) *Journal of Conflict Resolution* 68-90.

¹¹⁴ *Ibid.*

¹¹⁵ H. Qi, 'The Line That America Shouldn't Cross in the South China Sea' (2015) *The National Interest*. Available at <http://nationalinterest.org/feature/the-line-america-shouldnt-cross-the-south-china-sea-13138>; accessed 13 September 2015.

¹¹⁶ *Kalayaan, Karapatan sa Karagatan* (Three-part video in Tagalog, Philippine Department of Foreign Affairs, Manila, Philippines, 2015). Available at https://www.youtube.com/results?search_query=Kalayaan%2C+Karapatan+sa+Karagatan; accessed 13 September 2015.

¹¹⁷ A. Panda, 'For the ASEAN-China South China Sea Code of Conduct, ninth time isn't the charm' (2015) *The Diplomat*. Available at <http://thediplomat.com/2015/08/for-the-asean-china-south-china-sea-code-of-conduct-ninth-time-isnt-the-charm/>; accessed 13 September 2015.

exploitation and the protection of critical fish habitats including coral reefs. The latter environmental protection can be strongly reinforced by the development of ecologically sustainable tourism. Tourism can only grow in the absence of military threat. Thus, increasing profit from, and economic dependence on, tourism can help to reduce regional militarization.

One reason for the failure to agree on a draft of a Code of Conduct implementation in 2012 was the inclusion of references to Exclusive Economic Zones (EEZ) and sovereignty by the Philippines over Scarborough Reef¹¹⁸. It is likely that any similar references in future drafts which amount to losses of claimed territory or perceived exclusive resource rights by one or another country will also lead to failed adoption.

Essentials for a Binding Code of Conduct

The success of any binding regional agreement for political and military stability across the South China Sea must include as a minimum:

1. **A freeze on claims.** A point in time must be chosen prior to the development of the agreement beyond which no changes in declared sovereignty can take place. It must be clear, however, that the agreement itself does not reinforce those claims.
2. **A freeze on claim-supportive activities.** It must be agreed that no actions during the period of effect of an agreement will be used in any future efforts to strengthen a case for sovereignty. This will immediately remove the motivations behind much of the militarization and environmental damage currently underway, such as the occupation of barely habitable islets mainly for purposes of demonstrating administrative control.
3. **A reduction in offshore military facilities.** Heavily armed military bases lead to widespread unease and potentially to attempts to balance military potential via an arms race. Given the high investments recently placed in the offshore bases, it may be necessary to make this a gradual phase-down. Military bases are excessively expensive, and so a period of lessening need for their maintenance will create pressures to reduce the maintenance expenditures.
4. **Reinforcement of encounter protocols.** There are well-developed protocols governing actions associated with encounters at sea and in the air of both military and civilian craft. These must be recognized as features inherent to the new agreement.
5. **A regional body to oversee resources.** Because of the combination of highly-migratory species and high degree of larval connectivity for less mobile species, the South China Sea must be seen as a common pool of fisheries resources. Achieving sustainability, optimal harvest and rational benefit distributions for these highly complex fisheries will require cutting-edge fisheries analysis and careful selection of management protocols. Environmental protection must a priority concern, in support of fisheries, tourism, and

¹¹⁸ C.A. Thayer 'ASEAN'S Code of Conduct in the South China Sea: A Litmus Test for Community-Building?' (2012) *The Asia-Pacific Journal: Japan Focus*. Available at http://www.japanfocus.org/-carlyle_A_-Thayer/3813/article.html; accessed 13 September 2015.

the broader values of these unique offshore ecosystems. Environmental impact analysis and mitigation procedures must be held to standards which are consistent regionally, instead of variable among nations. The exploitation of fossil fuels must be regulated in concert with efforts to protect the environment, but also overseen so as to ensure rational benefit distribution. The regional body which will oversee all resources in the South China Sea will require regional buy-in and so must include government representation. However, it must also be led by the highest possible quality of science. This is generally not possible when approached solely in terms of national representation. Thus, the intergovernmental body of representation must share responsibility with an international body of thematic experts. These, in turn should work with independent international organizations with responsibility for South China Sea resources, such as various UN agencies, regional resource bodies such as SEAFDEC, and the WorldFish Center, with the inclusion of experts and focused research efforts tapping the global pool of scientists. Data sharing and archiving must be mandatory, so as to make optimal use of research expenditures.

6. **Well-defined inspection, arbitration and enforcement procedures.** ‘Binding’ implies enforceable. There must be transparency throughout the offshore South China Sea, with the unrestricted freedom of visits to any research or development activity by all signatories. There must be clear arbitration procedures for various classes of dispute, and clear actions to be followed in cases of disregard for essential agreement provisions.

The Antarctic Treaty¹¹⁹ is a starting point for much of the development of a binding Code of Conduct. It was formulated based on problems similarly arising from overlapping national claims, and as a means to protect the common heritage of humankind. It includes both a freeze on claims and a freeze on claim-supportive activities. There are reasonably clear procedures for site inspection and dispute arbitration, the latter including both committees specifically appointed from among the ratifying or signatory nations, as well as agreements to settle other issues within the Permanent Court of Arbitration¹²⁰. There are important issues with this treaty to avoid in the Code of Conduct, such as the many gaps in environmental and fisheries protection which have been the focus of subsequent agreements and proposed actions¹²¹. However, it is a well-tested document to serve as a basis on which to build and improve.

The Transboundary Peace Park Option

‘Marine protected areas’ (MPA) are marine areas which are afforded special environmental protection because of the unusual importance of these areas to humankind. The term ‘marine park’ is used as a form of MPA. The definition of such a park varies case-to-case, but usually refers to an MPA under a central administration which allows tourism activities and often fishing in specific areas. Other areas within a large marine park or marine reserve may include ‘no-

¹¹⁹ 1959 Antarctic Treaty (Washington, D.C., 1 December 1959, in force 23 June 1961) 402 UNTS 71.

¹²⁰ *Ibid.*

¹²¹ S.L. Chown, J.E. Lee, K.A. Hughes, J. Barnes, P.J. Barrett, D.M. Bergstrom, P. Convey, D.A. Cowan, K. Crosbie, G. Dyer, Y. Frenot, S.M. Grant, D. Herr, M.C. Kennicutt, M. Lamers, A. Murray, H.P. Possingham, K. Reid, M.J. Riddle, P.G. Ryan, L. Sanson, J.D. Shaw, M.D. Sparrow, C. Summerhayes, A. Terauds, D.H. Wall, Challenges to the Future Conservation of the Antarctic (2012) 337 *Science* 158-159.

fishing reserves' or other classified areas intended to help with the mission of making resources sustainable across generations. Transboundary Peace Parks are parks on land or across areas of water whose mission of protecting the environment are often combined with that of reducing tensions associated with disputed national boundaries. The first specifically designated peace park was the Waterton-Glacier International Peace Park established in 1932, which includes the United States and Canada in joint management of natural resources in an area where the national boundaries were unsettled. Since then, a large number of transboundary peace parks have been initiated, particularly in Africa. A marine example is the Red Sea Peace Park involving Israel and Jordan¹²². As discussed previously, there have been multiple proposals to include part or all of the Spratly Islands into a transboundary park or network of parks.

The establishment of the Greater Spratly Islands Peace Park, including Scarborough Reef, would be a major step in not only helping to stabilize fish stocks across the South China Sea, but in promoting tourism and regional political stability. The administration of the Park could be handled by an independent contracted agency, under the supervision of a panel consisting of claimant nations and with an advisory panel made up of thematic experts of global stature.

A second area for consideration as a peace park would be the Paracel Islands. Given the strongly entrenched nature of the PRC within this archipelago, it may be difficult to establish such as Peace Park until such time as Vietnam challenges the PRC for sovereignty rights via international arbitration. Should the PRC's position as the legal administrators of the Paracels be thus challenged, then perhaps a Paracels Peace Park could be considered as an alternative to the unlikely option of the PRC abandoning the island group.

Concluding Remarks

The very large, highly speciose offshore coral reef structures of the South China Sea are part of the common heritage of humankind. They are irreplaceable components of the total package of resources that current generations must pass on to later generations. Their importance extends far beyond the confines of the South China Sea. Were the offshore reefs of either the Greater Spratly Islands or Parcel Islands comfortably within the undisputed regime of a single nation, they would certainly qualify as World Heritage Sites. In these ways, they are similar to the resources of Antarctica. In the latter case, only 12 nations had originally registered claims to the area. However, there are currently 52 nations which are parties to the Treaty¹²³. This Treaty can serve as a starting point for either an offshore South China Sea treaty, or a more geographically restricted Greater Spratly Islands Peace Park, or both. It may be necessary for the immediate future, in order for progress to be made, to keep negotiations and ratification limited to the nations surrounding the South China Sea, plus perhaps other members of the ASEAN organization. However, ultimately the global nature of the problems may necessarily lead to an expansion of ratification to a global level.

¹²² M.P. Crosby *et al.*, "The Red Sea Marine Peace Park: Early Lessons Learned from a Unique Trans-boundary Cooperative Research, Monitoring and Management Program," in Proceedings of the IUCN/WCPA-EA-4 Taipei Conference (Taipei, Taiwan, IUCN/WCPA, 2002).

¹²³ Anon., 'Parties' *Secretariat of the Antarctic Treaty*.

Available at http://www.ats.aq/devAS/ats_parties.aspx?lang=e; accessed 13 September 2015.

Declaration of Prof. Kent E. Carpenter, Ph.D.

1. I have reviewed the Tribunal's letter of 1 April 2016 asking the Philippines to seek clarification from Dr. John McManus regarding the estimates provided in his 2015 report, *Offshore Coral Reef Damage, Overfishing and Paths to Peace in the South China Sea*, of the amount of coral reef that has been damaged by, on the one hand, shallow dredging by China and, on the other, extraction of giant clams. I have also reviewed Dr. McManus' response to the Tribunal's request, including his revised report. Since I cited Dr. McManus' 2015 report in my response to questions from the Tribunal during the oral hearings, I would like to take this opportunity to comment on the clarification which Dr. McManus has provided.

2. As I explained during my testimony, I estimated using GIS calculations that 13.62 km² of coral reef has been destroyed by China's artificial island-building activities. I noted that this calculation was close to the 14.2 km² that Dr. McManus calculated was destroyed by landfill (12.82 km²) and associated dredging of deep channels (1.38 km²).¹

3. Dr. McManus' clarification does not undermine the conclusion that a large area of coral reef has been destroyed by China's artificial island-building. In fact, he has revised upward, to 13.23 km², the calculation of coral reef area destroyed by landfill. I note that this is consistent with an article by Camilo Mora et al., which was published on 31 March 2016 in the peer-reviewed Public Library of Science Biology (submitted herewith as Annex 893). That article estimated that approximately 11.6 km² of coral reef had been destroyed through May 2015 (the slightly lower calculation is likely due to the fact that Mora et al. considered satellite imagery taken through May 2015, while Dr. McManus' 2015 report evaluated subsequent imagery taken after more dredging had taken place).

¹ Tr. (30 Nov. 2015), pp. 147:18-148:7 (Testimony by Prof. Carpenter).

4. Although it was not a focus of my expert report or testimony, Dr. McManus's 2015 report calculated that, beyond the coral reefs destroyed by landfill and deep dredging, an additional 79.2 km² of coral reef had been damaged by shallow dredging undertaken by China to obtain material for its artificial island-building project. Dr. McManus concluded in that report that it would take decades for these coral reefs to recover, assuming they are not subject to further disturbance.²

5. As the Tribunal's expert has observed, subsequent reporting by Victor Robert Lee, published on 15 January 2016, describes widespread and intense extraction of giant clams. This was also detailed in reporting by the BBC's Rupert Wingfield-Hayes in December 2015.³ The extraction methods employed by Chinese fishermen, which are countenanced by the Chinese government, are extremely destructive to reef habitat and represent unprecedented harm to the marine environment. I addressed the environmental impact of extracting giant clams, which are listed as endangered species, in my expert reports and testimony. At the time these were prepared, however, I had not appreciated the scale upon which this is occurring.⁴

6. The Tribunal's expert has asked Dr. McManus to estimate the proportion of reef that he would confidentially assign to dredging versus clam shell extraction. I note that Dr. McManus' revised report calculates that 39.30 km² have been damaged by shallow

² John McManus, "Offshore coral reef damage, overfishing and paths to peace in the South China Sea", *The South China Sea: An International Law Perspective, Conference Papers* (6 Mar. 2015), pp. 23-24. Annex 850.

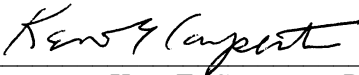
³ See Rupert Wingfield-Hayes, "Why are Chinese fishermen destroying coral reefs in the South China Sea?", *BBC* (15 Dec. 2015), available at <http://www.bbc.com/news/magazine-35106631>. Annex 862.

⁴ See Kent E. Carpenter, Ph.D., *Eastern South China Sea Environmental Disturbances and Irresponsible Fishing Practices and their Effects on Coral Reefs and Fisheries* (22 Mar. 2014), pp. 5-6, 14-15. Memorial of the Philippines, Vol. VII, Annex 240; K.E. Carpenter & L.M. Chou, *Environmental Consequences of Land Reclamation Activities on Various Reefs in the South China Sea* (14 Nov. 2015), pp. 29-32. Annex 699; Tr. (26 Nov. 2015), pp. 53:21-54:13 (Testimony by Dr. Carpenter).

dredging, with an additional 68.75 km² of coral reef having been damaged by giant clamming.

7. This clarification corroborates and, I believe, reinforces, the conclusions I expressed in my testimony, where I concluded that China's actions have caused grave harm to the marine environment, both to the individual reefs directly subject to China's artificial island-building program, and also to the health of the overall South China Sea ecosystem.

Date: 24 April 2016



Kent E. Carpenter, Ph.D.