Assessment of the potential environmental consequences of construction activities on seven reefs in the Spratly Islands in the South China Sea

Expert report of Dr. rer. nat. Sebastian C.A. Ferse, Professor Peter Mumby, PhD and Dr. Selina Ward, PhD

Table of Contents

I. Executive summary

This report reviews the scientific literature, other publicly available documents and information provided by the Permanent Court of Arbitration (PCA) with regard to large-scale Chinese construction activities on seven reefs in the Spratly Islands (Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef) from 2013 onwards.

Section II of this Report outlines the academic and professional background of the three authors. Section III provides background on the report, coral reefs, the impacts of fishing, reef accretion and island formation, and the South China Sea ecoregion.

Section IV provides an overview of the ecology and status of the Spratly Islands, and the seven affected reefs, prior to the commencement of large-scale construction activities.

In Sections V to VIII, the report further provides an overview over the types and extent of impacts from dredging and land reclamation activities, assessing the nature and extent of possible impacts on the seven affected reefs, the extent to which such impacts can be linked to the Chinese construction activities, their broader ecological ramifications, and the anticipated duration of impacts and potential for recovery of the reefs.

The remainder of the report independently assesses two previous expert reports compiled on behalf of the Philippines, as well as a number of statements by Chinese officials and scientists regarding the nature and effects of the construction activities.

The Spratly Islands are an area of high biodiversity and important fishing grounds. They are among the least impacted reefs in the South China Sea, and are very likely to play an important role in the maintenance of biodiversity and fisheries productivity in adjacent parts of the South China Sea and the Coral Triangle region. However, the area is not pristine, and has been significantly affected by anthropogenic impacts (i.e. impacts originating from human activity, such as overfishing and destructive fishing, construction activities and human habitation) for several decades prior to commencement of large-scale construction in 2013.

The construction activities have impacted reefs on a scale unprecedented in the region, and according to a 2016 study analysing satellite imagery[1] have directly destroyed up to 60% of the shallow reef habitat of the affected reefs. Construction-related sedimentation and turbidity (i.e. decreased clarity of the water) are visible from available imagery to have affected large portions of the reefs beyond the immediate area of construction. The effects of these impacts on the reefs, together with altered hydrodynamics and released nutrients, are likely to have wide-ranging and long-lasting ecological consequences for the affected reefs and the wider ecosystem of the Spratly Islands, and possibly beyond. Reefs subjected to direct land reclamation have disappeared entirely. Reefs subjected to dredging in order to create landfill will have lost their complex structure that was built over centuries to millennia. This structure will take decades to centuries to recover. Reefs that did not experience dredging directly but were impacted by the associated sedimentation and nutrient release will likely have

[1] Mora, C., Caldwell, I. R., Birkeland, C., & McManus, J. W. (2016) "Dredging in the Spratly Islands: Gaining Land but Losing Reefs," *PLoS Biology,* 14: e1002422.

experienced severe coral mortality and recovery will take place more slowly than in natural settings, likely taking decades. The capacity for ongoing biogenic (i.e. stemming from living organisms) carbonate production is severely diminished on several of the reefs, and their capacity to keep up with increasing sea level rise is impaired.

As set out in Part IX of the Report, we have found the previous two expert reports submitted by the Philippines to be generally accurate descriptions of the construction impacts, based on the available information, although in some cases we argue that the damage has been overstated, whereas in others we feel that the potential damage might be underestimated.

The reviewed statements by Chinese officials and scientists contained accurate descriptions of the environmental conditions at the reefs, but their assessments regarding the nature and extent of impacts from construction were found to be largely in disagreement with the available information. We offer specific comments that detail in what respect the statements differ from our assessment of the information.

II. About the authors

1. Sebastian C. A. Ferse

Dr. Ferse is a trained coral reef ecologist with over 10 years of research experience in Southeast Asia (particularly Indonesia), the Pacific Islands, East Africa and the Red Sea. After undergraduate and graduate studies at the Georg-August University Göttingen, the University of California at Santa Barbara and the University of Bremen, he received his doctorate degree in Marine Biology from the University of Bremen in 2008. Since then, he has worked at the Leibniz Center for Tropical Marine Ecology (ZMT) Bremen and the University of Hawaii at Manoa. His ecological work has focused largely on coral reef restoration and ecological functioning, in particular the roles of reef fishes and their link to the reef habitat. In addition, he is working on the impact of environmental and anthropogenic factors on coral reef benthic communities. Furthermore, Dr. Ferse has conducted socio-economic research on the livelihoods of reef-dependent coastal communities, fisheries and trade, and coral reef governance. He previously has coordinated a joint Indonesian-German research project addressing pollution impacts on coastal systems and coral reefs in Jakarta Bay and offshore islands. Currently, he leads an interdisciplinary working group that addresses the resilience of coral reef social-ecological coral reef systems in Melanesia, and heads a research project assessing anthropogenic influences on reef ecology in Indonesia.

Dr. Ferse has been teaching interdisciplinary and participatory research in a graduate course on tropical aquatic ecology at the University of Bremen since 2009, and has given numerous guest lectures in training courses and summer schools at universities and institutions in Europe, East Africa and Southeast Asia. He has acted as principal supervisor for 19 MSc students, 3 PhD students, and 1 post-doc, and as co-supervisor of 8 MSc/Diploma students and 14 PhD students.

Dr. Ferse has published over 30 papers in peer-reviewed journals, has served as reviewer for more than 20 scientific journals, and is regularly asked to review manuscripts on coral reef health, restoration and management. Furthermore, he has served as academic editor for the journal *PLoS ONE* since 2011 and has handled more than 100 scientific publications in that position. His CV is attached to this report.

2. Peter J. Mumby

Peter Mumby is a Professor of coral reef ecology at the University of Queensland, Australia. He obtained his PhD in 1998 having developed new ways to use satellite and airborne imagery to evaluate the health of coral reefs. After his PhD at the University of Sheffield (UK), he moved to the Universities of Newcastle (1998-2002) and Exeter (2002-2010) as a Royal Society Research Fellow. He was awarded a chair (full professorship) in 2005 at the age of 34. In 2010 he migrated to Australia to take up a prestigious ARC Laureate Fellowship and continuing appointment at the University of Queensland.

Professor Mumby's research combines field experiments, observational studies, remote sensing and ecological modelling to understand ecosystem dynamics. He uses ecological studies to parameterise ecosystem models and then ask questions about the response of reefs to disturbance and ability of management interventions to improve the outlook of reefs. He has published widely on the effects of fishing, climate change, reef resilience, marine protected areas, and ecosystem functioning.

Professor Mumby has published more than 220 peer-reviewed journal articles, including multiple articles in the prestigious journals *Science*, *Nature*, and *PNAS*. His h-index is 60 and he has more than 15,000 citations. According to Thompson-Reuters, he is ranked #1 for research productivity in the field of coral reefs in the last 5 years. He has won several awards including the Rosenstiel Award in Marine Science, a Pew Fellowship in Marine Conservation, the Marsh Award, and was recently winner of the inaugural award for contributions to reef science by a mid-career scientist by the International Society for Reef Studies. He has raised more than $25m in research funding.

Professor Mumby has advised a number of governments on coral reef and fisheries policy including Australia, Belize, the Bahamas, Bonaire, the Maldives, and Indonesia. He has chaired a remote sensing working group for the World Bank, and is currently Chief Scientist of the World Bank / GEF Capturing Coral Reef Ecosystem Services Project. Professor Mumby has advised the UNDP on coastal management, UNEP on reef resilience, and UNESCO on marine ecosystem services. He is a former President of the Australian Coral Reef Society. His CV is attached to this report.

3. Selina Ward

Dr. Selina Ward is a coral biologist working as a Senior Lecturer in the School of Biological Sciences at the University of Queensland, Australia. She completed her PhD in 1997 and completed a postdoctoral Fellowship with the University of Sydney before starting at the University of Queensland. Dr. Ward has conducted important research into the responses of corals to environmental stress including elevated nutrients, mechanical damage and elements of climate change such as ocean acidification and temperature elevations. She has been particularly interested in the early life history stages of corals.

Dr. Ward has been an advisory editor at *Coral Reefs* and is an ex-president of the Australian Coral Reef Society, where she is an active council member coordinating many submissions on important reef issues for the Australian Government. She is regularly asked to provide advice to government, industry and non-governmental organisations. She does a great deal of Australian and international media work and speaks regularly at public fora and meetings.

Dr. Ward coordinates the Stanford University in Australia program, along with other undergraduate and postgraduate courses at UQ, and supervises a number of postgraduate students. She created and ran an employee program for Rio Tinto Alcan over many years, which involved taking four groups a year to the reef for a field and lecture course on coral reefs.

Dr. Ward was the Program and Partnerships manager for the International Riversymposium for eleven years and is a board member of the International River Foundation. Her CV is attached to this report.

III. Background

The purpose of this report is to assist the Tribunal constituted at the Permanent Court of Arbitration in The Hague in the arbitration commenced by the Philippines against China by:

> examining and analysing the record submitted by the Philippines on the issue of environmental harm to coral reefs as a result of island building activities at Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef; assessing the accuracy and certainty of the scientific conclusions drawn by the Philippines and its experts; reporting on the condition of the coral reefs at Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef prior to the commencement of Chinese construction activities, and the extent to which any likely harm to the reef systems can be attributed to such activities; reporting on the nature and extent of the possible harm to coral reefs as a result of China's construction activities, as those activities are described in the record or in other publicly available sources; reporting on the broader impacts of China's construction activities on the marine ecosystem in and around the South China Sea and on fisheries resources; and reporting on the anticipated duration of likely harm to coral reefs and the prospects and likely rate at which the coral reefs in question will rejuvenate.[2]

In order to address these points adequately, this report will first begin by providing a general background on the role and ecology of coral reefs, the impacts by fishing activities, the process of reef accretion and island formation, and the resilience and capacity of coral reefs to recover. It will be followed by a brief overview of the South China Sea ecoregion, its fishery resources, and connectivity (i.e. the degree of linkage between populations of reef organisms) within the region. The points on which expert advice was sought by the Tribunal are then addressed individually.

---

[2] PCA Case No. 2013-19, The Republic of the Philippines v. The People's Republic of China, Expert Terms of Reference under Article 24 of the Rules of Procedure.

1. The importance and status of coral reefs

Tropical coral reefs are the most biodiverse marine ecosystem on our planet. Although covering less than 0.1% of the global ocean area[3], they contain about one quarter of all fish species[4]. Recent estimates put the number of multicellular species on coral reefs at between 550,000 and 1,330,000[5]. Coral reefs are a unique and valuable resource for humanity, fulfilling a range of important ecosystem functions, including fisheries production, provision of building materials, genetic resources, tourism and cultural values, coastline protection, filtering of pollution and element cycling. The total annual value of ecosystem services provided by coral reefs has been estimated at 9.9 trillion US$[6], ranging from 36,794 US$/ha/year to 2,129,122 US$/ha/year[7].

Coral reefs are highly threatened by human activities, in particular overfishing and destructive fishing, pollution and coastal development, which together pose immediate and direct threats to more than 60% of the world's reefs[8]. The situation is particularly severe in Southeast Asia, where nearly 95% of the reefs are threatened by local human activities[9]. Overall, it is estimated that 19% of the planet's reefs had already been effectively lost by 2008[10]. This has led to warnings that coral reefs may be the first ecosystem perishing worldwide as a result of human activities[11]. The international community has recognised the importance and threatened status of coral reefs in a number of initiatives and mechanisms, such as initiatives under the 1992 Convention on Biological Diversity and the Ramsar Convention on Wetlands of International Importance[12], the 1973 Convention on the International Trade in Endangered Species, the Coral Reef Unit of the United Nations Environment Programme, and the International Coral Reef Initiative.

---

[3] Spalding, M. D., Ravilious, C., & Green, E. P. (2001) *World Atlas of Coral Reefs*. Berkeley, CA, USA: University of California Press.

[4] McAllister, D. E. (1995) "Status of the World Ocean and its biodiversity," *Sea Wind,* 9: 14.

[5] Fisher, R., O'Leary, Rebecca A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, Russell E., et al. (2015) "Species Richness on Coral Reefs and the Pursuit of Convergent Global Estimates," *Current Biology,* 25: 500-505.

[6] Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., et al. (2014) "Changes in the global value of ecosystem services," *Global Environmental Change,* 26: 152-158.

[7] de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., et al. (2012) "Global estimates of the value of ecosystems and their services in monetary units," *Ecosystem Services,* 1: 50-61.

[8] Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011) *Reefs at Risk Revisited*. Washington, DC, USA: World Resources Institute (WRI).

[9] *Ibid.*

[10] Wilkinson, C., ed. (2008) *Status of Coral Reefs of the World*. Townsville, Australia: Global Coral Reef Monitoring Network (GCRMN) and Reef and Rainforest Research Centre. This is the most recent global assessment and does not yet consider the impacts of the 2010 bleaching event affecting large parts of Southeast Asia, or of the current bleaching event with effects around the globe.

[11] Cesar, H. S. J. (2000) "Coral reefs: their functions, threats and economic value," In *Collected Essays on the Economics of Coral Reefs,* edited by H. S. J. Cesar. Kalmar, Sweden: CORDIO, Kalmar University.

[12] Goodwin, E. J. (2011) *International Environmental Law and the Conservation of Coral Reefs*. Oxon, UK: Routledge/Taylor & Francis.

2. Resilience and recovery of coral reefs

Coral reefs have a certain capacity to absorb and recover from stressors and disturbance, which is termed their resilience[13]. If this capacity is exceeded, reefs can shift in their composition to alternative states characterised by reduced biodiversity, structural complexity, and a reduction or loss of coral cover. Resilience is context-dependent and is lowered by exposure to chronic stressors, such as nutrient enrichment or overfishing, loss of biodiversity, and reduced connectivity[14]. Impacted reefs can become locked in a degraded state by a number of feedback loops (i.e. mutually reinforcing or dampening ecological processes) that prevent recovery once certain thresholds are crossed[15]. For example, seaweeds can prevent the successful recruitment of coral larvae, overwhelm the capacity of herbivores to reduce them, outcompete stony corals, and thus reduce the structural complexity of reefs, further decreasing fish biomass[16]. Fish populations can also be adversely affected by loss of live coral cover, with a 60% decline in fish abundance across all functional groups observed following loss of at least 10% coral cover[17]. Additionally, loose coral rubble following mass-mortality of branching corals forms an unstable substrate (i.e. cover of the seafloor) that is unsuitable for the successful resettlement by coral larvae[18]. As a result, rubble fields generated by blast fishing may take decades to recover[19].

Related to the concept of resilience is the capacity of reefs to recover. While resilience encompasses the extent to which stressors can act upon a system without causing a fundamental change in its composition or structure (sometimes termed *resistance*), capacity to recover specifically relates to the extend and speed with which a system can rebound to its former state once it has been impacted (sometimes used as a more narrow definition of resilience, *engineering resilience*)[20]. While the resilience concept considers the existence of multiple possible configurations of a system (such as reefs dominated by stony corals, and those on which seaweeds have taken over), recovery capacity is concerned with the return to one particular system configuration. This capacity depends on the nature and extent of damage, and on the environmental setting of the impacted reef, including the presence and

---

[13] Nyström, M., Folke, C., & Moberg, F. (2000) "Coral reef disturbance and resilience in a human-dominated environment," *Trends in Ecology & Evolution,* 15: 413-417.

[14] McClanahan, T. R., Polunin, N. V. C., & Done, T. J. (2002) "Ecological states and the resilience of coral reefs," *Conservation Ecology,* 6: 18.

[15] Mumby, P. J., & Steneck, R. S. (2008) "Coral reef management and conservation in light of rapidly evolving ecological paradigms," *Trends in Ecology & Evolution,* 23: 555-563; Nyström, M., Norström, A., Blenckner, T., de la Torre-Castro, M., Eklöf, J., Folke, C., et al. (2012) "Confronting Feedbacks of Degraded Marine Ecosystems," *Ecosystems,* 15: 695-710.

[16] Mumby & Steneck *op. cit.* ref. 15.

[17] Pratchett, M. S., Hoey, A. S., Wilson, S. K., Messmer, V., & Graham, N. A. J. (2011) "Changes in biodiversity and functioning of reef fish assemblages following coral bleaching and coral loss," *Diversity,* 3: 424-452.

[18] Yadav, S., Rathod, P., Alcoverro, T., & Arthur, R. (2016) "“Choice” and destiny: the substrate composition and mechanical stability of settlement structures can mediate coral recruit fate in post-bleached reefs," *Coral Reefs,* 35: 211-222.

[19] Fox, H. E., & Caldwell, R. L. (2006) "Recovery from blast fishing on coral reefs: a tale of two scales," *Ecological Applications,* 16: 1631-1635; Hernández-Delgado, E. A., Montañez-Acuña, A., Otaño-Cruz, A., & Suleimán-Ramos, S. E. (2014) "Bomb-cratered coral reefs in Puerto Rico, the untold story about a novel habitat: from reef destruction to community-based ecological rehabilitation," *Revista de Biologia Tropical,* 62: 350-367.

[20] Nyström, M., Graham, N., Lokrantz, J., & Norström, A. (2008) "Capturing the cornerstones of coral reef resilience: linking theory to practice," *Coral Reefs,* 27: 795-809.

persistence of stressors[21]. The availability of coral larvae and their ability to settle and survive are a crucial factor for reef recovery. In degraded areas with unstable substrate, sediment cover, and the presence of thick turf algae, coral larvae have a decreased likelihood of settlement and survival[22]. If disturbances are of limited temporal and spatial extent, the reef is in healthy condition, there is an abundant supply of coral larvae, and external stressors are low and infrequent, recovery of reef communities can take place within 10-20 years[23] (although populations of massive corals such as *Porites* may take several centuries to recover fully[24]). However, if chronic stressors persist (or acute stressors reoccur frequently), recovery may not occur at all.

3. Fishing impacts on reefs

Coral reefs are intensely targeted by a range of fishing and other marine resource extraction activities. The amount of biomass that can be sustainably harvested from a coral reef varies widely depending on local environmental context and ecological integrity of the reef (from 0.1-44 $t/km^2/year$)[25], but for healthy reefs is estimated to be in the order of 5-10 $t/km^2/year$[26]. This includes both finfish and invertebrates. Similar to other fisheries, fishing activities on coral reefs tend to remove larger, long-lived species high in the food chain first[27]. While at a lower trophic level (i.e. feeding lower in the food chain), large herbivorous species tend to be primary fisheries targets as well[28]. As ecological function (such as feeding impact) and

[21] Endean, R. (1976) "Destruction and recovery of coral reef communities," In *Biology and Geology of Coral Reefs,* edited by O. A. Jones & R. Endean. New York, NY, USA; San Francisco, CA, USA; London, UK: Academic Press.; Pearson, R. G. (1981) "Recovery and recolonization of coral reefs," *Marine Ecology Progress Series,* 4: 105-122; Done, T. J. (1988) "Simulation of recovery of pre-disturbance size structure in populations of *Porites* spp. damaged by the crown of thorns starfish *Acanthaster planci*," *Marine Biology,* 100: 51-61.

[22] Birrell, C. L., McCook, L. J., & Willis, B. L. (2005) "Effects of algal turfs and sediment on coral settlement," *Marine Pollution Bulletin,* 51: 408-414; Arnold, S. N., Steneck, R. S., & Mumby, P. J. (2010) "Running the gauntlet: inhibitory effects of algal turfs on the processes of coral recruitment," *Marine Ecology Progress Series,* 414: 91-105.

[23] Endean *op. cit.* ref. 21; Pearson *op. cit.* ref. 21; Halford, A., Cheal, A. J., Ryan, D., & Williams, D. M. (2004) "Resilience to large-scale disturbance in coral and fish assemblages on the Great Barrier Reef," *Ecology,* 85: 1892-1905; Adjeroud, M., Michonneau, F., Edmunds, P. J., Chancerelle, Y., Loma, T. L., Penin, L., et al. (2009) "Recurrent disturbances, recovery trajectories, and resilience of coral assemblages on a South Central Pacific reef," *Coral Reefs,* 28: 775-780.

[24] Done *op. cit.* ref. 21.

[25] McAllister, D. E. (1988) "Environmental, economic and social costs of coral reef destruction in the Philippines," *Galaxea, Journal of Coral Reef Studies,* 7: 161-178; Dalzell, P. (1996) "Catch rates, selectivity and yields of reef fishing," In *Reef Fisheries,* edited by N. V. C. Polunin & C. M. Roberts. London, UK: Chapman and Hall.

[26] Warren-Rhodes, K., Sadovy, Y., & Cesar, H. (2003) "Marine Ecosystem Appropriation in the Indo-Pacific: A Case Study of the Live Reef Fish Food Trade," *AMBIO: A Journal of the Human Environment,* 32: 481-488; Newton, K., Côté, I. M., Pilling, G. M., Jennings, S., & Dulvy, N. K. (2007) "Current and Future Sustainability of Island Coral Reef Fisheries," *Current Biology,* 17: 655-658.

[27] Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F. (1998) "Fishing Down Marine Food Webs," *Science,* 279: 860-863; Myers, R. A., & Worm, B. (2003) "Rapid worldwide depletion of predatory fish communities," *Nature,* 423: 280-283; Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., et al. (2011) "Trophic Downgrading of Planet Earth," *Science,* 333: 301-306; McClanahan, T. R., Graham, N. A. J., MacNeil, M. A., & Cinner, J. E. (2014) "Biomass-based targets and the management of multispecies coral reef fisheries," *Conservation Biology,* 29: 409-417.

[28] Bejarano, S., Golbuu, Y., Sapolu, T., & Mumby, P. J. (2013) "Ecological risk and the exploitation of herbivorous reef fish across Micronesia," *Marine Ecology Progress Series,* 482: 197-215.

reproductive output usually increase with body size in a non-linear way[29], the removal of larger species and individuals has disproportional and wide-ranging effects on the ecosystem[30].

As herbivorous fishes play an important role in controlling seaweeds on reefs, which are direct and often superior competitors of stony corals, and free space for the settlement of coral larvae[31], the removal of herbivorous fishes decreases the capacity of reefs to maintain a healthy coral cover[32]. Indeed, there are indications that both the ratio of stony corals to seaweeds and the percent cover of seaweeds on reefs begin to be negatively affected at levels of fishable biomass that are still above those for maximum sustainable yield, underlining the sensitivity of herbivore-reef relations to fishing impacts[33].

Cyanide and blast fishing are highly destructive methods that have been widely used in Southeast Asia over the past decades, including the Spratly Islands. In addition, stony corals are frequently harvested as construction material, or for sale in the curio trade, e.g. to tourists. The repeated, targeted removal of coral colonies can modify the community structure[34] – branching species are preferably targeted for the curio trade, and their removal leads to an overall loss of structural complexity. Decreased live coral cover and structural complexity severely affects the reef fish community[35], as a large proportion of the species on the reef utilise live corals at some point in their life history[36].

---

[29] Blueweiss, L., Fox, H., Kudzma, V., Nakashima, D., Peters, R., & Sams, S. (1978) "Relationships between body size and some life history parameters," *Oecologia,* 37: 257-272; Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V., Micheli, F., Brumbaugh, D. R., et al. (2006) "Fishing, Trophic Cascades, and the Process of Grazing on Coral Reefs," *Science,* 311: 98-101; Lokrantz, J., Nyström, M., Thyresson, M., & Johansson, C. (2008) "The non-linear relationship between body size and function in parrotfishes," *Coral Reefs,* 27: 967-974.
[30] Mumby et al. *op. cit.* ref. 29; Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008) "Predicting ecological consequences of marine top predator declines," *Trends in Ecology & Evolution,* 23: 202-210.
[31] Bellwood, D. R., Hughes, T. P., Folke, C., & Nyström, M. (2004) "Confronting the coral reef crisis," *Nature,* 429: 827-833.
[32] Steneck, R. S., Arnold, S. N., & Mumby, P. J. (2014) "Experiment mimics fishing on parrotfish: insights on coral reef recovery and alternative attractors," *Marine Ecology Progress Series,* 506: 115-127; Mumby, P. J., Steneck, R. S., Adjeroud, M., & Arnold, S. N. (2015) "High resilience masks underlying sensitivity to algal phase shifts of Pacific coral reefs," *Oikos*: in press.
[33] McClanahan, T. R., Graham, N. A. J., MacNeil, M. A., Muthiga, N. A., Cinner, J. E., Bruggemann, J. H., et al. (2011) "Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries," *Proceedings of the National Academy of Sciences,* 108: 17230-17233; Bozec, Y.-M., O'Farrell, S., Bruggemann, J. H., Luckhurst, B. E., & Mumby, P. J. (2016) "Tradeoffs between fisheries harvest and the resilience of coral reefs," *Proceedings of the National Academy of Sciences*: in press.
[34] Cinner, J. E., Marnane, M. J., McClanahan, T. R., Clark, T. H., & Ben, J. (2005) "Trade, Tenure, and Tradition: Influence of Sociocultural Factors on Resource Use in Melanesia," *Conservation Biology,* 19: 1469-1477.
[35] Wilson, S. K., Graham, N. A. J., Pratchett, M. S., Jones, G. P., & Polunin, N. V. C. (2006) "Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient?," *Global Change Biology,* 12: 2220-2234; Pratchett, M. S., Munday, P. L., Wilson, S. K., Graham, N. A. J., Cinner, J. E., Bellwood, D. R., et al. (2008) "Effects of climate-induced coral bleaching on coral-reef fishes - ecological and economic consequences," *Oceanography and Marine Biology: an Annual Review,* 46: 251-296.
[36] Jones, G. P., McCormick, M. I., Srinivasan, M., & Eagle, J. V. (2004) "Coral decline threatens fish biodiversity in marine reserves," *Proceedings of the National Academy of Sciences of the United States of America,* 101: 8251-8253; Coker, D. J., Wilson, S. K., & Pratchett, M. S. (2014) "Importance of live coral habitat for reef fishes," *Reviews in Fish Biology and Fisheries,* 24: 89-126.

Sea cucumbers play an important role in the bioturbation (i.e. the digging and mixing of sediments by living organisms) and filtration of reef sediments. Their removal via overharvesting has been shown to be detrimental to tropical seagrass areas and is likely to have significant consequences for the element cycling and filtering capacities of reef sediments[37], and has been hypothesized to decrease the capacity of reefs to cope with nutrient inputs[38].

Giant clams have historically been harvested widely throughout Southeast Asia and beyond, both for their meat and their shells. The larger species can reach considerable sizes (the largest species, *Tridacna gigas*, can reach almost 1.5m in size and a weight of over 300kg[39]), but they grow slowly. Thus, large individuals have become rare on most reefs. As their shells are highly coveted, collectors have begun to target fossil shells buried in the reef flat (the shallow, extensive habitat on top of reefs). Excavation is highly destructive, with early reports showing a drop in coral cover by 95% from its original value[40]. More recently, fishermen in the South China Sea are reported to utilise the propellers of their boats to excavate shells from reef flats in the Spratly Islands on an industrial scale, leading to near-complete destruction of the affected reef areas[41].

While coral reefs may withstand the moderate removal of organisms from different trophic levels[42], the overharvesting of key groups such as herbivores, and the combined impacts of fishing on multiple groups, erodes the resilience of reefs towards disturbance[43].

4. Reef accretion and island formation

The natural process of island formation builds on the physical and biological erosion of biologically-generated carbonate structures. As the eroded materials supply sediments for the build-up of island structures, new carbonate structures are constantly generated in a "biological sediment factory"[44]. While the growth rate of individual corals ranges from a few

---

[37] Uthicke, S. (1999) "Sediment bioturbation and impact of feeding activity of *Holothuria (Halodeima) atra* and *Stichopus chloronotus*, two sediment feeding holothurians, at Lizard Island, Great Barrier Reef," *Bulletin of Marine Science,* 64: 129-141; Alongi, D. M., Pfitzner, J., & Trott, L. A. (2006) "Deposition and cycling of carbon and nitrogen in carbonate mud of the lagoons of Arlington and Sudbury Reefs, Great Barrier Reef," *Coral Reefs,* 25: 123-143; Wolkenhauer, S.-M., Uthicke, S., Burridge, C., Skewes, T., & Pitcher, C. R. (2010) "The ecological role of *Holothuria scabra* (Echinodermata: Holothuroidea) within subtropical seagrass beds," *Journal of the Marine Biological Association of the United Kingdom,* 90: 215-223.

[38] Albert, S., Grinham, A., Dunbabin, M., Bird, B., Moore, B., Jimuru, M., et al. (2011) "Preliminary assessment of a large fish kill in Marovo Lagoon, Solomon Islands," In. Brisbane, Australia: University of Queensland.

[39] Knop, D. (1996) *Giant Clams. A comprehensive Guide to the Identification and Care of Tridacnid Clams*. Ettlingen, Germany: Dähne Verlag GmbH.

[40] Lachmuddin, S. (1987) "The exploration of giant clam fossils on the fringing reef areas of Karimun Jawa Islands," *Biotrop Special Publication,* 29: 59-64.

[41] Wingfield-Hayes, R. (2015) "Why are Chinese fishermen destroying coral reefs in the South China Sea?," *BBC News* 15. December 2015; Lee, V. R. (2016) "Satellite Imagery Shows Ecocide in the South China Sea," *The Diplomat* January 15, 2016; McManus, J. W. (2015) "Offshore coral reef damage, overfishing and paths to peace in the South China Sea," Paper presented at the conference *The South China Sea: An International Law Perspective* on March 06, 2015. Brussels, Belgium. Revised version: 21. April 2016.

[42] Jennings, S., & Polunin, N. V. C. (1996) "Impacts of fishing on tropical reef ecosystems," *Ambio,* 25: 44-49.

[43] McClanahan et al. *op. cit.* ref. 33; Mellin, C., Aaron MacNeil, M., Cheal, A. J., Emslie, M. J., & Julian Caley, M. (2016) "Marine protected areas increase resilience among coral reef communities," *Ecology Letters*: in press.

[44] *Ibid.*

mm to more than 15 cm per year[45], reef growth is a much slower process still, as reefs grow by the slow accumulation and sedimentation of carbonate material precipitated by living organisms and eroded by biological and physical factors. Thus, reefs grow only a few mm per year, with those in the Indo-Pacific growing slower than those in the Caribbean, in the range of 2-8 mm per year[46]. The long-term integrity of reef islands depends on the balance between carbonate accretion and erosion[47]. While healthy reefs are able to keep up with moderate increases in sea level and may even increase in extent[48], degradation of the biological sediment factory threatens the long-term integrity of the reefs, reducing or eliminating their potential to keep up with predicted sea level rises[49].

5. The South China Sea ecoregion

The South China Sea is classified as one of South-East Asia's Large Marine Ecosystems[50]. This means that it forms a distinct unit based on four linked ecological criteria, i.e. (i) bathymetry, (ii) hydrography, (iii) productivity, and (iv) trophic relationships[51]. It also entails that management of the area requires regional coordination, and that ecological processes within the area need to be considered from a regional perspective, as high interlinkages between the subcomponents of the ecoregion are expected. These linkages comprise both links between populations and ecosystems in terms of living organisms (i.e. connectivity) as well as physical links via current systems that can disperse water masses and substances therein (e.g. pollutants) over large areas and national boundaries. There are a number of ecological subregions within the South China Sea, with distinct faunal assemblages[52]. Connectivity between these subregions is largely dependent on the current regime in the South China Sea, to the effect that some subregions show strong larval connectivity (i.e. unidirectional or bidirectional transfer of larvae), while there are limited linkages among others. Several lines of evidence indicate that the Spratly Islands constitute an important

---

[45] Dullo, W.-C. (2005) "Coral growth and reef growth: a brief review," *Facies,* 51: 33-48.
[46] *Ibid.*
[47] Perry, C. T., Spencer, T., & Kench, P. S. (2008) "Carbonate budgets and reef production states: a geomorphic perspective on the ecological phase-shift concept," *Coral Reefs,* 27: 853-866.
[48] Webb, A. P., & Kench, P. S. (2010) "The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific," *Global and Planetary Change,* 72: 234-246.
[49] Perry et al. *op. cit.* ref. 47; Perry, C. T., Murphy, G. N., Kench, P. S., Smithers, S. G., Edinger, E. N., Steneck, R. S., et al. (2013) "Caribbean-wide decline in carbonate production threatens coral reef growth," *Nature Communications,* 4: 1402.
[50] Sherman, K., & Hempel, G. (2009) "The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas," *UNEP Regional Seas Report and Studies 182*. Nairobi, Kenya: United Nations Environment Programme.
[51] Sherman, K., & Alexander, L. (1986) "Variability and management of large marine ecosystems," *AAAS Selected Symposium 99*. Boulder, CO, USA: Westview Press, Inc.
[52] Huang, D., Licuanan, W. Y., Hoeksema, B. W., Chen, C. A., Ang, P. O., Huang, H., et al. (2015) "Extraordinary diversity of reef corals in the South China Sea," *Marine Biodiversity,* 45: 157-168; Chen, C. A., Ablan, M. C. A., McManus, J. W., Bell, J., Tuan, V. S., Cabanban, A. S., et al. (2004) "Population Structure and Genetic Variability of Six Bar Wrasse (*Thallasoma hardwicki*) in Northern South China Sea Revealed by Mitochondrial Control Region Sequences," *Marine Biotechnology,* 6: 312-326; Lane, D. J. W., Marsh, L. M., VandenSpiegel, D., & Rowe, F. W. E. (2000) "Echinoderm fauna of the South China Sea: an inventory and analysis of distribution patterns," *The Raffles Bulletin of Zoology,* Supplement 8: 459-493.

source of larvae for coastal reefs in the western, northern and eastern parts of the South China Sea[53].

The South China Sea region borders the Coral Triangle, the global centre of marine biodiversity. It features an extremely high diversity of habitats and species, although detailed numbers are notoriously difficult to arrive at due to a lack of research, and lack of international scientific publications, on parts of the region likely to host the highest number of species[54]. Published species numbers for the region include 571 species of stony corals[55], 3365 species of marine fishes[56], more than 1500 species of sponges (of which the large majority appears to be endemic to the region)[57], 982 species of echinoderms (12% of which are endemic to the region)[58], 45 mangrove species, 20 seagrass species, and 7 species of giant clams[59].

The South China Sea furthermore is an important fisheries area, with a reported 6 million tonnes of annual landings[60]. Pelagic (i.e. occurring in the open sea), transnational stocks of yellowfin tuna, mackerel, billfishes, anchovies and several shark species, as well as demersal species such as groupers, some sharks, penaeid shrimps, giant clams and sea cucumbers are important commercial groups[61]. As a result of rapid economic development, population growth, and challenges for fisheries management arising from inadequate enforcement and the contested nature of jurisdiction over large parts of the South China Sea, the marine resources of the region are severely overharvested[62]. The biologist John McManus has estimated that the coastlines of the South China Sea are fished at more than twice the level that they should be for maximum economic benefit and ecological sustainability[63]. Using trophic modelling and fisheries- and satellite-derived data on biomass and primary productivity, scientists at the Fisheries Center in Vancouver in 2003 estimated that in the previous 40 years, the abundance of organisms at trophic levels >3 (i.e. the majority of

---

[53] McManus, J. W. (1994) "The Spratly Islands: A Marine Park?," *AMBIO,* 23: 181-186; Huang et al. *op. cit.* ref. 52; Dorman, J. G., Castruccio, F. S., Curchitser, E. N., Kleypas, J. A., & Powell, T. M. (2016) "Modeled connectivity of *Acropora millepora* populations from reefs of the Spratly Islands and the greater South China Sea," *Coral Reefs,* 35: 169-179.

[54] Morton, B., & Blackmore, G. (2001) "South China Sea," *Marine Pollution Bulletin,* 42: 1236-1263.

[55] Huang et al. *op. cit.* ref. 52.

[56] Randall, J. E., Lim, K. K. P., & (eds.). (2000) "A checklist of the fishes of the South China Sea," *The Raffles Bulletin of Zoology,* Supplement 8: 569-667.

[57] Hooper, J. N. A., Kennedy, J. A., & van Soest, R. W. M. (2000) "Annotated checklist of sponges (Porifera) of the South China Sea region," *The Raffles Bulletin of Zoology,* Supplement 8: 125-207.

[58] Lane et al. *op. cit.* ref. 52.

[59] Morton & Blackmore *op. cit.* ref. 54.

[60] Heileman, S. (2009) "South China Sea LME," In *The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas,* edited by K. Sherman & G. Hempel. Nairobi, Kenya: United Nations Environment Programme.

[61] *Ibid*; Valencia, M. J. (1991) "Coastal area management in ASEAN: the transnational issues," In *Towards an Integrated Management of Tropical Coastal Resources,* edited by L. M. Chou, T.-E. Chua, H. W. Khoo, P. E. Lim, J. N. Paw, G. T. Silvestre, M. J. Valencia, A. T. White & P. K. Wong. Singapore: National University of Singapore; National Science and Technology Board, Singapore; ICLARM, Philippines; Rosenberg, D. (2009) "Fisheries Management in the South China Sea," In *Security and International Politics in the South China Sea: Towards a Co-operative Management Regime,* edited by S. Bateman & R. Emmers. Oxon, UK: Routledge, Taylor & Francis.

[62] Rosenberg *op. cit.* ref. 61; Khemakorn, P. (2006) "Sustainable Management of Pelagic Fisheries in the South China Sea Region," New York, USA: United Nations.

[63] McManus *op. cit.* ref. 41.

commercially-targeted fish species, except small pelagics) had decreased by 60%[64]. Most of the inshore coral reefs, mangroves and seagrass habitats are threatened or degraded, and the least impacted coral reefs of the region remain in parts of the Philippines and the offshore reefs and atolls of the Pratas, Paracel and Spratly Islands[65].

IV. Condition of the coral reefs at Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef prior to the commencement of Chinese construction activities

There are very few studies that have been conducted on the seven reefs affected by the recent Chinese construction activities, and the majority of them have been carried out by Chinese scientists and are usually published in Chinese. Where we were able to locate the latter, we had to rely mostly on English abstracts or translation provided by Google Translate, and in some instances on unofficial courtesy English translations provided by the PCA. More information is available on the general condition of the Spratly Islands, and as it likely reflects the conditions at the seven reefs prior to the commencement of construction, that information is thus summarized first, before describing what is known for each reef in turn.

The Spratly Islands consist of 117 reefs, including 64 atolls (43 of which are exposed at low tide). The total area of reef flat is around 508 km^2, with an additional 31 km^2 of fore-reef (i.e. outward-facing reef slope). Most of the coral reefs in the area are lagoonal reefs, comprising an area of 2397 km^2 in total[66]. The shallow reef flat of many reefs likely contains seagrass meadows[67], but beyond a general estimate that seagrass areas in the Spratly Islands cover at least 22 km^2, little information exists on their species composition or spatial distribution[68]. Coral reefs on the atolls follow a general ecological zonation. The six distinct zones are (I) reef-front living coral zone (also fore-reef or outer slope), (II) outer reef flat coral zone, (III) reef-ridge coral-branch-cemented zone, (IV) inner reef flat branching-coral/sand zone, (V) lagoon slope branching-coral/fine-sand zone, and (VI) lagoon basin-floor silt zone. The ecological zonation described here is for Fiery Cross Reef, but according to Liu et al. the

---

[64] Christensen, V., Garces, L. R., Silvestre, G. T., & Pauly, D. (2003) "Fisheries impact on the South China Sea Large Marine Ecosystem: a preliminary analysis using spatially-explicit methodology," In *Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries,* edited by S. G. T., L. R. Garces, I. Stobutzki, M. Ahmed, R. A. Valmonte-Santos, C. Z. Luna, L. Lachica-Aliño, P. Munro, V. Christensen & P. D.: WorldFish Center Conference Proceedings 67.

[65] Huang et al. *op. cit.* ref. 52; Morton & Blackmore *op. cit.* ref. 54.

[66] Liu, Z., Huang, W., Li, J., Wang, P., Wang, R., Yu, K., et al. (2009) "Sedimentology," In *The South China Sea: Paleoceanography and Sedimentology,* edited by P. Wang & Q. Li. Dordrecht, The Netherlands: Springer Netherlands.

[67] Dai, C.-F., & Fan, T.-Y. (1996) "Coral fauna of Taiping Island (Itu Aba Island) in the Spratlys of the South China Sea," *Atoll Research Bulletin,* 436: 1-21; Rollon, R. N., Cayabyab, N. M., & Fortes, M. D. (2001) "Vegetative dynamics and sexual reproduction of monospecific *Thalassia hemprichii* meadows in the Kalayaan Island Group," *Aquatic Botany*, 71: 239-246.

[68] Fortes, M. D. (2004) "National Report on Seagrass in the South China Sea - Philippines," In. Bangkok, Thailand: UNEP/GEF South China Sea Project; Zheng, F., Qiu, G., Fan, H., & Zhang, W. (2013) "Diversity, distribution and conservation of Chinese seagrass species," *Biodiversity Science,* 21: 517-526 [in Chinese; unofficial translation using GoogleTranslate].

zonation applies in similar form to the other seven reefs[69]. In Fiery Cross Reef, the outer slope naturally has the highest coral diversity and can have up to 90% coral cover, predominantly of branching *Pocillopora* and *Acropora* species. The outer reef flat zone usually has less live coral cover and smaller coral colonies, mostly of massive and branching species <30cm in diameter. The narrow reef ridge consists of broken rubble and dead coral branches thrown up by winds and wave action, and is exposed at low tide. The inner reef flat zone is the widest part of an atoll, with shallow waters and an increasing cover of corals, usually of hardy species, but subject to frequent mass mortalities due to temperature increases in the shallow water[70]. Destructive fishing and other disturbance can greatly reduce the coral cover on the outer slope, so that the reef flat is the area with the highest coral cover, in some cases above 50%[71]. The lagoon slope is usually shallow, with a sandy bottom, and often finely-branched coral species that benefit from the calmer water conditions, as well as a few massive *Porites* colonies. Lastly, the lagoon basin is deeper, mostly covered with silt, and has very few living corals[72].

A total of 333 stony coral species[73] and 205 echinoderm species[74] have been recorded from the Spratly Islands. As described above, the reefs of the Spratly Islands are generally seen to be among the least affected by human activities in the South China Sea[75]. However, they have been affected by both anthropogenic and environmental impacts over the past decades. More than 40 of the reefs and islands have been occupied by military installations or outposts from several countries for at least two decades, and impacts on reef environments such as shooting of seabirds and turtles, fishing in the surrounding reefs, trampling of corals and use of explosives for fishing have been attributed to the personnel stationed on the reefs[76]. From 1985 onwards, fishers from southern China increasingly targeted the Spratly Islands, and in the following 13 years, around 2200 fishing vessels went to fish among the islands. In recent years, fishing has developed increasingly rapid, and in 2001, there were 556 fishing vessels from Guangxi, Hainan, Hong Kong and Macao fishing in the Spratly Islands[77]. Already in the 1970s, cyanide fishing operations targeting large groupers and wrasses for Hong Kong markets had swept through the Spratly Islands and depleted the stocks of these top reef carnivores[78]. Blast fishers and coral-smashing muro-ami fishers from the Philippines have caused severe local damage on a number of reefs in the Spratly Islands[79]. As evidenced by the various accounts of arrests and inspections of fishers on reefs of the South China Sea over the

[69] Yu, K.-F., Zhao, J.-X., Collerson, K. D., Shi, Q., Chen, T.-G., Wang, P.-X., et al. (2004) "Storm cycles in the last millennium recorded in Yongshu Reef, southern South China Sea," *Palaeogeography, Palaeoclimatology, Palaeoecology,* 210: 89-100; Liu et al. *op. cit.* ref. 66.
[70] *Ibid.*
[71] Dai & Fan *op. cit.* ref. 67.
[72] Liu et al. *op. cit.* ref. 66.
[73] Huang et al. *op. cit.* ref. 52.
[74] Lane et al. *op. cit.* ref. 52.
[75] Morton & Blackmore *op. cit.* ref. 54.
[76] McManus *op. cit.* ref. 53.
[77] Zhao, H.-T., & Wu, T.-Q. (2008) "Some ideas about further development of the Xisha, Nansha and Zhongsha Islands," *Tropical Geography,* 28: 369-375 [in Chinese; unofficial translation using GoogleTranslate].
[78] Johannes, R. E., & Riepen, M. (1995) "Environmental, Economic, and Social Implications of the Live Reef Fish Trade in Asia and the Western Pacific," Arlington, VA, USA: The Nature Conservancy.
[79] McManus *op. cit.* ref. 53.

past three decades (Scarborough Shoal and Second Thomas Shoal), listed in the Annexes from the arbitration, sharks, sea turtles and giant clams have been targeted intensively, and live corals have been removed from many reefs in the area[80]. In recent years, the excavation of clam shells with the aid of boat propellers appears to have taken place on a number of reefs in the Spratly Islands, resulting in extensive damage of shallow reef flats[81]. Joint Vietnamese-Philippine research expeditions to the Spratly Islands in the years 1996, 2000 and 2005 found severely depleted stocks of target species such as Caesionidae (Fusiliers, targeted in blast and muro-ami fishing), a reduced size of groupers, and noted an absence of sea cucumbers, lobsters, pearl oysters, turtles, sea snakes, large predators, manta rays and sharks (while this does not mean these species were truly absent from the area, it indicates that stocks were at least severely depleted). Four of seven giant clam species occurring in the South China appeared locally extinct. However, except for localised damage, the coral cover was reported to still be in good condition[82].

The Spratly Islands have been affected by elevated sea surface temperatures caused by the El Niño phenomenon in 1998-1999 and 2006-2007, leading to bleaching and mortality of corals in the area[83]. Recent analyses of coral cores taken from massive coral colonies at Mischief and Fiery Cross Reefs suggest that temperature-related mortalities might have affected the Spratly Islands repeatedly over the past two centuries[84]. A study by the Chinese Academy of Sciences in 2007 found widespread bleaching of corals, and noted an outbreak of the coral-eating Crown-of-Thorn Starfish[85]. While this coral predator occurs naturally on coral reefs in low densities and mass outbreaks may result naturally from connectivity patterns among populations[86], it is hypothesised that mass outbreaks are also driven by eutrophication, i.e. an increase of nutrients in the water usually linked to terrestrial run-off (leading to increased larval survival), and overfishing of its main predators, Triton shells (*Charonia* sp.) and Humphead Wrasse (*Cheilinus undulatus*). A recent meta-analysis of published data for the South China Sea by Chinese and Australian scientists found that coral

---

[80] Various reports of arrests and searches as provided in the Annex materials [see Annex 28-32, 41, 45, 46, 49, 50-52, 55 (which shows pictures of fossil clam shells most likely excavated from the reef), 57 (which shows pictures of corals and clams that were harvested live, as well as fossil clam shells), 58, 59, 77-80, 414]; Hughes, T. P., Huang, H. U. I., & Young, M. A. L. (2013) "The Wicked Problem of China's Disappearing Coral Reefs," *Conservation Biology,* 27: 261-269.

[81] Wingfield-Hayes *op. cit.* ref. 41; Lee *op. cit.* ref. 41; McManus *op. cit.* ref. 41; Annex 860. Prof. John McManus estimates that a total of 68.8km^2 of shallow reef area have been damaged throughout the Greater Spratly Islands (including Scarborough Reef) from clam excavation using boat propellers.

[82] Pal, A. (2007) "Spratlys Fish Stocks Dwindling, Say Scientists," *Philippine Daily Inquirer* 03. May 2007.

[83] McManus, J. W., Shao, K.-T., & Lin, S.-Y. (2010) "Toward Establishing a Spratly Islands International Marine Peace Park: Ecological Importance and Supportive Collaborative Activities with an Emphasis on the Role of Taiwan," *Ocean Development & International Law,* 41: 270-280.

[84] Yu, K.-F., Zhao, J.-X., Shi, Q., Chen, T.-G., Wang, P.-X., Collerson, K. D., et al. (2006) "U-series dating of dead Porites corals in the South China sea: Evidence for episodic coral mortality over the past two centuries," *Quaternary Geochronology,* 1: 129-141.

[85] Feng, X.-j., Yang, Q., Li, Y.-q., & Ao, L. (2011) "Survey and protection countermeasure on ecosystem of coral reef in Nansha coral reef," *Journal of Logistical Engineering University,* 27: 68-71 [in Chinese; unofficial translation provided by PCA].

[86] Hock, K., Wolff, N. H., Condie, S. A., Anthony, K. R. N., & Mumby, P. J. (2014) "Connectivity networks reveal the risks of crown-of-thorns starfish outbreaks on the Great Barrier Reef," *Journal of Applied Ecology,* 51: 1188-1196.

cover declined dramatically in the offshore reefs during just the past decade, from over 60% to around 20%, and is now not much higher than for inshore reefs in the region[87].

A Chinese survey of Fiery Cross Reef, Mischief Reef, Cuarteron Reef, Subi Reef and Johnson Reef in 2009-2010 underlined that the general trend of coral decline in the Spratly Islands is reflected on these five reefs as well, citing heavy overfishing and destructive fishing, together with localised impacts from construction activities, as the main causes of decline[88].

1. Cuarteron Reef

Cuarteron Reef is an elongate, ellipse-shaped reef extending roughly 5km along an axis from west to east, with a total area of around 6km^2, lacking a lagoon, and with a shallow reef flat area of less than 0.5m depth[89]. During two fishery surveys among the seven reefs considered here conducted in 1998 and 1999, Cuarteron was recorded as having the highest abundance of fish caught by handline (which targets carnivorous species at higher trophic levels)[90]. The same surveys concluded that Cuarteron and Fiery Cross Reefs were abundant in reef fish resources and had the highest exploitation potential of the seven reefs, indicating that species such as sharks, parrotfishes and groupers were still relatively abundant[91]. The 2009-2010 survey reported a mean live coral cover of around 10% on the reef flat of Cuarteron Reef, with higher coral cover on the outer slope[92]. However, as that survey did not specify the sampling methodology, or the location of sampling points, its coral cover estimates have to be regarded with caution. According to an assessment of satellite imagery by the journalist Victor Lee, the reef flat of Cuarteron Reef was subject to intense clam shell mining operations in March 2014, involving a total of 89 boats using their propellers to dig up the substrate of the shallow reef[93].

2. Fiery Cross Reef

Fiery Cross Reef is an open spindle-shaped atoll that extends for about 25km from northeast to southwest, with a width of about 6km from northwest to southeast. An extensive reef flat in the southwest, surrounding a small closed lagoon in its centre (380m long and 150m wide, with a maximum depth of 12m)[94], is the location of the recent Chinese construction activities. The present coral reef on Fiery Cross Reef has developed approximately between 7000 and 8000 years ago and has been growing continuously since then, reaching a thickness of 17-18m[95]. The 1998 and 1999 fisheries surveys list Fiery Cross Reef as the site with the highest abundance of fisheries resources for gillnetting (which provides an indication of reef

---

[87] Hughes et al. *op. cit.* ref. 80.
[88] Feng et al. *op. cit.* ref. 85.
[89] Zhao, H., Weng, X., Sun, Z., Zheng, D., & Yuan, J. (1996) "Nansha Islands coral reef natural features," *Acta Oceanologica Sinica,* 18: 61-70 [in Chinese; unofficial translation using GoogleTranslate]; Mora et al. *op. cit.* ref. 1.
[90] Li, Y.-Z., & Chen, P.-M. (2004) "Quantitative distribution of fish resources in main coral reef waters of Nansha Islands," *Journal of Fisheries of China,* 28: 651-656 [in Chinese; English abstract].
[91] Li, Y.-Z., Lin, Z.-J., Chen, P.-M., Sun, D.-R., Chen, Y., Chen, G.-B., et al. (2003) "Survey for coral reef fish resources in the center & north waters of the Nansha Islands," *Journal of Fisheries of China,* 27: 315-321 [in Chinese; English abstract].
[92] Feng et al. *op. cit.* ref. 85.
[93] Lee *op. cit.* ref. 41.
[94] Yu et al. *op. cit.* ref. 69.
[95] *Ibid*.

fishes at medium trophic levels)[96]. Trammel net surveys[97] in 2004 and 2005 yielded 19 fish species in the waters above the reef, close to the average of the Spratly reefs surveyed at that time[98]. The outer reef had live cover of up to 90% and featured a highly biodiverse coral community, predominantly of branching *Acropora* and *Pocillopora* species, but also including massive *Porites*, *Favia* and *Goniastrea* species[99]. The reef has a closed lagoon, and coral cover (predominantly of *Acropora* species) was up to 60% in the deeper parts of the inner reef flat[100]. Up to 20% of the massive *Porites* sp. corals in this zone were dead, with heights of usually less than 70cm, indicating frequent growth disturbances potentially due to recurring temperature anomalies over the past two centuries[101]. The 2009-2010 survey, however, reported a mean live coral cover of only around 10% on the reef flat of Fiery Cross Reef, while the outer slope was observed to still have a higher coral cover (mean up to 50%)[102]. Again, the estimates from that survey have to be treated with caution. Satellite images indicate that the reef flat of Fiery Cross Reef was subject to intense clam shell harvesting using boat propellers in May 2014[103].

3. Gaven Reef

Gaven Reef sits on the rim of an extensive, largely submerged atoll, which also includes Itu Aba Island approximately 23km to the northeast of Gaven Reef. Its reef flat extends about 1.9km from north to south and 1.2km from east to west, without a central lagoon[104]. Very little information exists on Gaven Reef. Fisheries expeditions have surveyed this reef in 1998, 1999, 2004 and 2005. In the earlier surveys, it was described as having the highest resources for longlining among the seven reefs[105]. While the reef was described as having lower fisheries resources than Fiery Cross and Cuarteron Reefs, it was judged to have ‘production value’[106]. Trammel net surveys of 2004 and 2005 resulted in 18 species, similar to Fiery Cross Reef[107].

4. Johnson Reef

Johnson Reef lies on the south-western tip of a largely submerged, extensive atoll reef complex, which extends for a total of approximately 54km from southwest to northeast. Johnson Reef itself measures approximately 4.6km from north to south, and 2.4km from east to west[108]. In its natural configuration prior to the beginning of construction activities, it had a semi-enclosed lagoon gradually becoming deeper and opening into the inner part of the larger atoll in the north-east. Information on the state of Johnson Reef prior to commencement of

[96] Li & Chen *op. cit.* ref. 90.
[97] Trammel nets consist of multiple layers of nets and are usually set near the bottom. They are less selective than gill nets and catch a broad range of species, including juveniles.
[98] Chen, G., Li, Y., & Chen, X. (2007) "Species diversity of fishes in the coral reefs of South China Sea," *Biodiversity Science,* 15: 373-381 [in Chinese; Tables in English].
[99] Yu et al. *op. cit.* ref. 69; Liu et al. *op. cit.* ref. 66.
[100] *Ibid.*
[101] Yu et al. *op. cit.* ref. 84.
[102] Feng et al. *op. cit.* ref. 85.
[103] Lee *op. cit.* ref. 41.
[104] Measurements according to GoogleEarth.
[105] Li & Chen *op. cit.* ref. 90.
[106] Li et al. *op. cit.* ref. 91.
[107] Chen et al. *op. cit.* ref. 98.
[108] Measurements according to GoogleEarth.

construction is similarly sparse. The fishery surveys of 1998 and 1999 concluded that Johnson had ‘basically no fisheries value’[109]. It yielded the lowest number of grouper species among all visited reefs, with a total of only 4 species[110]. A reef survey at the end of 2009 found a slightly higher live coral cover (15%) on the reef flat of this than of three other surveyed reefs[111].

5. Hughes Reef

Hughes Reef sits on the rim of the same atoll complex as Johnson Reef, which is located approximately 29km to the southwest. It measures about 2.1km from north to south, and 2.0km from east to west. Prior to the beginning of construction activities, it featured a natural deeper lagoon part meandering across its centre and opening to an adjacent deeper lagoon through a narrow, shallow channel on the eastern side of the reef[112]. For Hughes Reef, only information from the 1998 and 1999 fisheries surveys could be found. The results list Hughes as having comparatively low fisheries potential, but still having ‘production value’[113]. It yielded 6 species of grouper, although none of the species usually preferred in the live reef food fish trade[114]. Satellite imagery shows the presence of scars on the shallow reef in February 2012, before the onset of large-scale land reclamation, indicating that clam removal using boat propellers has taken place on the reef flat[115].

6. Mischief Reef

Mischief Reef is a large atoll that has three natural passes (1.8m, 18m and 24m deep) into the lagoon, which has a depth of 20-27m[116]. The lagoon features a number of well-developed patch reefs with massive, foliose and branching corals[117]. A 2007 survey found 94 species of stony corals. The reef slope had a live coral cover of 51%, mostly branching *Acropora* and *Montipora* and massive *Porites* species. Patch reefs within the lagoon had 24-35% live coral cover (mostly massive *Porites*), the reef flat 24% (almost all branching *Montipora*), and the inner lagoon slope between 1 and 16% live coral cover[118]. During the same research cruise, coral bleaching was observed to affect a total of 26 coral species. 27% of the colonies on the reef flat were bleached, while only 18% of colonies on the inner lagoon slope were affected. The lowest amount of bleaching was observed at a site on the north-western outer reef slope with a coral cover of more than 90%, where only 6% of the colonies were bleached. Branching corals (*Acropora* and *Pocillopora* species) were found to be most sensitive, while

[109] Li et al. *op. cit.* ref. 91.
[110] Chen, G.-B., & Li, Y.-Z. (2005) "Composition and distribution of Serranidae in main coral reef waters of South China Sea," *South China Fisheries Science,* 1: 18-25 [in Chinese; Tables in English].
[111] Feng et al. *op. cit.* ref. 86.
[112] Measurements according to GoogleEarth. From satellite imagery available on GoogleEarth, it can be estimated that the lagoon part measured somewhere between 5 and 10m depth.
[113] Li et al. *op. cit.* ref. 91.
[114] Chen & Li *op. cit.* ref. 110.
[115] See 2012 image in Annex 86.
[116] Zhao et al. *op. cit.* ref. 89; Shen, J., & Wang, Y. (2008) "Modern microbialites and their environmental significance, Meiji reef atoll, Nansha (Spratly) Islands, South China Sea," *Science in China Series D: Earth Sciences,* 51: 608-617.
[117] Liu et al. *op. cit.* ref. 66.
[118] Zhao, M. X., Yu, K. F., Shi, Q., Chen, T. R., Zhang, H. L., & Chen, T. G. (2013) "Coral communities of the remote atoll reefs in the Nansha Islands, southern South China Sea," *Environmental Monitoring and Assessment,* 185: 7381-7392.

several massive corals (*Porites* and *Favia* species) were also affected[119]. The inner reef flat of Mischief Reef had several large *Porites* colonies of 3-4 m height, showing a long history of growth, but observations of dead smaller colonies with 1-2.5 m height and information from coral cores indicate recurrent temperature-induced mortality every few decades over the past two centuries[120]. Observations of cyanobacterial growth[121] on living and dead corals in the lagoon of Mischief Reef in 2004 indicated some nutrient enrichment in the enclosed lagoon, although the authors attributed this to natural causes[122]. Fisheries surveys in 1998 and 1999 described Mischief Reef as having low fisheries resources, but still possessing 'production value'[123], while the 2004 and 2005 trammel net surveys at Mischief Reef yielded only two species of fish[124], potentially reflecting increased fishing pressure by that time. Satellite images show extensive propeller damage on the reef flat by boats likely harvesting giant clams in January 2015[125].

7. Subi Reef

Subi Reef is a pear-shaped atoll in the northern Spratly Islands, with about 5.75km in length and 3.25km width. Originally, it was a closed atoll, with no passes into the lagoon, which has a maximum depth of 24m[126]. In 2002, a total of 314 macrobenthic species (i.e. species larger than 1 mm living on the benthos, or seafloor; these included 130 molluscs and 110 crustaceans) were recorded from Subi Reef[127]. Two fisheries surveys carried out in 1998 and 1999 concluded that, similar to Johnson Reef, Subi had 'basically no fisheries value'[128], indicating that it may have been overfished already at that time. A detailed survey of the coral community at Subi Reef was carried out in 2007[129]. The researchers recorded 74 species of stony corals, with significant differences between the lagoon and outer reef slope communities. Live coral cover was higher in the lagoon, with coral cover between 28% and 35%. Coral cover at all four outer slope stations was less than 5%. The study recorded a low amount of bleaching (slightly higher in the lagoon), but a high amount of dead coral (above 85% on the outer slope). Predation by Crown-of-Thorns Starfish was seen as one possible cause of death, along with human impacts. The absence of a channel into the lagoon was seen

---

[119] Li, S., Yu, K., Chen, T., Shi, Q., & Zhang, H. (2011) "Assessment of coral bleaching using symbiotic zooxanthellae density and satellite remote sensing data in the Nansha Islands, South China Sea," *Chinese Science Bulletin,* 56: 1031-1037.
[120] Yu et al. *op. cit.* ref. 84.
[121] Cyanobacteria are microscopic organisms occurring naturally on the surface of reefs. They are capable of photosynthesis, but unlike true algae their cells do not possess a nucleus. Several of them are capable of fixing nitrogen. Cyanobacteria may form blooms in response to nutrient input, and have been implicated in the overgrowth of disturbed reef areas.
[122] Shen & Wang *op. cit.* ref. 116.
[123] Li et al. *op. cit.* ref. 91.
[124] Chen et al. *op. cit.* ref. 98.
[125] Lee *op. cit.* ref. 41.
[126] Zhao et al. *op. cit.* ref. 118.
[127] Li, X.-Z., Li, B.-Q., Wang, H.-F., Wang, S.-Q., Wang, J.-B., & Zhang, B.-L. (2007) "Macrobenthic community characters of Zhubi Reef, Nansha Islands, South China Sea," *Acta Zoologica Sinica,* 53: 83-94 [in Chinese; English abstract].
[128] Li et al. *op. cit.* ref. 91.
[129] Huang, H., Zhang, C.-L., Yang, J.-H., You, F., Lian, J.-S., & Tan, Y.-H. (2012) "Scleractinian coral community characteristics in Zhubi reef sea area of Nansha Islands," *Journal of Oceanography in Taiwan Strait,* 31: 79-84 [in Chinese, unofficial translation provided by PCA].

as one explanation of the better state of corals there compared to the outer slope. Due to the dominance of *Pocillopora verrucosa*, a faster-growing pioneer species, on most of the slope stations, the authors speculated that the reef had recently been severely degraded and was in an early stage of recovery. In conclusion, they stated that the outer slope had reached an almost complete breakdown.

A second survey in 2007 by a different team of scientists recorded 64 species of stony corals[130]. They recorded a similar low coral cover for the outer slope (3-10%, mostly massive *Porites* and branching *Montipora* species). For the outer reef flat, they found only 4% of live stony corals, but on the inner reef flat, live coral cover ranged from 12-61%, almost all of which were branching *Montipora* species[131]. During the same cruise, 12 species of corals were observed to be affected by bleaching, with 30% of the surveyed colonies displaying symptoms[132].

The 2009-2010 survey recorded a higher live coral cover (15%) on the reef flat of Subi than of three other surveyed islands, but reported no living corals within a radius of 80m from the stilt structures on the reef (i.e. the earlier constructions before land reclamation began)[133]. This study reported a significantly higher cover of live corals on the outer reef (40-50%) than recorded during the survey two years earlier, indicating some recovery may have taken place in between, but again, because details on the methodology are not provided, those values have to be treated with caution.

8. Summary

Information on the ecological status of the seven reefs prior to construction activities is limited and heterogeneous. Based on the available information, it appears that all have been subject to intense harvesting of fish and invertebrate resources, and have suffered localised loss of stony coral cover from thermal stress, destructive fishing (including the removal of buried clam shells from the reef flat with the use of boat propellers), and as a result of the presence of small structures on the reef. Unfortunately, no underwater visual surveys of reef fish communities appear to have been carried out, so it is not possible to assess the status of the reef fish communities of the seven reefs accurately. Seagrasses likely occurred on the reef flats of all reefs, although no specific information on their extent or composition is available in the literature, and it is difficult to ascertain from aerial pictures or satellite images. Fiery Cross Reef apparently had the highest coral cover on the outer slope among the seven reefs, and comparatively good fish stocks. Mischief Reef had good coral cover on the outer slope (>50%), and well-developed patch reefs in its lagoon. Subi Reef appears to have been most heavily fished and to have lost most coral cover on the outer slope, but still retained a fair coral community on its reef flat and in its lagoon. Cuarteron Reef had comparatively good fish resources, but reduced coral communities. Information for the remaining three reefs is even less complete – fisheries resources apparently were low, and apart from a comparatively

[130] Zhao et al. *op. cit.* ref. 118.
[131] *Ibid.*
[132] Li et al. *op. cit.* ref. 119.
[133] Feng et al. *op. cit.* ref. 85.

good coral cover on the reef flat at Johnson Reef (15%), no information on the state of the coral reef was found.

V. Nature and extent of the possible harm to coral reefs as a result of China's construction activities, as those activities are described in the record or in other publicly available sources

There are three types of impacts construction and dredging activities can have on the reef systems:

- direct destruction of reef habitat through burial under sand, gravel and rubble generated from dredging, and eventually under concrete and tarmac, as well as the destruction of shallow reef and seagrass habitat through dredging activities, together with changed hydrodynamics related to modifications in bathymetry and the construction of hard structures
- indirect impacts on benthic organisms such as corals and seagrasses via increased sedimentation, turbidity, and potential nutrient enrichment as a side-effect of dredging
- indirect impacts on organisms in the water column, such as fishes and larvae, from sediments, chemical and nutrient release, and noise generated during dredging and construction activities[134].

The construction work in the South China Sea included the use of a cutter suction dredge (CSD)[135]. This is the preferred machine for many dredge operations as it is able to tackle all sorts of materials from hard rocks to soft sediments. There are two types of CSD, the nonpropelled which must be towed like a pontoon and the propelled, which operates like a ship. Both must be moored when in use and have spuds held by anchors to hold position. The general effects of this method (cutter section dredging) include the three types of impacts described above. A perceived advantage of the CSD is that, if used correctly and in the right setting, it can create less of a plume (i.e. cloud of suspended sediments) than other dredges and is generally more cost effective than the trailing suction hopper dredge. It can suck up the dredged material and pass it via pipes either to receiving barges or via floating pipes to the shore or another dump site. CSD are not good in rough seas but function best in canals or harbours. They are also not easily moved.

Table 1 summarises the likelihood, severity and spatial and temporal extent of possible impacts from dredging activities on reefs. As this overview is based on information for the Great Barrier Reef, the exact nature and extent of possible harm will differ for the oceanic

---

[134] Erftemeijer, P. L. A., & Robin Lewis III, R. R. (2006) "Environmental impacts of dredging on seagrasses: A review," *Marine Pollution Bulletin,* 52: 1553-1572; PIANC. (2010) "Dredging and port construction around coral reefs," Brussels, Belgium: UNEP, The World Association for Waterborne Transport Infrastructure (PIANC); Erftemeijer, P. L. A., Riegl, B., Hoeksema, B. W., & Todd, P. A. (2012) "Environmental impacts of dredging and other sediment disturbances on corals: A review," *Marine Pollution Bulletin,* 64: 1737-1765; McCook, L. J., Schaffelke, B., Apte, S. C., Brinkman, R., Brodie, J., Erftemeijer, P., et al. (2015) "Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef: Report of an Independent Panel of Experts," Townsville, Australia: Great Barrier Reef Marine Park Authority.

[135] Description provided in Annex 799-800.

atolls and reefs of the Spratly Islands due to differences in bathymetry and hydrodynamics, but some general inferences can be made from that compilation.

Table 1: Qualitative risk assessment of the types, likelihood and extent of major pressures for coral reef ecosystems from dredging[136]. This overview table was developed for the Great Barrier Reef, where dredging operations occur inshore, and is provided here mainly as an overview of the different types of pressures associated with dredging operations. Impacts are likely to be similar in other reef systems, but the precise spatial and temporal scales of impacts of a dredging operation depend on its size and varies among locations according to the local environment, such as currents and weather, which will be different in offshore locations such as the Spratly Islands compared to inshore locations such as the Great Barrier Reef. A "?" indicates a high degree of uncertainty in the score.

Pressures	***Likelihood***	***Consequence***	***Spatial Scale***	***Temporal Scale***	***Predictability***
Immediate: during dredging and disposal activities					
Removal	Certain	Severe	Small (immediate area)[137]	Permanent	High
Burial	Certain	Severe	Small (immediate area)[138]	Permanent	High
Sedimentation	Certain	Moderate	Local	Days – Months	Moderate
Turbidity	Certain	Moderate	Local	Days – Months	Moderate
Nutrients	Certain (-Likely#)	Moderate (-Minor#)	Local	Days – Months	Moderate
Contaminants	Rare*	Major (variable)	Local	Days – Months	High
Hydrodynamics	Certain	Minor – Moderate# (variable)	Local	Permanent	? Moderate
Noise	Likely	? Minor – Moderate	? Small – Local	Days – Weeks	High – Moderate**
Medium- to long-term: due to resuspension and transport					
Sedimentation	? Likely	? Minor – Moderate (variable)	? Large	Years – Decades	Limited
Turbidity	? Likely	? Minor – Moderate (variable)	? Large	Years – Decades	Limited
Nutrients	Possible	? Minor	? Large	Years – Decades	Limited
Contaminants	Rare	Major (variable)	? Large	Years – Decades	Moderate#

Likelihood: Refers to how probable a pressure is to occur: Certain; Likely; Possible; Unlikely; Rare.
Consequences: Refers to the impact of the pressure, where and when it does occur: Severe; Major; Moderate; Minor; Insignificant.
Spatial Scale: Refers to the approximate spatial extent over which a pressure occurs: Small: Immediate, defined area of activity (e.g. dredging excavation or disposal ground) < ~20 km^2; Local: Bay-wide: ~20-200 km^2; Large: 200-2000 km^2; Regional: >2000 km^2.
Temporal Scale: Refers to the approximate duration in time over which a pressure occurs: Hours to days; days to weeks; weeks to months; months to years; years to decades; permanent.
Predictability: Refers to the precision and accuracy with which managers can predict the likelihood, consequences and scale of each pressure, whether using computer models or other techniques; assumes availability of relevant sampling and data: High; Moderate; Limited.
*Assuming effective implementation of current management guidelines[139].

[136] Adopted from McCook et al. *op. cit.* ref. 134: pp. 14-16.
[137] The immediate area can be extensive, depending on the scale of the operation. In Australia, some dredging operations have reached volumes of several million m^3.
[138] Burial of corals can however extend to a very large area due to sediment plumes generated during dredging operations: Barnes, B. B., Hu, C., Kovach, C., & Silverstein, R. N. (2015) "Sediment plumes induced by the Port of Miami dredging: Analysis and interpretation using Landsat and MODIS data," *Remote Sensing of Environment,* 170: 328-339.

** Adequate data not currently available, but should be readily acquired using available technology and methods.
# Assessments differed among the Expert Panel in McCook et al.[140]

The most drastic of changes to the reefscape resulting from dredging is the replacement of shallow reef flat with land. The consequences of losing this habitat – in some cases in its entirety – are likely to be severe not only for biodiversity but also for fisheries. The shallow nature of reef flats (often <1 m) means that penetration of sunlight is high and algae grow at their greatest rates. Algae are mostly consumed by various herbivores – fishes and invertebrates – and this forms a major part of the coral reef food web that supports fisheries. Herbivore biomass is typically maximal in these shallow habitats[141], so a loss of reef flats will reduce the most productive environment.

Studies of reef fish zonation find that reef flat assemblages are quite distinct[142], though only one species is thought to be an obligate inhabitant of this habitat; the epaulette shark (*Hemiscyllium ocellatum*). A striking aspect of many reef flats is the high density of juvenile reef fish, prompting speculation, albeit uncertain, about their role as nursery habitats[143]. Habitat quality will have declined at two scales through the impacts of dredging. First, the loss of large-scale reef geomorphology through the direct effects of land reclamation and dredging will remove key habitat for ambush predators like groupers that typically utilise large reef structures[144]. At a finer scale, the loss of coral habitat through direct dredging effects and acute sedimentation will reduce its suitability to provide shelter for reef fish (i.e., the reefs become flatter and flatter). Evidence from elsewhere has clearly demonstrated that a

---

[139] Such as PIANC *op. cit.* ref. 134.
[140] McCook et al. *op. cit.* ref. 134.
[141] Steneck, R. S. (1988) "Herbivory on coral reefs: a synthesis," In *6th International Coral Reef Symposium,* edited by J. H. Choat, D. Barnes, M. A. Borowitzka, J. C. Coll, P. J. Davies, P. Flood, B. G. Hatcher, D. Hopley, P. A. Hutchings, D. Kinsey, G. R. Orme, M. Pichon, P. F. Sale, P. Sammarco, C. C. Wallace, C. Wilkinson, E. Wolanski & O. Bellwood. Townsville, Australia.
[142] Harborne, A. R. (2013) "The ecology, behaviour and physiology of fishes on coral reef flats, and the potential impacts of climate change," *Journal of Fish Biology,* 83: 417-447.
Reef flats appear to be a nursery for the blackfin dartfish, *Ptereleotris evides* (McCormick and Makey 1997). In the Red Sea, one third of fishes recorded on shallow seagrass, coral patches and reef flats were juveniles (Ashworth et al. 2006). Recruitment of the commercially-important grouper *Epinephelus merra* in Reunion Island was higher on reef flats than elsewhere (Letourneur et al. 1998), and the commercially-important snapper, *Lutjanus carponotatus*, mainly recruits to reef flats on the Great Barrier Reef (Wen et al. 2013).
McCormick, M. I., & Makey, L. J. (1997) "Post-settlement transition in coral reef fishes: overlooked complexity in niche shifts," *Marine Ecology Progress Series,* 153: 247-257.
Ashworth, J. S., Bruce, O. E., & Hellw, M. E. (2006) "Fish assemblages of Red Sea backreef biotopes," *Aquatic Conservation: Marine and Freshwater Ecosystems,* 16: 593-609.
Letourneur, Y., Chabanet, P., Vigliola, L., & Harmelin-Vivien, M. (1998) "Mass Settlement and Post-Settlement Mortality of *Epinephelus merra* (Pisces: Serranidae) On Réunion Coral Reefs," *Journal of the Marine Biological Association of the United Kingdom,* 78: 307-319.
Wen, C. K. C., Pratchett, M. S., Almany, G. R., & Jones, G. P. (2013) "Patterns of recruitment and microhabitat associations for three predatory coral reef fishes on the southern Great Barrier Reef, Australia," *Coral Reefs,* 32: 389-398.
[143] Harborne *op. cit.* ref. 142.
[144] Wen et al. *op. cit.* ref. 142.

loss of reef fish nursery habitats can be associated with severe losses of reef fisheries productivity[145].

The direct impacts by burial are confined to the immediate area of reclamation. The extent of habitat destruction through dredging depends on the amount of material collected for reclamation and the depth to which the target areas are dredged. The vast majority of benthic organisms on reefs, seagrass beds and soft-bottom communities depend on oxygen and are found either on the substrate surface, or in the upper layer (reaching down to ca. 0.5-1m depth, depending on the coarseness of the substrate). Chinese information on the large cutter suction dredger employed on the seven reefs describes the dredger to be capable of digging a 0.6m deep pit the size of a football field within one hour[146]. Information on the operation of a cutter suction dredger similar to those employed in the Spratly Islands describe it as removing the top layer of substrate in an arc-shape motion, and then to move after a swing of the dredger is completed, resulting in arc-shaped dredging scars[147]. In both cases, a large area is affected to generate the fill materials used in land reclamation.

Direct harm from changes in hydrodynamics and bathymetry on the seven reefs is possible as a result of a deepening of lagoonal habitat, and construction and widening of channels and basins, which lead to modifications of the flow regime on the reefs. These are localised (i.e. reef-wide) impacts, which however have the potential to affect the entire reef habitat of each of the impacted reefs. Benthic reef communities are strongly shaped by conditions of water flow[148], and modifications of the flow regime will lead to long-term changes in the benthic habitat. Furthermore, construction of hard structures on the reef flat also modifies the current and wave regime, leading to increased erosion in some and increased sediment deposition in other parts. As reef hydrodynamics and atoll geomorphological dynamics are complex processes, the exact type and extent of impacts depend on the local configuration of each reef are difficult to predict without hydrodynamic and bathymetric models.

Indirect harm to benthic organisms is possible due to sedimentation, increased turbidity, and the release of nutrients as a result of dredging activities[149]. Even if it does not lead to outright burial and choking, sedimentation affects the ecology of benthic and pelagic coral reef organisms, including seagrasses, corals, and fishes. Sediments and turbidity generated by dredging activities impair the photosynthesis of seagrasses and corals[150], and sedimentation

[145] Mumby, P. J., Edwards, A. J., Arias-Gonzalez, E. J., Lindeman, K. C., Blackwell, P. G., Gall, A., et al. (2004) "Mangroves enhance the biomass of coral reef fish communities in the Caribbean," *Nature,* 427: 533-536.
[146] Description provided in Annex 799-800.
[147] Description by the Dutch company Van Oord provided in Annex 796.
[148] Graus, R. R., & Macintyre, I. G. (1989) "The zonation patterns of Caribbean coral reefs as controlled by wave and light energy input, bathymetric setting and reef morphology: computer simulation experiments," *Coral Reefs,* 8: 9-18; Hamner, W. M., & Wolanski, E. (1988) "Hydrodynamic forcing functions and biological processes on coral reefs: A status review," In *6th International Coral Reef Symposium,* edited by J. H. Choat, D. Barnes, M. A. Borowitzka, J. C. Coll, P. J. Davies, P. Flood, B. G. Hatcher, D. Hopley, P. A. Hutchings, D. Kinsey, G. R. Orme, M. Pichon, P. F. Sale, P. Sammarco, C. C. Wallace, C. Wilkinson, E. Wolanski & O. Bellwood. Townsville, Australia.
[149] Erftemeijer & Robin Lewis III *op. cit.* ref. 134; Erftemeijer et al. *op. cit.* ref. 134; McCook et al. *op. cit.* ref. 134.
[150] Erftemeijer & Robin Lewis III *op. cit.* ref. 134; Erftemeijer et al. *op. cit.* ref. 134.

can decrease the reproductive output, wound healing and growth of corals[151]. The settlement and survival of coral larvae is negatively affected by sedimentation[152]. Sedimentation furthermore can modify predator-prey interactions, impair the feeding of planktivorous fishes, and deter fish herbivory[153].

A recent review of the impacts of sediments from dredging on corals[154] suggests that many laboratory experiments conducted in the past may have been misleading owing to the inaccuracy of some estimations of components of the dredging. Specifically, light regimes used in some prominent studies may have been unreasonably intense thereby underestimating dredging effects[155]. Sediment proxies such as black carborundum[156] and silicon carbide[157] may also underestimate effects due to larger particle size and other characteristics that differ from dredge sediment. Sediment traps used to estimate the levels of sediment in the sea may also provide only a vague approximation so appropriate levels may not have been used in all experiments[158]. In spite of these limitations mostly suggested to underestimate the effects of dredging sediment, there are many studies showing deleterious effects across many animal phyla.

---

[151] Dodge, R. E., Aller, R. C., & Thomson, J. (1974) "Coral Growth Related to Resuspension of Bottom Sediments," *Nature,* 247: 574-577; Rogers, C. S. (1990) "Responses of coral reefs and reef organisms to sedimentation," *Marine Ecology Progress Series,* 62: 185-202; Meesters, E. H., Bos, A., & Gast, G. J. (1992) "Effects of sedimentation and lesion position on coral tissue regeneration," In *7th International Coral Reef Symposium,* edited by R. H. Richmond. Guam, Micronesia: University of Guam Press, UOG Station, Guam; Crabbe, M., & Smith, D. (2005) "Sediment impacts on growth rates of *Acropora* and *Porites* corals from fringing reefs of Sulawesi, Indonesia," *Coral Reefs,* 24: 437-441.

[152] Salinas-de-León, P., Costales-Carrera, A., Zeljkovic, S., Smith, D. J., & Bell, J. J. (2011) "Scleractinian settlement patterns to natural cleared reef substrata and artificial settlement panels on an Indonesian coral reef," *Estuarine, Coastal and Shelf Science,* 93: 80-85.

[153] Bellwood, D. R., & Fulton, C. J. (2008) "Sediment-mediated suppression of herbivory on coral reefs: Decreasing resilience to rising sea-levels and climate change?," *Limnology and Oceanography,* 53: 2695-2701; Wenger, A. S., Johansen, J. L., & Jones, G. P. (2012) "Increasing suspended sediment reduces foraging, growth and condition of a planktivorous damselfish," *Journal of Experimental Marine Biology and Ecology,* 428: 43-48; Wenger, A. S., McCormick, M. I., McLeod, I. M., & Jones, G. P. (2013) "Suspended sediment alters predator–prey interactions between two coral reef fishes," *Coral Reefs,* 32: 369-374.

[154] Jones, R., Bessell-Browne, P., Fisher, R., Klonowski, W., & Slivkoff, M. (2016) "Assessing the impacts of sediments from dredging on corals," *Marine Pollution Bulletin,* 102: 9-29.

[155] Cooper, T. F., & Fabricius, K. E. (2012) "Pigmentation of massive corals as a simple bioindicator for marine water quality," *Marine Pollution Bulletin,* 65: 333-341; Flores, F., Hoogenboom, M. O., Smith, L. D., Cooper, T. F., Abrego, D., & Negri, A. P. (2012) "Chronic Exposure of Corals to Fine Sediments: Lethal and Sub-Lethal Impacts," *PLoS ONE,* 7: e37795; Browne, N. K., Tay, J., & Todd, P. A. (2015) "Recreating pulsed turbidity events to determine coral–sediment thresholds for active management," *Journal of Experimental Marine Biology and Ecology,* 466: 98-109; Jones et al. *op. cit.* ref. 154.

[156] Yonge, C. M., & Nicholls, A. G. (1931) "Studies on the physiology of corals. V. The effect of starvation in light and in darkness on the relationship between corals and zooxanthellae," *Scientific Reports of the Great Barrier Reef Expedition 1928-1929,* 1: 177-211.

[157] Stafford-Smith, M. G., & Ormond, R. F. G. (1992) "Sediment-rejection mechanisms of 42 species of Australian scleractinian corals," *Marine and Freshwater Research,* 43: 683-705; Junjie, R. K., Browne, N. K., Erftemeijer, P. L. A., & Todd, P. A. (2014) "Impacts of Sediments on Coral Energetics: Partitioning the Effects of Turbidity and Settling Particles," *PLoS ONE,* 9: e107195; Browne et al. *op. cit.* ref. 155.

[158] Jones et al. *op. cit.* ref. 154.

Fish diversity and abundance have been reduced with elevated sediment[159]. Elevated sediment levels have caused inhibition of visual and chemical cues that are used for foraging[160], habitat choice[161], and interactions between predators and prey[162]. Parrotfish have been found not to graze on the epilithic algal matrix when it is exposed to elevated sediment, specifically with reduced grazing when coarse sediment is present compared to fine silt and when organic loads in the sediment are low[163]. When sediment is present for the development period of larval fishes, the pelagic stage can be extended[164]. When clownfish larvae were exposed to suspended sediments, the gills produced increased mucous, the gill epithelium thickened and the bacterial community on the gills shifted from a healthy one to a pathogenic one[165].

For molluscs, although no effects were found on mortality of the abalone *Haliotis iris* when exposed to sediments simulating a proposed dredging program, they were found to avoid sediment in their predation refugia by moving to vertical surfaces and they were unable to right themselves – a key behaviour in allowing them to reattach following dislodgement[166]. Scallops may have higher mortality when buried under fine sediment than coarse sediment and with longer burial time[167]. In contrast, most species of sponges studied were not dramatically affected by a single pulse of increased sediment loads. Those with a higher mortality were cup-shaped sponges[168].

Aside from the limitations to adult coral growth with high densities of sediment, the early life history stages of corals can be negatively affected by dredging-related sediment release and turbidity at most stages[169]. Tomascik and Sander[170] and Kojis and Quinn[171] both found

---

159 Fabricius, K. E. (2005) "Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis," *Marine Pollution Bulletin,* 50: 125-146; Mallela, J., Roberts, C., Harrod, C., & Goldspink, C. R. (2007) "Distributional patterns and community structure of Caribbean coral reef fishes within a river-impacted bay," *Journal of Fish Biology,* 70: 523-537; Cheal, A. J., Emslie, M., MacNeil, M. A., Miller, I., & Sweatman, H. (2013) "Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs," *Ecological Applications,* 23: 174-188.

160 Wenger et al. 2012 *op. cit.* ref. 153.

161 Bertram, D. F., & Leggett, W. C. (1994) "Predation risk during the early life history periods of fishes: separating the effects of size and age," *Marine Ecology Progress Series,* 109: 105-114.

162 Wenger et al. 2013 *op. cit.* ref. 153.

163 Gordon, S. E., Goatley, C. H. R., & Bellwood, D. R. (2016) "Low-quality sediments deter grazing by the parrotfish *Scarus rivulatus* on inner-shelf reefs," *Coral Reefs,* 35: 285-291.

164 Wenger, A. S., McCormick, M. I., Endo, G. G. K., McLeod, I. M., Kroon, F. J., & Jones, G. P. (2014) "Suspended sediment prolongs larval development in a coral reef fish," *Journal of Experimental Biology,* 217: 1122-1128.

165 Hess, S., Wenger, A. S., Ainsworth, T. D., & Rummer, J. L. (2015) "Exposure of clownfish larvae to suspended sediment levels found on the Great Barrier Reef: Impacts on gill structure and microbiome," *Scientific Reports,* 5: 10561.

166 Chew, C. A., Hepburn, C. D., & Stephenson, W. (2013) "Low-level sedimentation modifies behaviour in juvenile *Haliotis iris* and may affect their vulnerability to predation," *Marine Biology,* 160: 1213-1221.

167 Szostek, C. L., Davies, A. J., & Hinz, H. (2013) "Effects of elevated levels of suspended particulate matter and burial on juvenile king scallops *Pecten maximus*," *Marine Ecology Progress Series,* 474: 155-165.

168 Pineda, M. C., Duckworth, A., & Webster, N. (2016) "Appearance matters: sedimentation effects on different sponge morphologies," *Journal of the Marine Biological Association of the United Kingdom,* 96: 481-492.

169 Jones, R., Ricardo, G. F., & Negri, A. P. (2015) "Effects of sediments on the reproductive cycle of corals," *Marine Pollution Bulletin,* 100: 13-33.

170 Tomascik, T., & Sander, F. (1987) "Effects of eutrophication on reef-building corals," *Marine Biology,* 94: 77-94.

171 Kojis, B. L., & Quinn, N. J. (1984) "Seasonal and depth variation in fecundity of *Acropora palifera* at two reefs in Papua New Guinea," *Coral Reefs,* 3: 165-172.

reductions in fecundity of coral species in high turbidity/eutrophication but sediment levels were not measured. In contrast, Padilla-Gamiño et al.[172] found no changes in fecundity between areas with different sediment trap accumulation rates.

Once the eggs and sperm are developed and ready to spawn, they are grouped together into egg sperm bundles ready for release. These float to the surface of the water so that the vast three dimensional ocean area is reduced to two dimensions at the surface where the egg sperm bundles break open and fertilisation can begin[173]. At sediment concentrations of $35 mg.L^{-1}$, sediment can prevent the ascent of coral egg sperm bundles by intercepting them and 'ballasting' back to the bottom[174]. The sperm are not spared. High concentrations of sediment were found to remove sperm from the water surface during coral spawning events due to an entanglement of the sperm within the sediment which caused the sperm to sink[175]. Clearly this removal of sperm from the surface would reduce fertilisation rates considerably.

Reductions in fertilisation success have been found over a range of sediment concentrations for acroporid corals[176]. Coral larvae do not like to settle on surfaces with too much sediment present[177] and are easily smothered for a long period following sediment due to their small size and lack of ability to repel sediment[178]. Release of nutrients can lead to the proliferation of bacteria, reducing oxygen, and of algae that compete with corals for space. These effects are local, i.e. on the reef scale, extending up to several kilometres from the dredging site. Immediate effects arising from dredging operations can last from days to months, while long-term effects from continued resuspension of sediments can last from years to decades. The long-term effects will last longer within confined bodies of waters, such as the lagoons and the newly-constructed basins and channels on the reef flats, whereas on the outer reef slope the released sediments will be transported offshore and into deeper waters within a few months to years, depending on the current regimes and the composition of the sediments that are released.

---

[172] Padilla-Gamiño, J. L., Hédouin, L., Waller, R. G., Smith, D., Truong, W., & Gates, R. D. (2014) "Sedimentation and the Reproductive Biology of the Hawaiian Reef-Building Coral *Montipora capitata*," *Biological Bulletin,* 226: 8-18.

[173] Harrison, P. L., & Wallace, C. C. (1990) "Reproduction, dispersal and recruitment of scleractinian corals," In *Ecoystems of the World,* edited by Z. Dubinsky. New York and Amsterdam: Elsevier Science.

[174] Ricardo, G. F., Jones, R. J., Negri, A. P., & Stocker, R. (2016) "That sinking feeling: Suspended sediments can prevent the ascent of coral egg bundles," *Scientific Reports,* 6: 21567.

[175] Ricardo, G. F., Jones, R. J., Clode, P. L., Humanes, A., & Negri, A. P. (2015) "Suspended sediments limit coral sperm availability," *Scientific Reports,* 5: 18084.

[176] Gilmour, J. (1999) "Experimental investigation into the effects of suspended sediment on fertilisation, larval survival and settlement in a scleractinian coral," *Marine Biology,* 135: 451-462; Humphrey, C., Weber, M., Lott, C., Cooper, T., & Fabricius, K. (2008) "Effects of suspended sediments, dissolved inorganic nutrients and salinity on fertilisation and embryo development in the coral *Acropora millepora* (Ehrenberg, 1834)," *Coral Reefs,* 27: 837-850.

[177] Hodgson, G. (1990) "Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*," *Coral Reefs,* 9: 41-43; Babcock, R., & Davies, P. (1991) "Effects of sedimentation on settlement of *Acropora millepora*," *Coral Reefs,* 9: 205-208; Gilmour *op. cit.* ref. 176; Babcock, R., & Smith, L. (2000) "Effects of sedimentation on coral settlement and survivorship," In *Proceedings of the 9th International Coral Reef Symposium*. Bali, Indonesia.

[178] Babcock & Smith *op. cit.* ref. 177.

The effects of dredging on coral reefs have been hard to quantify as the effects are complex. Dredge plumes (i.e. clouds of sediments released by dredging activities) can extend considerable distances depending on the size of the dredging operation and local water conditions, with distances varying between 3 and 20 km in a recent study of 73 sites from three large-scale capital dredging programs in Australia[179]. In other studies, sediment accumulation has been negatively correlated with live coral cover following dredging periods[180]. Large plumes of sediment coinciding with dredging activity in Miami recently smothered corals in the area. Extensive plumes were detected for around one year after dredging began, but the duration of individual plumes in the case of Miami is difficult to determine since the analysis was based on individual daily images (with fluctuations between images) rather than continuous coverage[181].

Reproduction of corals in areas affected by construction work in the South China Sea will likely be reduced. With so much of the reef removed, the number of fecund corals will be reduced significantly. During the construction work it is likely that a great percentage of the corals in the surrounding reef slopes and deeper areas will have been smothered or diseased or otherwise weakened by the sediment plumes from extensive dredging.

Lingering higher sedimentation would impact the different reproductive stages of corals, particularly if the local water quality declines in response to pollution associated with the new island residents. Fecundity could be reduced along with fertilisation success and settlement rates and survival rates of recruits. Fewer corals means less chance of successful fertilisation taking place particularly if sediment in the water negatively affects the rise of the egg sperm bundles and the ability of the sperm to remain on the surface.

It is highly likely that the extended presence of personnel on islands will further increase fishing pressure on reefs and rapidly deplete fisheries, particularly of the most vulnerable larger carnivorous species[182].

VI. Extent to which any likely harm to the reef systems can be attributed to Chinese construction activities

Three forms of natural coral disturbance have been documented in the Spratly Islands (or if not entirely natural, not driven by local human effects): coral bleaching[183], typhoons[184], and

[179] Fisher, R., Stark, C., Ridd, P., & Jones, R. (2015) "Spatial Patterns in Water Quality Changes during Dredging in Tropical Environments," *PLoS ONE,* 10: e0143309.

[180] Li, X.-b., Huang, H., Lian, J.-s., Liu, S., Huang, L.-m., & Yang, J.-h. (2013) "Spatial and temporal variations in sediment accumulation and their impacts on coral communities in the Sanya Coral Reef Reserve, Hainan, China," *Deep Sea Research Part II: Topical Studies in Oceanography,* 96: 88-96; Appeldoorn, R., Ballantine, D., Bejarano, I., Carlo, M., Nemeth, M., Otero, E., et al. (2015) "Mesophotic coral ecosystems under anthropogenic stress: a case study at Ponce, Puerto Rico," *Coral Reefs,* 35: 63-75.

[181] Barnes et al. *op. cit.* ref. 138.

[182] Pauly et al. *op. cit.* ref. 27; McManus *op. cit.* ref. 53; Mumby, P. J., Steneck, R. S., Edwards, A. J., Ferrari, R., Coleman, R., Harborne, A. R., et al. (2012) "Fishing down a Caribbean food web relaxes trophic cascades," *Marine Ecology Progress Series,* 445: 13-24.

[183] Yu et al. *op. cit.* ref. 84.

[184] Yu et al. *op. cit.* ref. 69.

Crown-of-Thorns Starfish (COTS)[185]. Typhoons are a frequent impact occurring approximately every three years with major events striking the reefs around once every 160 years[186]. While bleaching is believed by most to be a recent phenomenon, being first observed in the early 1980s[187], reefs are used to experiencing periodic typhoons and COTS events. Thus while it is common to find patches of damaged reef, the average reef-scale coral cover would usually be high (>40%). Bleaching has historically caused large-scale mass mortality particularly of branching corals[188]. However, the large massive corals like *Porites* rarely experience mass mortality from bleaching, and even when they do, recovery of tissue fragments can occur within 15 years through a process known as 're-sheeting'[189]. In short, reefs experiencing a combination of these three 'natural' disturbances do not have symptoms that include excess sediment covering the reef, extensive areas of upturned large corals (particularly in leeward environments), and excessive mortality of massive corals. These impacts thus can be attributed to construction activities, but their extent is difficult to assess without monitoring efforts on the ground.

The impact from burial of the reef flat by artificial island construction can be attributed with certainty to Chinese construction activity. The extent of the area affected at each reef can be determined from satellite images. A recent study by Mora et al. used Landsat8 images to track the area of artificial land constructed and the amount of shallow reef habitat lost during the process, and by doing so tracked the time of main dredging activity[190] (see Figs. 1-7 below). It is important to note that Mora et al. used satellite images taken at intervals of several weeks and interpolated the data. The information in Figs. 1-7 should thus not be understood as exactly showing the beginning and end of dredging, but rather as an indication of the main periods of land accretion. According to the data presented in Mora et al., 27% of the shallow reef area of the seven reefs was permanently lost (i.e. buried or excavated beyond visibility from the surface) within just over two years. From the area that was identified as shallow reef habitat prior to the onset of large-scale construction activity, 2% has been converted into artificial land after land reclamation was finished at Johnson Reef, 5% at Hughes and Cuarteron Reefs, 13% at Gaven Reef, 48% at Mischief Reef, and 61 and 62% at Subi and Fiery Cross Reefs, respectively. While incorporating the amount of shallow reef lost as a result of channel and harbour construction, this study did not take into account the amount of shallow reef that was impacted by removal of the surface layer, but without significant deepening of the area (i.e. change in habitat quality, but not much change in terms of bathymetry). According to one calculation, channel dredging affected 1.4km^2 of reef on the seven reefs considered here, while the amount of shallow reef area affected by dredging for the gathering of fill materials is 39.3km^2. Added to this damage caused by construction-

---

[185] Feng et al. *op. cit.* ref. 85.
[186] Yu et al. *op. cit.* ref. 69.
[187] Glynn, P. W. (1984) "Widespread Coral Mortality and the 1982–83 El Niño Warming Event," *Environmental Conservation,* 11: 133-146.
[188] Wilkinson, C. (1998) *Status of Coral Reefs of the World: 1998*. Townsville, Australia: Global Coral Reef Monitoring Network, Australian Institute of Marine Science.
[189] Roff, G., Bejarano, S., Bozec, Y.-M., Nugues, M., Steneck, R. S., & Mumby, P. J. (2014) "Porites and the Phoenix effect: unprecedented recovery after a mass coral bleaching event at Rangiroa Atoll, French Polynesia," *Marine Biology,* 161: 1385-1393.
[190] Mora et al. *op. cit.* ref. 1.

related dredger activity are an additional estimated 68.8km^2 of shallow reef damage believed to be caused by boat propeller-assisted clam excavation[191]. Aerial and satellite imagery from the seven impacted reefs show arc-like scars over large parts of the shallow reef flat, but dredger activity is documented only in the lagoon area (for Mischief and Subi Reefs) or, in the case of Cuarteron, Hughes, Gaven, Johnson and Fiery Cross Reefs, on those parts of the reef flat that were excavated to form channels and harbour basins. Only one picture from Gaven Reef shows small boats or barges over the shallow reef flat with floating hoses attached. On a different picture, small boats are visible on the reef flat, but the absence of attached hoses and the presence of larger transport boats anchored off the reef indicates excavation of clam shells rather than dredging for sediments[192]. Furthermore, arc-shaped scars are visible on the shallow reef flats before major land reclamation began on most reefs, further indicating clam excavation as likely origin of these scars. As described above, the shallow reef flat habitat on these reefs likely contained diverse coral communities that in parts had a live coral cover of above 60%. The two reefs for which the highest coral cover on the reef flat was reported in earlier studies, Subi and Fiery Cross Reefs, are also the ones that lost most shallow reef habitat due to construction. However, to what extent live coral cover was lost due to impacts such as clam excavation in the years prior to construction, and which part of the shallow reef flat was impacted by dredging to generate material for land reclamation, is difficult to ascertain.

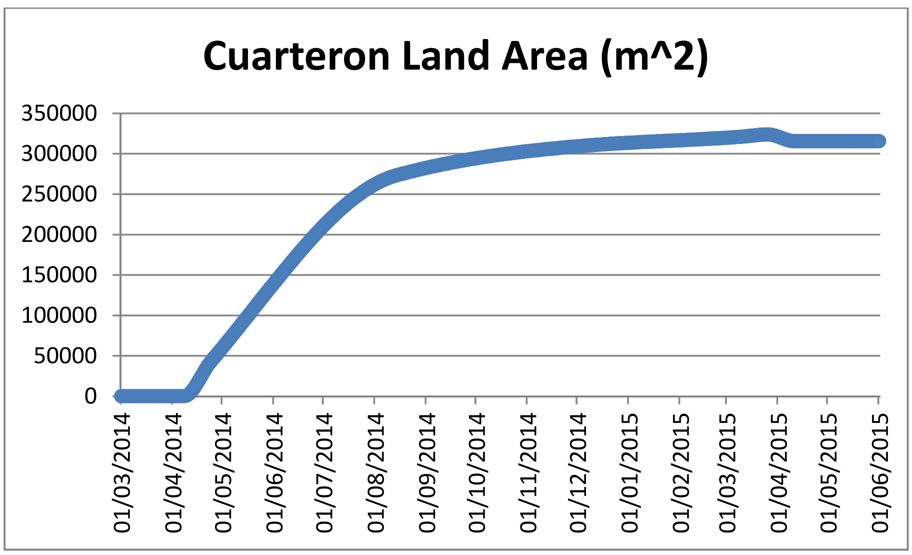


Fig. 1: Increase in land area at Cuarteron Reef, derived from Landsat8 imagery[193].

[191] McManus *op. cit.* ref. 41. Note that this estimated area is not confined to the seven reefs affected by construction activities, but covers reefs throughout the Spratly Islands and Scarborough Reef.

[192] Pictures of 5 June 2014 and 5 May 2014, respectively, in Annex 783. McManus (*op. cit.* ref. 41) argues that most of the shallow reef areas seen on satellite imagery to be affected by arc-shaped scars are too shallow for the drafts of the large cutter suction dredgers involved in island construction, which range from 3.5 to 5.5m.

[193] Data derived from Mora et al. *op. cit.* ref. 1.

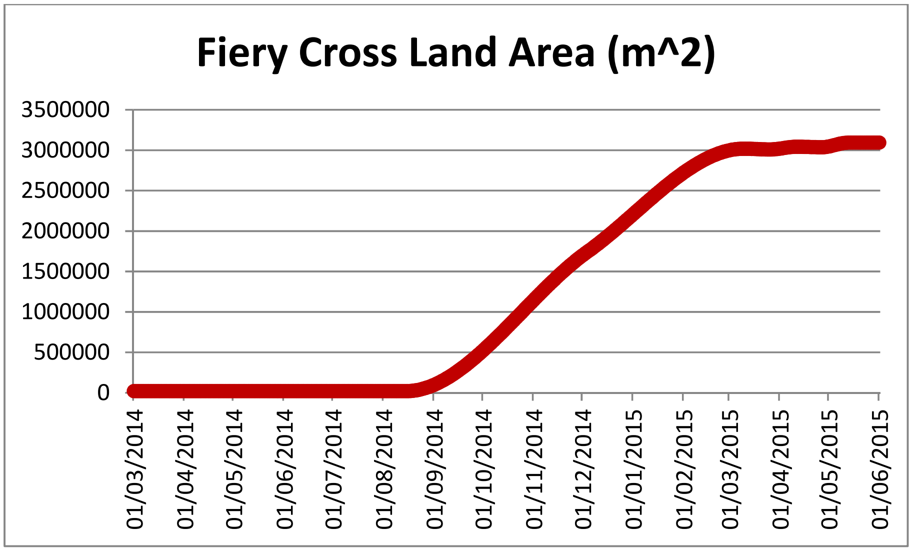


Fig. 2: Increase in land area at Fiery Cross Reef, derived from Landsat8 imagery[194].

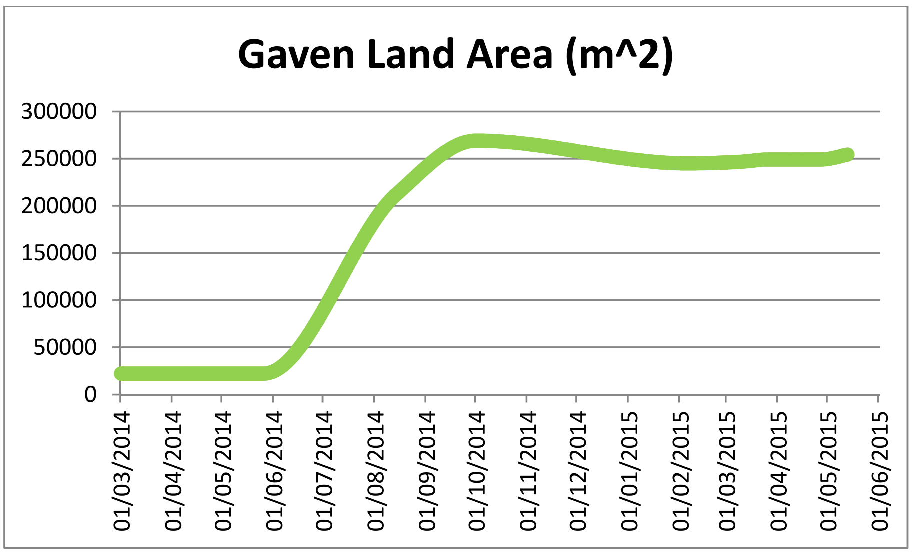


Fig. 3: Increase in land area at Gaven Reef, derived from Landsat8 imagery[195].

[194] *Ibid*.
[195] *Ibid*.

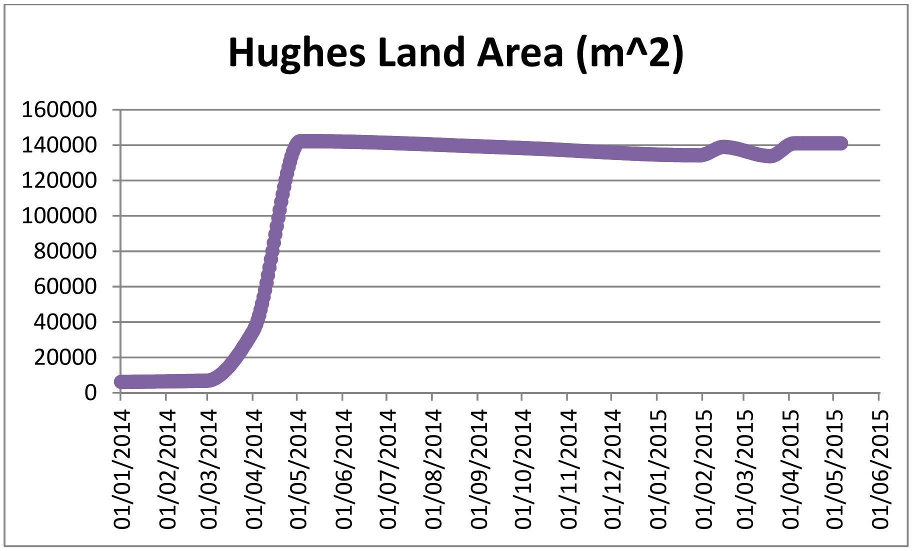


Fig. 4: Increase in land area at Hughes Reef, derived from Landsat8 imagery[196].

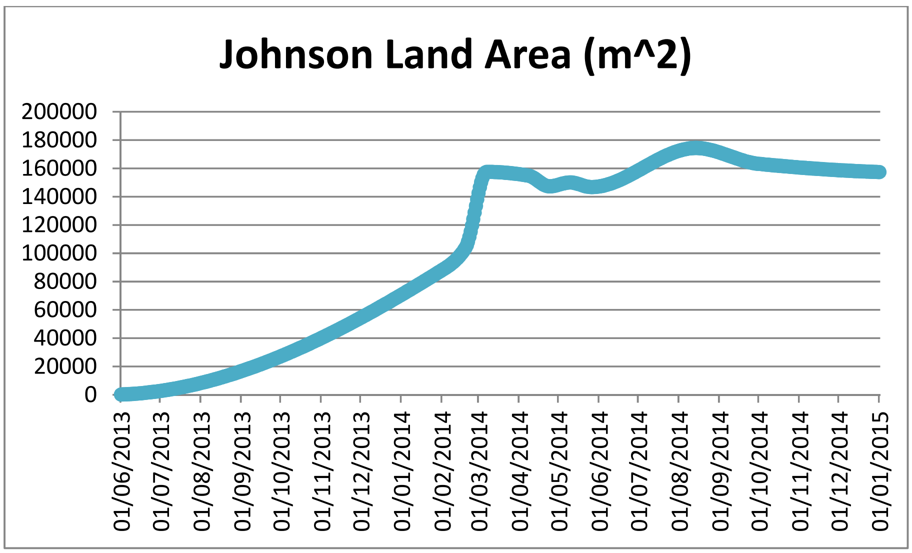


Fig. 5: Increase in land area at Johnson Reef, derived from Landsat8 imagery[197].

196 *Ibid*.
197 *Ibid*.

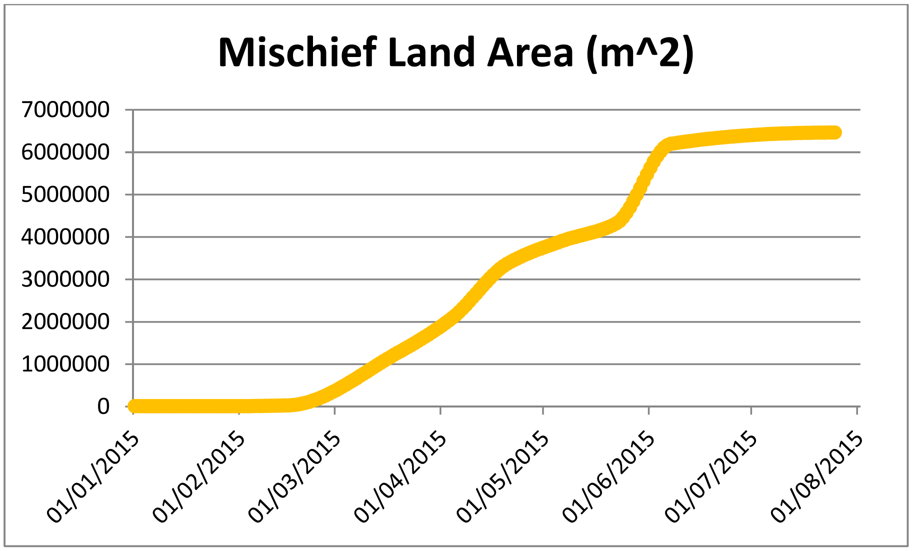


Fig. 6: Increase in land area at Mischief Reef, derived from Landsat8 imagery[198].

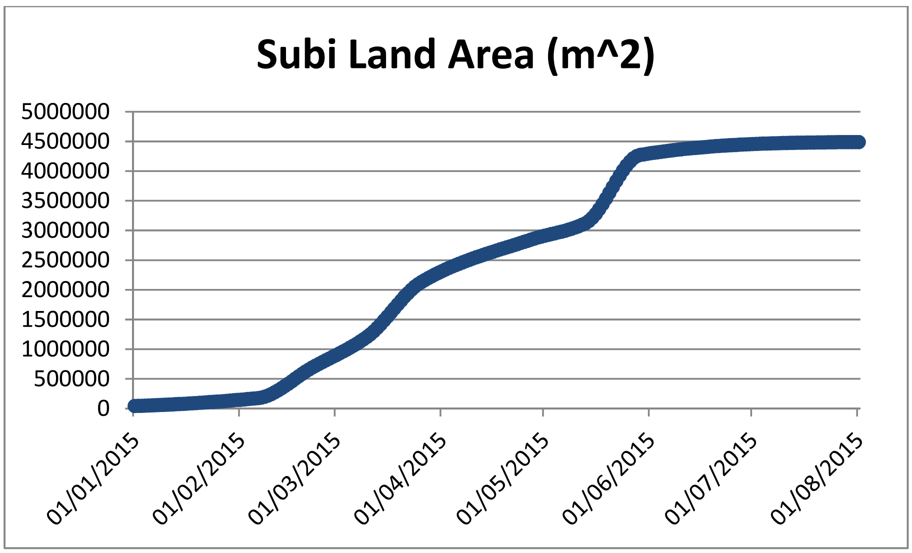


Fig. 7: Increase in land area at Subi Reef, derived from Landsat8 imagery[199].

Chinese descriptions of the dredging activity state that it was concentrated on the deeper parts of the lagoons[200], which appears to accord with available satellite and aerial imagery for the two reefs with deep lagoons (Mischief and Subi Reef). As mentioned above, shallow reef areas were excavated at the other five reefs, and in the construction of channels and basins. On some of the images, however, dredge boats are close to the rim of the lagoon, and the high level of suspended sediment in the water makes it difficult to see whether dredging was indeed carried out in deeper water or affected shallower slope areas. The deeper parts of the lagoon usually contain far less live coral cover than the reef flat or lagoonal slopes and patch reefs[201], and also usually do not sustain seagrass beds due to limited light availability with greater depth and turbidity in the lagoon. However, in the case of Subi Reef, the lagoon floor

[198] *Ibid.*
[199] *Ibid.*
[200] Annex 821.
[201] Yu et al. *op. cit.* ref. 69; Liu et al. *op. cit.* ref. 66.

in the general area targeted by dredging activities had a live coral cover of around 30%[202]. While the deeper lagoon floor has less live corals, it contains more unconsolidated and fine sediments that are easily resuspended during dredging operations, leading to increased turbidity[203]. The extensive sediment plumes generated during dredging operations in the lagoon waters are visible as bright blue clouds on aerial and satellite imagery of the construction activities at the Fiery Cross, Mischief and Subi Reefs[204].

Harm arising from changes in hydrodynamics can also be directly attributed to construction activities, although their effects are difficult to predict and depend on the local topography at each reef. The widening of existing passages and creation of artificial passages and basins in lagoons and reef flats alters flow conditions and thus the dynamics of sediment resuspension and deposition. At Subi Reef, which in its original configuration did not have a passage into its lagoon, the excavation of an artificial entrance into the lagoon and the construction of artificial land encircling about 60% of the lagoon is certain to have dramatically altered the hydrodynamic regime. Tidal waters that previously entered and exited the lagoon by flowing over the reef flat[205] are now channelled mostly through the single passage, leading to strong water flows there. This will likely lead to continued resuspension of sediments generated during the dredging operation and deposited in the lagoon as visible on satellite images[206], resulting in increased turbidity and sedimentation within the lagoon. This means continued stress for any bottom-dwelling organisms within the lagoon for the coming years to decades. As the lagoon at Subi Reef previously was the habitat with the highest remaining coral cover[207], this drastic alteration of the lagoon environment is very likely to have significantly reduced the remaining live coral communities on that reef. The hard structures built on the reef flat, particularly when reinforced by sea walls, will reflect waves and redirect current dynamics on top of the reefs, leading to increased erosion and sediment resuspension in those parts where flows are increased, and sediment deposition in the flow shade of the structures. Dredging and propeller scars on the shallow reef flat are very likely to lead to resuspension of fine sediments and release of nutrients stored in the reef flat sediments from burial of plant material. Following a visit to Tieshi Reef east of Thitu Reef (Pag-asa) in late February 2016, the ecologist Prof. John McManus reported silt and sand released from propeller dredging to have been transported by currents at least 500m downstream of the reef flat[208].

The indirect harm to the reef ecosystem from sediments and nutrients released during the dredging activity is more difficult to ascertain. Satellite and aerial images show extensive sediment plumes during dredging operations that affect the entire lagoon at Subi Reef and large parts of the lagoon at Mischief Reef, as well as the outer reef slope on all reefs (with the exception of Johnson Reef, where sediment plumes may have been restricted to the reef flat)

---

[202] Huang et al. *op. cit.* ref. 129.
[203] Shen & Wang *op. cit.* ref. 116.
[204] Annex 597, 781, 782, 785, 786, 788, 792, 795.
[205] Huang et al. *op. cit.* ref. 129.
[206] Annex 781.
[207] Huang et al. *op. cit.* ref. 129.
[208] McManus, J. (2016) "Update on Spratly Islands," http://coral.aoml.noaa.gov/pipermail/coral-list/2016-April/016891.html. Accessed 27 April 2016.

[209]. While the images available in the Annex were taken with several weeks distance between them and it cannot be verified from them that dredging operation went on continuously; satellite-derived data shows a continuous growth of land area on both Subi and Mischief Reefs (Figs. 6 and 7). Due to the near-complete atoll ring at both reefs, water exchange between the lagoon and the open ocean is limited[210], so that suspended sediments and nutrients will have stayed in the lagoon waters longer than for dredging operations in well-flushed environments, and it can thus be assumed that a large part of the reefs in the lagoons were subject to several months of intense sedimentation and increased turbidity, which is unlikely to be survived by even the most resistant coral species[211]. Both Subi and Mischief Reefs had well-developed coral communities in their lagoon, which in the case of Mischief Reef also featured patch reefs with coral cover that was higher than on the reef flat[212]. As a result of burial, turbidity and sedimentation, the large majority of live corals on the reef flat and in the lagoon of both reefs have most likely been killed by the construction activities.

The effect on the outer reef slope communities at all reefs is more difficult to assess from the available information. Some of the outer reef slopes of Mischief and Fiery Cross Reefs had a live coral cover of >90%[213]. While the literature is not clear regarding the location where coral cover was estimated at Fiery Cross Reef, on Mischief Reef transects were surveyed in the north-west, a section shown by satellite data to have been affected by sediment plumes at least in September and October 2015[214]. The affected reef slope community is likely to have suffered severe mortality as a result. At the other affected reefs, sediment plumes also likely had severe effects on the remaining benthic communities of the outer slopes, but as information regarding their previous state as well as the intensity and duration of sediment exposure is scarce, the exact extent of impacts is difficult to assess without monitoring on the ground.

As can be seen from satellite data tracking the increase in land area at each reef (Figs. 1-7), land reclamation lasted for several months at each reef, falling mostly in spring and summer. At Hughes, Fiery Cross, Mischief and Subi Reefs, sediment plumes are visible on aerial and satellite imagery several months after the end of documented land increase in the study by Mora and colleagues[215]. Corals in this area are assumed to display peak spawning times twice a year, around April and October[216]. Dredging impacts thus are likely to have interfered with at least one (and in the case of Mischief and Fiery Cross Reefs, two) spawning peak, resulting both in impaired reproductive output of, and recruitment into, the reefs.

[209] Annex 597, 781-792, 795.
[210] Huang et al. *op. cit.* ref. 129.
[211] Erftemeijer et al. *op. cit.* ref. 134.
[212] Huang et al. *op. cit.* ref. 129; Liu et al. *op. cit.* ref. 66; Zhao et al. *op. cit.* ref. 118.
[213] Yu et al. *op. cit.* ref. 71; Li et al. *op. cit.* ref. 119.
[214] Annex 792.
[215] Mora et al. *op. cit.* ref. 1; Annex 784, 788, 792, 795.
[216] Dorman et al. *op. cit.* ref. 53.

VII. Broader impacts of China's construction activities on the marine ecosystem in and around the South China Sea and on fisheries resources

Conclusions regarding the broader impacts of construction activities on the seven reefs are limited by the paucity of scientific field studies on connectivity in the Spratly Islands. Two studies that used combinations of oceanographic current models and biological information on fish and coral larvae were able to establish patterns of connectivity between the Spratly Islands and the wider tropical Western Pacific region[217] as well as among reefs in the Spratly Islands themselves[218]. Their results showed that a) the Spratly Islands are important sources of larvae for coastal reefs in the western Philippines, reaching up to the Sulu Archipelago, b) larvae from the Sulu Archipelago barely reach the South China Sea, and c) the reefs of the western Spratly Islands (to which the seven reefs impacted by recent Chinese construction activities belong) have the lowest number of source reefs among other Spratly Island reefs and are thus least resilient to perturbations. However, while larvae may indeed reach the Philippines, this does not necessarily imply that such connections are important for maintaining fisheries or biodiversity. A more pertinent question is whether larval supply to reefs of the main Philippine islands contains an ecologically important component from the Spratly Islands. For example, if the Spratly Islands only comprised 1% of all the larvae arriving in the Philippines it is doubtful that this would be ecologically important.

In fact, the Kool et al. paper[219] does undertake a region-wide analysis of the potential connectivity of coral reef fishes. To do this, they release virtual larvae from reefs throughout the wider Coral Triangle and South China Sea. Careful analysis of this study suggests that the Spratly Islands do indeed have the potential to be an important source of fish larvae to the Philippines and vice-versa; that reefs of the Philippines, especially those in Palawan, are strongly connected to the Spratly Islands by ocean currents. It is not possible to provide a specific figure on the strength of these links but inspection of the results suggest that the potential for larval dispersal is about equal in both directions, depending on the seasons.

The great potential for bi-directional larval exchange between the Philippines and Spratly Islands implies that healthy marine wildlife populations on the Spratly Islands could have beneficial effects in helping sustain fisheries of the western Philippines. This is particularly likely to be true given the heavily over-exploited nature of fisheries resources in the Philippines. When larvae arrive at a reef, their chances of survival are often strongly limited by the number of predators and available hiding places[220]. If predator abundance is low – because of overfishing – then larval survivorship will be relatively high, and the local population is said to be 'recruitment limited' and highly sensitive to fluctuations in the number of incoming larvae. Moreover, because local fish stocks are heavily depleted, their contributions to fisheries replenishment will be relatively modest. Thus, healthy offshore fish populations in the Spratly Islands are most likely to have a significant positive impact on

---

[217] Kool, J. T., Paris, C. B., Barber, P. H., & Cowen, R. K. (2011) "Connectivity and the development of population genetic structure in Indo-West Pacific coral reef communities," *Global Ecology and Biogeography,* 20: 695-706.
[218] Dorman et al. *op. cit.* ref. 53.
[219] Kool et al. *op. cit.* ref. 217.
[220] Hixon, M. A., & Beets, J. P. (1993) "Predation, Prey Refuges, and the Structure of Coral-Reef Fish Assemblages," *Ecological Monographs,* 63: 77-101.

Philippine fisheries when local fisheries are over-exploited – as has been the case for decades[221]. In short, it seems highly likely that over-exploitation of fisheries resources on the Spratly Islands will have a negative impact on fish stocks and fisheries in the Philippines.

A more recent study by Dorman et al. took a similar 'particle tracking on ocean currents' approach to exploring the regional importance of coral populations on the Spratly Islands[222]. A problem with this study is that it only looked at the one-directional relationship from the Spratly Islands to regional reefs, so while it did find connections, their ecological importance cannot be evaluated. Nonetheless, the study did make the interesting conclusion that reefs of the western Spratly Islands are more isolated from potential sources of larvae than those from the east. This implies that western reefs may take longer to recover should their coral populations be damaged.

Although the ecological importance of the coral study is difficult to ascertain, both the Kool and Dorman studies reveal the existence of some larval exchange among the Spratly Islands, Scarborough Shoals, Paracel Islands, and reefs of the main Philippine Islands. Such connectivity doubtless has evolutionary importance in maintaining the flow of genes throughout the region and therefore in maintaining the biodiversity of the Spratly Islands[223].

There is a potential criticism of the approach taken to measure larval connectivity in the Kool and Dorman studies. That is, that the scale of the oceanographic models – approximately 5 km grid cells – is too coarse to represent larval dispersal adequately. While it is true that some fish species have very limited larval dispersal[224], others have dispersal that exceeds 100 kilometres (Jones, pers. comm.) as predicted by Kool et al.[225]. Moreover, tests of the ability of the same particle-tracking model to predict observed patterns of coral gene flow have generally found strong concordance[226].

The discussion of connectivity above articulates the regional importance of the Spratly Islands for both fish and corals. This regional role of the islands, as a source of fisheries replenishment, could easily be diminished through a loss of habitat quality and increase in local fisheries exploitation based on permanent dwellings.

---

[221] McManus, J. W. (1997) "Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia," *Coral Reefs,* 16: S121-S127.

[222] Dorman et al. *op. cit.* ref. 53.

[223] Beger, M., Selkoe, K. A., Treml, E., Barber, P. H., von der Heyden, S., Crandall, E. D., et al. (2014) "Evolving coral reef conservation with genetic information," *Bulletin of Marine Science,* 90: 159-185.

[224] Jones, G. P., Almany, G., Russ, G., Sale, P., Steneck, R., van Oppen, M., et al. (2009) "Larval retention and connectivity among populations of corals and reef fishes: history, advances and challenges," *Coral Reefs,* 28: 307-325; Almany, Glenn R., Hamilton, Richard J., Bode, M., Matawai, M., Potuku, T., Saenz-Agudelo, P., et al. (2013) "Dispersal of Grouper Larvae Drives Local Resource Sharing in a Coral Reef Fishery," *Current Biology,* 23: 626-630.

[225] Kool et al. *op. cit.* ref. 217.

[226] Foster, N. L., Paris, C. B., Kool, J. T., Baums, I. B., Stevens, J. R., Sanchez, J. A., et al. (2012) "Connectivity of Caribbean coral populations: complementary insights from empirical and modelled gene flow," *Molecular Ecology,* 21: 1143-1157.

Field-verified models have established that a loss of reef habitat complexity reduces the productivity of the fishery threefold[227]. Therefore, not only will the reefs affected by construction have a greatly reduced capacity to sustain local fisheries but their ability to help replenish the fisheries of neighbouring jurisdictions will also be vastly diminished – at least threefold.

The loss of reef flat habitats is furthermore likely to have a major local impact on the foraging success for visiting seabirds, though this has not been quantified.

VIII. Anticipated duration of likely harm to coral reefs and the prospects and likely rate at which the coral reefs in question will rejuvenate

Coral reefs that are more isolated and have limited supply of external larvae are less likely to recover from impacts[228]. The recent study by Dorman et al. on modelled connectivity among the Spratly Islands[229] stated that the reefs of the western Spratly Islands appear to have limited connectivity to other reefs in the region and concluded that they "should be considered the most susceptible to large climate perturbations or disturbance events"[230]. An important caveat of the Dorman study is that it did not consider the level of larval supply from outside the Spratly Islands to the western reefs, but only looked at the fate of larvae released in the Spratly Islands. However, as the nearest sources of larvae for the seven impacted reefs are the other reefs of the Spratly Islands, and since the coastal reefs of the South China Sea are more degraded than the reefs of the Spratly Islands, the Dorman study provides important information on the potential main sources of larvae for replenishment. Furthermore, the construction activities on the seven reefs do not occur in an ecological vacuum, but need to be viewed in the wider ecological context of the Spratly Islands. As described above, the reefs in this area have been subject to significant, often destructive, fishing impacts over the past three decades. Construction of shelters, and sometimes reclamation of shallow reef areas, has taken place on several dozen reefs in the Spratly Islands, with associated negative impacts on the reef communities[231]. Furthermore, there are indications of extensive damage to shallow reefs areas throughout the Spratly Islands from the excavation of giant clam shells, further increasing sediment and nutrient loads and decreasing coral populations that could serve as a source for rejuvenation[232]. The overall capacity of the Spratly Islands reefs to absorb further impacts and provide larvae for reefs to rejuvenate has thus already been compromised before the large-scale construction on the seven reefs considered here began. The prospects and likely rates for rejuvenation differ depending on the environmental setting of each particular affected habitat area.

---

[227] Rogers, A., Blanchard, Julia L., & Mumby, Peter J. (2014) "Vulnerability of Coral Reef Fisheries to a Loss of Structural Complexity," *Current Biology,* 24: 1000-1005.
[228] Graham, N. A. J., Wilson, S. K., Jennings, S., Polunin, N. V. C., Bijoux, J. P., & Robinson, J. (2006) "Dynamic fragility of oceanic coral reef ecosystems," *Proceedings of the National Academy of Sciences of the USA,* 103: 8425-8429.
[229] Dorman et al. *op. cit.* ref. 53.
[230] *Ibid*, p. 177.
[231] McManus *op. cit.* ref. 53.
[232] Lee *op. cit.* ref. 41, McManus *op. cit.* ref. 41.

First, the prospects of recovery of coral (and fish, the majority of which require a coral habitat) are extremely low for areas that have been dredged to form navigable channels. This is because accelerated flow will likely cause excessive scouring of the substratum and prevent successful colonisation[233] and because of the need for periodic repeats of dredging to maintain shipping access[234].

Second, where major geomorphological structures have been removed through dredging, such as large coral 'bommies' (accumulations of corals that typically stand several metres above the substrate), there is little prospect for recovery on ecological time scales. These structures constitute accumulated reef growth on geological time scales of centuries to millennia[235]. This statement applies to much of the lagoon and deeper parts of the reef flat where these features (bommies or patch reefs) have been described in the Spratly Islands[236].

Recovery of corals may occur on areas damaged by dredging and smothering of sediments (which in some cases appear to be the reef slope throughout the entire circumference of the reef[237]). For Tieshi Reef in the northern Spratly Islands, the reef flat of which appears to have been subject to intense clam excavation between 2 and 4 years ago, the ecologist Prof. John McManus reported after a recent visit in early 2016 that apparently strong currents had washed out most of the finer gravel and sand generated during excavation, revealing larger old parts of dead coral skeleton on which some fast-growing corals were regrowing. He estimated that for this environment and the fast-growing species occuring there previously, recovery may occur within one to two decades, although he cautioned that the unstable substrate would be slowing the rate of recovery[238]. The remaining section deals with timescales of recovery of the areas damaged by dredging and smothering of sediments on the seven reefs considered in this report.

The ideal conditions for coral recovery occur when reef habitat quality is good (stable and hard), there are no chronic and only infrequent acute stressors, and surrounding reefs have healthy corals able to reproduce and help replenish damaged areas. Under these conditions, the fastest-growing corals (branching *Acropora*) can recover within around 10-15 years[239]. However, recovery is likely to take considerably longer than this for several reasons:

> (i) Low population size – Unlike most disturbances, which have patchy impacts on reef health, leaving some areas relatively intact, the damage from dredging and sedimentation appears to be extensive. Under these circumstances it is possible that coral recovery will be limited by a paucity of replenishing larvae. This is particularly likely in the western Spratly Islands which are more isolated from one another[240]. The issue is further aggravated by the degradation of other reefs in the area that could serve

[233] Dudgeon, S. R., Aronson, R. B., Bruno, J. F., & Precht, W. F. (2010) "Phase shifts and stable states on coral reefs," *Marine Ecology Progress Series,* 413: 201-216.
[234] McManus *op. cit.* ref. 41.
[235] Fagerstrom, J. A. (1987) *The evolution of reef communities*. New York, NY, USA: John Wiley and Sons Inc.
[236] Yu et al. *op. cit.* ref. 69.
[237] Annex 597, 781, 782, 788, 792, 795.
[238] McManus *op. cit.* ref. 208.
[239] Halford et al. *op. cit.* ref. 23; Adjeroud et al. *op. cit.* ref. 23.
[240] Dorman et al. *op. cit.* ref. 53.

as potential source for larvae. The problem will be particularly acute for brooding coral species, those whose larvae only remain in the plankton for a few hours and typically travel short distances of less than a kilometre. Even in relatively intact ecosystems where damage is patchy, the rate of recovery of brooding species is strongly determined by the local adult population size[241]. Therefore, extensive areas of low coral cover will take a long time to recover.

(ii) Deeper reefs do not necessarily provide a refuge – It is sometimes hoped that deeper corals might help replenish the shallow-water populations damaged by dredging and sedimentation. However, genetic evidence reveals that there is very limited connectivity between deep water and shallower water corals of the same species[242]. Therefore, even if deep water corals remain relatively healthy, this does not necessarily help shallow water corals recover.

(iii) Poor habitat quality, dominated by rubble and sediment can greatly impede coral settlement – Sediment can prevent coral colonisation[243] and areas of reef dominated by small rubble, consistent with dredging, provide an unstable substratum that is continually rolled by the turbulence of incident waves. As a result, settling corals are periodically buried as the substrate to which they are attached moves around[244]. Recovery rates from heavily damaged reefs can be slow, albeit uncertain[245]. Recovery after blast fishing had not occurred after six years in one study[246], and observations from Indonesia suggest that it might take at least 15-20 years for recovery to occur and then only for fast-growing branching corals (Mumby, pers. obs.)[247].

(iv) Recovery rates are even slower for massive corals – Reef recovery is typically started with colonisation by rapidly-growing branching or table corals[248], which are more susceptible to bleaching events that are predicted to increase in frequency in the coming years as a result of climate change[249]. The larger, mound-shaped (massive) corals such as *Porites* grow at around 1 cm per year but typically reach sizes in excess of 1 m diameter (up to 10 m diameter). These corals are found in virtually all reef habitats and have been described frequently in the Spratly Islands. While *Porites* can

[241] Gilmour, J. P., Smith, L. D., Heyward, A. J., Baird, A. H., & Pratchett, M. S. (2013) "Recovery of an Isolated Coral Reef System Following Severe Disturbance," *Science,* 340: 69-71; Doropoulos, C., Ward, S., Roff, G., González-Rivero, M., & Mumby, P. J. (2015) "Linking Demographic Processes of Juvenile Corals to Benthic Recovery Trajectories in Two Common Reef Habitats," *PLoS ONE,* 10: e0128535.
[242] Van Oppen, M. J. H., Bongaerts, P. I. M., Underwood, J. N., Peplow, L. M., & Cooper, T. F. (2011) "The role of deep reefs in shallow reef recovery: an assessment of vertical connectivity in a brooding coral from west and east Australia," *Molecular Ecology,* 20: 1647-1660.
[243] Birrell et al. *op. cit.* ref. 22.
[244] Yadav et al. *op. cit.* ref. 18.
[245] Fox & Caldwell *op. cit.* ref. 19; McManus, J. W., Reyes Jr, R. B., & Nañola Jr, C. L. (1997) "Effects of Some Destructive Fishing Methods on Coral Cover and Potential Rates of Recovery," *Environmental Management,* 21: 69-78.
[246] Fox & Caldwell *op. cit.* ref. 19.
[247] This is similar to the rates of recovery for branching species on Spratly Island reefs damaged by extensive shell excavation as estimated by McManus *op. cit.* ref. 208.
[248] Connell, H. J. (1997) "Disturbance and recovery of coral assemblages," *Coral Reefs,* 16: S101-S113.
[249] Hoegh-Guldberg, O. (1999) "Climate change, coral bleaching and the future of the world's coral reefs," *Marine and Freshwater Research,* 50: 839-866.

resist modest levels of sedimentation, they are likely to experience mortality where directly impacted by dredges and under the intense sedimentation indicated in satellite imagery[250]. Recovery of these corals will take a minimum of decades and likely centuries[251].

(v) Fundamental changes to reef attractiveness – A related issue to habitat quality is the degree to which reefs attract larval fish. Larval fish can literally hear the reef and will actively swim towards noisy reefs[252]. Much of this noise is carried out by snapping shrimp and it is expected that populations of these shrimps will be devastated in dredged areas and also peripheral reefs impacted by heavy sedimentation. If the reefs become quiet, recovery of reef fish will likely be delayed.

(vi) Loss of fish nursery habitats – Many commercially-important coral reef fishes including groupers and snappers have very specific nursery habitat requirements. These are most commonly found in the habitats that have been subjected to intense dredging and land reclamation – sandy areas with scattered live branching corals in the lagoon and reef flat[253]. Loss of these nursery habitats will increase the mortality of juvenile reef fish and reduce biodiversity and fishery productivity.

IX. Examination and analysis of the record submitted by the Philippines on the issue of environmental harm to coral reefs as a result of island building activities at Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef, and assessment of the accuracy and certainty of the scientific conclusions drawn by the Philippines and its experts

1. Comment on Carpenter (2014) report[254] for accuracy and certainty

This is the shorter of the two reports and is largely succeeded by the co-authored Carpenter & Chou (2015)[255].

We did not have access to all of the reports available to the author from the Republic of the Philippines (e.g., Section IV on the Interpretation of Evidence of Environmental Harm). The available information, in the form of various accounts of arrests and inspections of fishers on reefs of the South China Sea over the past three decades (Scarborough Shoal and Second Thomas Shoal), confirms that sharks, sea turtles and giant clams have been targeted intensively by Chinese nationals (although it is worth pointing out that other nations have also been involved in fishing in the region), and live corals have been removed from many reefs in the area[256]. We therefore confine our analysis of this report to the interpretation of likely

[250] Annex 597, 781, 782, 788, 792, 795.
[251] Done *op. cit.* ref. 21.
[252] Kennedy, E. V., Holderied, M. W., Mair, J. M., Guzman, H. M., & Simpson, S. D. (2010) "Spatial patterns in reef-generated noise relate to habitats and communities: Evidence from a Panamanian case study," *Journal of Experimental Marine Biology and Ecology,* 395: 85-92.
[253] Wen et al. *op. cit.* ref. 142.
[254] Annex 240.
[255] Annex 699.
[256] Various reports of arrests and searches as provided in the Annex materials, see Annex 28-32, 41, 45, 46, 49, 50-52, 55 (which shows pictures of fossil clam shells most likely excavated from the reef), 57 (which shows pictures of corals and clams that were harvested live, as well as fossil clam shells), 58, 59, 77-80, 414.

consequences of the harm described (i.e., without being able to verify that harm has indeed occurred). In general, we agree with the interpretation of likely consequences on reefs and offer the following specific notes of clarification.

a) Connectivity of larvae between the Spratly Islands and Palawan (broader fisheries impacts; pages 8-9)

The specific information provided, taken from Kool et al. (2011)[257], focuses on whether reef fish larvae from the Spratly Islands reach reefs outside the Islands (i.e., a one-way direction from the Spratly Islands to the Philippines). Carpenter presents a figure in which Kool et al.[258] simulated the release of larvae from the Spratly Islands and tracked their fate on ocean currents. The caveats of the Kool study with regards to its ecological relevance are discussed above in Section VII.

b) Further specific comments

The effects of live coral cover loss for the fish community are discussed in detail in a number of studies that could have been referenced to support the discussion on page 14[259].

Regarding the impacts of cyanide fishing (page 15), the physiological effects of cyanide use could have been supported with references to the literature. The main problem for the corals is that cyanide very effectively bleaches coral, so patches of bleached corals are left when this takes place[260].

2. Comment on Carpenter & Chou (2015) report[261] for accuracy and certainty

Again, we agree with much of what is written but clarify a few specific issues. In some cases we argue that the damage has been overstated whereas in others we feel that the potential damage might be underestimated.

a) Comments on damage to Cuarteron Reef (page 18)

The text states that "China's activities have permanently changed the character of the reef, damaging it beyond the point of recovery". It is difficult to substantiate this claim other than where land reclamation has occurred such that the reef has been fundamentally converted to land. Having said that, the satellite imagery of this reef (Fig. 19 in Annex 699) reveals evidence of profound damage to reef flats that were not described explicitly in the report. The texture of the shallow reef flats surrounding the reclaimed land is unnatural and reveals clear evidence of anthropogenic damage across the vast majority of observable shallow reef. The causes of this damage are likely to be 'prop chopping' in the search for giant clam shells, though this activity cannot be ascribed directly to the land reclamation projects. This reef flat zone typically has high levels of live *Montipora* and *Acropora* corals in such environments on

---

[257] Kool et al. *op. cit.* ref. 217.
[258] *Ibid.*
[259] For example, Pratchett et al. *op. cit.* ref. 17; Wilson et al. *op. cit.* ref. 35; Pratchett et al. *op. cit.* ref. 35; Jones et al. *op. cit.* ref. 36; Coker et al. *op. cit.* ref. 36.
[260] Jones, R. J., & Hoegh-Guldberg, O. (1999) "Effects of cyanide on coral photosynthesis: implications for identifying the cause of coral bleaching and for assessing the environmental effects of cyanide fishing," *Marine Ecology Progress Series,* 177: 83-91.
[261] Annex 699.

Spratly reefs[262] and this will have been entirely removed. Moreover, by blasting this habitat with propeller wash the larger massive corals (e.g., *Porites*) will have been upturned and likely killed. Recovery of these assemblages will take up to centuries; ageing studies of *Porites* colonies in this habitat at Fiery Cross Reef reveal ages from ~200 to 50 years[263]. In short, while recovery might occur, it will take at least 50 years, and more likely centuries for massive corals to regain their previous sizes.

b) Understates the importance of the reef slope (page 24)

While it is true that the outer reef slope is less productive than the reef flat (as stated), a fairer reflection of the relative importance of these habitats would consider a broader range of ecosystem functions, not just primary productivity. In general, the highest levels of ecosystem services are found on complex reef slope environments, including tourism activities, fisheries, and biodiversity[264].

c) Effects of sedimentation and turbidity on reproduction and recruitment processes not fully considered (pages 24 and 25)

In addition to the described effects on adult coral colonies, sedimentation and turbidity resulting from dredging activities significantly affect the reproductive output of coral colonies, fertilisation success, and settlement of coral larvae[265], and the development of fish larvae[266].

d) Release of nutrients and pollutants from sediments (page 25)

The described release of pollutants is of lesser concern than the release of nutrients at these reefs, as the amount of pollutants physically and chemically bound in the sediments should be low at such a remote location. An increase in nutrients increases the susceptibility of corals to bleaching[267], and affects their reproduction by impairment of gametogenesis and fecundity, fertilisation and settlement[268].

e) Limited evidence on details of connectivity (pages 26 and 27)

Information on population connectivity is largely inferred from two modelling studies (see assessment of the first Carpenter report above). While these provide important insight into the general patterns of connectivity among reefs in the Spratly Islands and with adjacent areas, the extent and detailed patterns of connectivity between the seven impacted reefs and other

[262] Yu et al. *op. cit.* ref. 69; Zhao et al. *op. cit.* ref. 118.
[263] Yu et al. *op. cit.* ref. 69.
[264] Mumby, P. J., Broad, K., Brumbaugh, D. R., Dahlgren, C. P., Harborne, A. R., Hastings, A., et al. (2008) "Coral Reef Habitats as Surrogates of Species, Ecological Functions, and Ecosystem Services," *Conservation Biology,* 22: 941-951.
[265] Jones et al. *op. cit.* ref. 169; Ricardo et al. *op. cit.* ref. 174; Ricardo et al. *op. cit.* ref. 175; Gilmour *op. cit.* ref. 176; Humphrey et al. *op. cit.* ref. 176; Hodgson *op. cit.* ref. 177; Babcock & Davies *op. cit.* ref. 177; Babcock & Smith *op. cit.* ref. 178.
[266] Wenger et al. *op. cit.* ref. 164; Hess et al. *op. cit.* ref. 165.
[267] Wooldridge, S. A. (2009) "Water quality and coral bleaching thresholds: Formalising the linkage for the inshore reefs of the Great Barrier Reef, Australia," *Marine Pollution Bulletin,* 58: 745-751; Wiedenmann, J., D'Angelo, C., Smith, E. G., Hunt, A. N., Legiret, F.-E., Postle, A. D., et al. (2013) "Nutrient enrichment can increase the susceptibility of reef corals to bleaching," *Nature Climate Change,* 3: 160-164.
[268] Tomascik and Sander *op. cit.* ref. 170; Loya, Y., Lubinevsky, H., Rosenfeld, M., & Kramarsky-Winter, E. (2004) "Nutrient enrichment caused by in situ fish farms at Eilat, Red Sea is detrimental to coral reproduction," *Marine Pollution Bulletin,* 49: 344-353.

reefs of the Spratly Islands are difficult to ascertain without extensive genetic studies, and are likely to vary for species with different duration of the larval stage and larval ecology. The statements that the "degradation of even one reef creates a gap in the overall connectivity of all the reefs in the Spratlys" (page 26) and leads to "the collapse of connectivity" (page 27) thus are very strong statements. It is beyond doubt that the degradation of the seven reefs will have significant effects on larval and population dynamics throughout the Spratly Islands, and very likely beyond, but their extent is difficult to ascertain based on the existing scientific information.

f) Talk of phase shifts to seaweed dominance not well justified (page 28)

The report describes how seaweeds can overgrow corals and lock reefs into an undesirable state, citing papers by Mumby, among others[269]. While it is true that reefs can become locked into undesirable states, there is no evidence that seaweeds have overtaken the reefs of the Spratly Islands. This is due, in part, to the scant evidence of the state of the reefs post-reclamation. In general, reefs of the Indo-Pacific Oceans rarely exhibit shifts towards fleshy algal dominance (seaweed), though there are some exceptions, particularly under intensive fishing[270]. Another exception has been described when reefs experience profound physical damage from typhoons. Here, nutrient released from the reef matrix may help sustain seaweed blooms[271]. Is it feasible, but uncertain, that intense dredging activity could cause local seaweed blooms that slow or even prevent coral recovery as they do elsewhere[272].

g) Impacts of land reclamation on flow across reefs (page 29)

We generally agree with this section but two points could be added. First, building islands where none existed previously will reduce the wind-driven flow to the leeward side of reefs (ordinarily water would be blown across the reef flat towards the leeside). A reduction of flow will likely reduce the productivity of the reef for fisheries because algal growth rates – the base of the reef food chain – are reduced under low flow conditions[273]. Secondly, cutting new channels through the reef will have significant effects on local reef recovery and the distribution and recovery of seagrass and algal beds of the lagoon. Typically, incident wave energy is compressed through these channels at a relatively high flow. Not only can high flow

---

[269] Mumby et al. *op. cit.* ref. 29; Mumby, P. J., Hastings, A., & Edwards, H. J. (2007) "Thresholds and the resilience of Caribbean coral reefs," *Nature,* 450: 98-101.

[270] Graham, N. A. J., Jennings, S., MacNeil, M. A., Mouillot, D., & Wilson, S. K. (2015) "Predicting climate-driven regime shifts versus rebound potential in coral reefs," *Nature,* 518: 94-97.

[271] Roff, G., Doropoulos, C., Zupan, M., Rogers, A., Steneck, R. S., Golbuu, Y., et al. (2015) "Phase shift facilitation following cyclone disturbance on coral reefs," *Oecologia,* 178: 1193-1203.

[272] Hughes, T. P., Rodrigues, M. J., Bellwood, D. R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., et al. (2007) "Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change," *Current Biology,* 17: 360-365; Mumby et al. *op cit.* ref. 30; Doropoulos, C., Roff, G., Bozec, Y.-M., Zupan, M., Werminghausen, J., & Mumby, P. J. (2016) "Characterizing the ecological trade-offs throughout the early ontogeny of coral recruitment," *Ecological Monographs,* 86: 20-44.

[273] Renken, H., Mumby, P. J., Matsikis, I., & Edwards, H. J. (2010) "Effects of physical environmental conditions on the patch dynamics of *Dictyota pulchella* and *Lobophora variegata* on Caribbean coral reefs," *Marine Ecology Progress Series,* 403: 63-74.

prevent seagrass from surviving[274], but the constant scouring of the seabed can prevent corals from recruiting and recovering[275].

h) Effects on turtles and other vertebrates (pages 29 and 32)

Construction activities are not only potentially interfering with the navigation of sea turtles via chemical and noise pollution, but the artificial light from buildings and construction sites may disorient turtles. Furthermore, impacts on migrating seabirds that depend on shallow reefs areas for foraging are not considered.

i) Further effects of sedimentation and loose substrate on reef ecology (pages 24 and 33)

The discussion of sedimentation effects is largely confined to the physiology of corals and other organisms covered by sediments. However, as discussed in Sections III.2 and V above, the generation of coral rubble from dredging and sedimentation-induced mass-mortality of corals creates an unstable substrate that is unfavourable to the recruitment of coral larvae[276], and sedimentation can hinder herbivory on algal turfs developing on dead corals[277]. Thus, dredging on the reefs is likely to result in feedback mechanisms that decrease the rate of recovery of affected areas.

X. Examination and analysis of documents concerning China's own assessments of the environmental impact of its activities

The People's Republic of China does not take part in the arbitration process and does not acknowledge or comment on it. As such, there are no official statements of the PRC's government or its position with respect to the environmental impact of its activities made in the frame of the arbitration process. Our assessment thus can only cover statements on these activities made by representatives of the PRC's government on different occasions, and publicly available documents, as identified by the Philippines or by the Tribunal and presented to the Parties for comment.

In this regard, the following documents and statements were considered of particular relevance and are addressed in turn. The first four statements are very similar in nature and are thus addressed together:

1. Public statements on environmental protection

Permanent Mission of the People's Republic of China to the United Nations, Statement by H.E. Ambassador Wang Min, Head of the Chinese Delegation at the 25th Meeting of States Parties to the UN Convention on the Law of the Sea (12 June 2014; Annex 617):

---

[274] Saunders, M. I., Leon, J. X., Callaghan, D. P., Roelfsema, C. M., Hamylton, S., Brown, C. J., et al. (2014) "Interdependency of tropical marine ecosystems in response to climate change," *Nature Climate Change,* 4: 724-729.

[275] Dudgeon et al. *op. cit.* ref. 24.

[276] Yadav et al. *op. cit.* ref. 18.

[277] Bellwood & Fulton *op. cit.* ref. 153.

> "*The construction activities followed a high standard of environmental protection and will not damage the marine environment and ecosystem of the South China Sea.*"

Ministry of Foreign Affairs of the People's Republic of China, Foreign Ministry Spokesperson Hua Chunying's Regular Press Conference on April 9, 2015 (9 Apr. 2015; Annex 624):

> "*China's construction projects on the islands and reefs have gone through scientific assessments and rigorous tests. We put equal emphasis on construction and protection by following a high standard of environmental protection and taking into full consideration the protection of ecological environment and fishing resources. The ecological environment of the South China Sea will not be damaged. We will take further steps in the future to monitor and protect the ecological environment of relevant waters, islands and reefs.*"

Ministry of Foreign Affairs of the People's Republic of China, Foreign Ministry Spokesperson Hong Lei's Regular Press Conference on April 28, 2015 (28 Apr. 2015; Annex 625):

> "*China carries out construction on its own islands and reefs, and attaches greater importance to protecting the ecological environment there than anyone else. One thing worth pointing out is that China's construction projects have gone through years of scientific assessments and rigorous tests, and are subject to strict standards and requirements of environmental protection. Such projects will not damage the ecological environment of the South China Sea.*"

Embassy of the People's Republic of China in Canada, An Interview on China's Construction Activities on the Nansha Islands and Reefs (27 May 2015; Annex 820):

> "*No one cares more than China about the ecological preservation of relevant islands, reefs and sea areas. It needs to be pointed out that China's relevant construction project has gone through science-based evaluation and assessment, with equal importance given to construction and protection. We have taken into full account issues of ecological preservation and fishery protection, followed strict environmental protection standards and requirements in the construction process, and adopted many effective measures to preserve the ecological environment. We will further step up our efforts of ecological monitoring and preservation on the relevant islands, reefs and waters. In addition, as a State Party to the United Nations Convention on Biological Diversity (CBD) and the United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), China will strictly observe provisions of the conventions and honor her obligations in good faith.*"

Comment: No information on the Environmental Impact Assessment, the measures taken to prevent negative impacts, and the standards applied during construction was found online. This does not rule out the possibility that such assessments, measures and standards were developed and followed, as any such documents would likely have been written in Chinese and potentially have been confidential. Chinese-language documents specific to the construction activities that were found online dealt with the engineering aspects of the projects, but did not appear to include consideration of how to minimize negative ecological effects[278]. Rather, several ecological studies of the area by Chinese researchers emphasise the need for conservation of the seven reefs later targeted by construction[279]. Furthermore, the available satellite and aerial imagery provides little indication of effective mitigation measures, which are mostly aimed at limiting sediment release and associated turbidity and sedimentation[280]. The imagery does not show any signs of sediment screens being employed, and instead shows extensive sediment plumes both at the places of dredger operation and adjacent to reclaimed land areas receiving dredged material. Nor does it appear that reclamation areas were confined by the construction of bund walls to minimise the release of sediments. Indeed, one Chinese-language description of the construction activities underlines that damming facilities were not necessary and "minor losses through drifts" neglected during the dredging activities in the Spratly Islands[281]. Furthermore, on several reefs reclamation activity appears to have occurred during the suspected spawning times of reef corals in the area. As discussed above in Section VI, coral spawning is believed to occur twice a year, around April and October[282]. The statement that construction activity does not damage the environment on the reefs is contradicted by the facts underlining certain damage to reefs detailed above in this report.

2. Article by Researcher Feng Aiping and Senior Engineer Wang Yongzhi from the First Ocean Research Institution of the State Oceanic Administration (10 June 2015; Annex 872)

Importantly, these scientists are not state officials, but represent views of a government-sponsored organisation:

> "*The construction was <u>undertaken with an emphasis on the protection of ecosystem and fishery resources</u>, carried out after scientific assessment and feasibility studies.*"

Comment: As mentioned in the previous comment, we did not find information regarding the environmental planning of the construction activities, and the measures taken for the protection of ecosystem and fisheries resources, and it cannot be ruled out that such planning was indeed carried out. However, the available information on the construction activities does not indicate a particular emphasis on the protection of ecosystem and fishery resources.

---

[278] Sun, Z. (2000) "Nansha Islands coral sand engineering properties," *Tropic Oceanology,* 19: 1-8; Wang, Z. (2008) "Engineering geological characteristics of the construction of Nansha Islands coral reefs and large-scale project feasibility study," *Institute of Rock and Soil Mechanics*. Wuhan, China: Chinese Academy of Sciences.
[279] Zhao & Wu *op. cit.* ref. 77; Feng et al. *op. cit.* ref. 85; Zhao et al. *op. cit.* ref. 118; Huang et al. *op. cit.* ref. 129.
[280] PIANC *op. cit.* ref. 134.
[281] Annex 737. It should be noted that this is not an official government statement.
[282] Dorman et al. *op. cit.* ref. 53.

"*Nansha Reefs present typical tropical reef landscape. To facilitate the ecological protection and development of the region, the Chinese government has conducted a large amount of research and scientific exploration since 1955 and obtained a relatively thorough understanding of the coral reef ecosystems. According to the studies, there are coelenterates, polychaete annelids, molluscs, crustaceans, echinoderms, bryozoans, algae and other categories of large benthos in the waters near Nansha Reefs, counted 309 families, 837 genera and 1444 species. It is estimated that there are between 127 and 200 species of shallow water reef building corals (hermatypic corals) surrounding the Nansha reefs.*"

"*There is sharp difference in the spatial distribution of corals. Generally speaking, there are more species and large coverage of corals on reef front slopes and in the lagoons; reef flats have the fewest species of corals and less coverage than in the lagoons because reef flats emerge from water periodically with the tides, have shallower water and are subject to stronger external force.*"

Comment: These descriptions are largely in line with the information we could locate on the environmental conditions of the Spratly Islands and the seven reefs. Based on the most recent information, the number of coral species in the Spratly Islands is higher than stated here[283].

"*Research has shown that the South China Sea is not a body of closed waters, therefore* <u>*nutrients and food organisms can be replenished constantly from surrounding waters*</u>."

Comment: While the South China Sea receives a seasonal inflow from the Java Sea in summer and from the Kuroshio Current in winter[284], the ecologically important question is what are the patterns of larval connectivity within the South China Sea, and in particular, among the Spratly Islands. Fish and coral larvae are required for the replenishment of impacted reefs. As discussed above, the available information on patterns of larval connectivity, both from inference based on prevailing currents and potential sources of larvae[285], and from modelling studies[286], suggests that the Spratly Islands are important sources of larvae for reefs in the South China Sea and the Coral Triangle, but also underlines limited connectivity of reefs particularly in the western Spratly Islands. Thus, the available information provides very limited support for the potential for replenishment of the impacted reefs from waters outside the Spratly Islands, let alone beyond the South China Sea.

"*In accordance with Chinese laws and regulations, these assessments put great emphasis on issues such as the suitability of the scale of the construction activities, the reasonableness in site selection, the impact on ecosystems, the impact on fishery resources* […]."

---

283 Huang et al. *op. cit.* ref. 52.
284 Morton & Blackmore *op. cit.* ref. 54.
285 McManus *op. cit.* ref. 53.
286 Dorman et al. *op. cit.* 53; Kool et al. *op. cit.* ref. 217.

Comment: As no information regarding the purported assessments was found, these statements are difficult to verify. However, as both the scale of the construction activities and the impact on the reef ecosystems are significant and unprecedented in the region, it is difficult to imagine how these activities can be reconciled with existing Chinese laws and regulations.

> "*As to scientific site selection, based on years of research, the distribution of coral reef ecosystems in Nansha exhibits significant spatial difference: the biodiversity level is higher in the lagoons than in reef flat areas; the coverage of hermatypic corals is far lower in the reef flat areas while their death rate is a lot higher than in the lagoons. Due to this characteristic, most of the construction sites selected are located in reef flats with the lowest hermatypic coral coverage or where hermatypic corals are mostly dead.*"

Comment: While it is correct that the reef flat environments of the impacted reefs appeared to have been degraded to some extent before construction began, Subi Reef reportedly had higher coral cover on the reef flat than on the outer slope, and the lagoonal reefs of Mischief and Subi Reefs had significant coral communities which have been severely impacted, and likely killed for the most part, by construction-related dredging and sedimentation. Furthermore, reef flat environments have high levels of primary productivity and are unique habitats for juvenile fishes, as described in Section V.

> "*The following specific environmental protection measures were implemented to minimize the impact on coral reefs, including:*
>
> *1) minimizing the extent of the reclamation and dredging areas;*

Comment: This is of course a relative statement, as the necessary extent of reclamation and dredging areas depend on the intended use of the reclaimed area. On the largest reefs (Mischief and Subi Reef), about half and 60% of the reef respectively have been lost due to land reclamation. Dredging-related sediment plumes have affected nearly all of the lagoon areas of these two reefs. However, at the third-largest reef (Johnson Reef), only about 2% of the reef flat area was covered by reclaimed land.

> *2) setting trash collecting screens;*

Comment: It is not entirely clear what kind of trash this refers to. No indication of sediment screens is visible on the available aerial and satellite imagery, and sediment plumes extent far beyond the immediate areas of dredging and land-filling.

> *3) timing construction reasonably, trying to avoid spawn periods of red snapper (mid-April), tuna (peak from June to August) and bonito (from March to August);*

Comment: As visible from the periods of largest growth in land area derived from satellite imagery (Figs. 1-7 above) and on satellite and aerial imagery[287], land construction has occurred in April on all reefs except Gaven Reef, between June and August on Cuarteron, Mischief and Gaven Reef, and between March and August on Cuarteron and Mischief Reef. According to the statement above, construction activities on several reefs thus coincided with the spawning periods of red snapper, tuna and bonito.

> 4) *monitoring the change of grain size of sand sediments regularly, ensuring that the area where sands are taken always consists of grits and avoiding fine sands from going into reclamation areas to maintain the water quality of coral reef areas;*

Comment: To what extent regular monitoring took place and the source area for sediments was selected according to sediment characteristics cannot be ascertained based on the available information. However, satellite and aerial imagery shows clearly that the water quality in the vicinity of each construction site was affected by increased sediment load and turbidity from dredging[288].

> 5) *reducing construction intensity during the peak of growth of Nansha and Xisha coral reefs, monitoring the turbidity change of waters dynamically and adjusting dredging intervals in light of the biological characteristics of coral reefs;*

Comment: Coral growth is light- and temperature-dependent[289], which in the Spratly Islands are at their maximum in spring and early summer[290]. As mentioned above, construction took place throughout this time. To what extent the environment was monitored throughout the construction activities, and dredging intervals adjusted, cannot be ascertained based on the available information.

> *6) monitoring the growth and health of coral reefs in construction areas and indicators such as species, population and diversity of swimming animals and plankton in coral reef areas;*
>
> *7) centrally collecting the waste water and solid waste produced from life and construction to be sent for treatment at land facilities of harbours;*
>
> *8) using newer vessels to ensure no oil spill happens; listening to weather and marine condition forecasts regularly and making prior preparation for typhoons and strong waves to avoid the loss of sands from structures.*"

Comment: The accuracy of these three statements cannot be verified based on the available information. At least one of the vessels used in the construction activities, the

---

[287] Annex 597, 781-792, 795.
[288] Annex 597, 781-792, 795.
[289] Lough, J. M., & Barnes, D. J. (2000) "Environmental controls on growth of the massive coral Porites," *Journal of Experimental Marine Biology and Ecology,* 245: 225-243.
[290] Yu et al. *op. cit.* ref. 84.

cutter suction dredger “Tianjang Hao”, is a modern vessel that has been in operation since 2010[291].

> “*After years of research and practice, domestic and international experts have experimented several ways to restoring coral reef ecosystems and designed multiple structures of artificial coral reefs, which proved that the restoration of coral reef communities could be realized should effective measures be taken.*”

Comment: This is a broad statement that does not do justice to the complexities of reef restoration science. Restoration is not likely to succeed if stressors (such as sedimentation and destructive fishing) persist, and if ecological connectivity and larval supply are disturbed. In the latter case, transplantation of coral fragments if required to re-introduce corals, and this is generally not recommended for large-scale impacts, as it simply displaces the impact over a larger area from which fragments are sourced[292]. In general, active reef restoration is recommended mostly for impacts of limited spatial extent – it has been carried out with some success only at scales of up to a few hectares[293]. Furthermore, transplantation is not likely to succeed as long as sedimentation persists[294], which will be the case in large parts of the area affected by the construction activities. Reef restoration scientists underline the need to balance a confidence in restoration with an acknowledgement that we may never know enough to create a fully natural ecosystem, and caution that overconfidence in the ability to restore nature may serve as an excuse for further degradation[295]. Indeed, a state-of-the-art guideline on reef restoration written by one of the foremost experts in the field, Alasdair Edwards, underlines that “[i]t should be emphasised to decision-makers that restoration science is still a long way from being able to recreate fully functional reef ecosystems”[296]. As the above statement by the two Chinese scientists does not detail what they mean by ‘effective measures’, the validity of their statement is difficult to assess.

> “*After assessing the construction’s environmental impact on coral reefs, the health of Nansha coral reefs were still rated “sub-healthy” after the construction was completed. Therefore, the construction activities neither affected the health of the ecosystems of Nansha nor harmed the coral reef ecosystems.*”

---

291 Annex 858.
292 Challenger, G. E. (2006) "International trends in injury assessment and restoration," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press; Edwards, A. J., & Clark, S. (1999) "Coral Transplantation: A Useful Management Tool or Misguided Meddling?" *Marine Pollution Bulletin,* 37: 474-487.
293 Edwards, A. J., & Gomez, E. D. (2007) *Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty*. St. Lucia, Australia: Coral Reef Targeted Research & Capacity Building for Management Programme.
294 Edwards & Clark *op. cit.* ref. 292.
295 Vidra, R. L. (2006) "Ethical dilemmas in coral reef restoration," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press.
296 Edwards, A. J. (2010) "Reef Rehabilitation Manual.," St Lucia, Australia: Coral Reef Targeted Research & Capacity Building for Management Program: p. 3.

Comment: As information on potential post-construction monitoring of the impacted reefs is not available, the alleged results of such an assessment cannot be verified. However, as described in detail above (Section VI), the available evidence leaves little doubt that the coral reef ecosystems of the seven affected reefs have suffered significant and extensive harm as a result of construction activities.

> "*In fact, due to the strong currents and waves in Nansha waters, the water bodies are updated fairly fast so that little suspended sands are produced from the constructions, leaving the photosynthesis of corals largely unaffected. Because the sites are located in areas where coverage of coral reefs is low, the overall community structure of coral reefs is not changed. In addition, since oceanographic and sediment status changes are only limited to areas near the construction sites, the physical and chemical living environment of coral reefs are not fundamentally changed, therefore their health was not significantly harmed by the construction activities. Plankton would also be replenished fairly quickly.*"

Comment: The available imagery of the construction process shows significant sediment plumes at all impacted reefs. At Subi, Mischief and Fiery Cross Reef, the sediment plumes are seen to envelop large sections of the outer reef slope, indicating that at least within the nearer vicinity of land reclamation, reef communities were subject to intense sedimentation impacts. Furthermore, as described above, within the lagoons of Mischief and Subi Reef, water exchange is limited, and the sediment plumes generated by dredging will thus have remained in the water column for several weeks. As coral species differ in their susceptibility to sedimentation and turbidity based on their morphology[297], the sedimentation plumes are very likely to have altered the community structure of the affected coral reefs. As described above (Section VI), the construction activities have permanently altered the hydrodynamics of the affected reefs, and the resuspension of sediments generated by the dredging activities is likely to maintain an elevated level of sediments, from months to years in those parts of the reefs that are well-flushed by open ocean waters, and from years to decades in areas with less flushing, such as the lagoons of Mischief and Subi Reef (see Table 1 in Section V).

> "*As to the impact of reclamation activities on fishery resources, on the one hand, because the construction avoided the spawning seasons of the main economic species, the impact on fishery resources is reduced to the minimum. Since the main spawning ground of some of these economic species including tuna is in the equatorial waters, the construction would not affect the spawning of tuna. Studies have shown that South China Sea is not a body of closed waters, therefore nutrients and food organisms can be replenished constantly from surrounding waters. Thus, the reclamation activities have not significantly harmed fishery resources.*"

Comment: The available information shows that construction activities occurred during the spawning seasons of several species, including fishes and corals. To what effect the

[297] Erftemeijer et al. *op. cit.* ref. 134.

spawning of tuna was affected by the construction activities cannot be determined based on the available information. As tuna spawn in open pelagic waters, it is unlikely that they were directly affected by construction, but indirect effects e.g. via food resources, construction noises or pollutants cannot be ruled out. As discussed in Sections III.5 and VII, the Spratly Islands have been identified in a number of studies as important potential sources of larvae for coastal reefs throughout the South China Sea, in particular the western Philippines. There is thus a high likelihood that reclamation activities have significantly harmed fishery resources.

> "*Research has also shown that coral reefs have strong capability of self-restoration. Generally speaking, coral reefs that have been severely damaged by natural factors or human activities can be restored initially in 5-10 years provided that effective measures are taken, and complex and complete ecosystems can be fully restored in 50-100 years.*"

Comment: As discussed in Sections III.2 and VIII, the recovery potential of reefs is highly context-dependent, and is reduced if damage is extensive, the surrounding environment is affected by human impacts, larval connectivity is limited, and stressors such as sedimentation remain, as is the case for the seven reefs considered here. Under the best possible conditions, recovery of coral communities takes upwards of ten years, and in that case will consist only of fast-growing species. Large parts of the seven reefs have been permanently destroyed by construction, and for the remaining areas, recovery is uncertain and, if it occurs, it will take more than a century until the large massive coral colonies have regrown. It not very clear what is meant by "effective measures" – this could refer either to measures to improve the environmental conditions by attempting to remove lingering stressors, or to active restoration activities. Restorative activities are extremely expensive and have only ever been attempted on small scales, far smaller than the scale of reclamation impacts[298].

> "*Even so, after the construction is completed, it is important to enhance monitoring of regional ecosystems and implement measures including release, coral restoration and transplantation in order to better protect the coral reefs.*"

Comment: The point of coral reef restoration has been addressed in a previous comment above. This statement further emphasises coral transplantation as a means to restore the impacted reefs. Coral transplantation is unlikely to be a suitable approach for restoration of the impacted reefs for a number of reasons. First, the resuspension of residual sediments will reduce the suitability of the affected reef areas for coral survival and growth for a long time (weeks up to decades, depending on specific local environmental conditions)[299]. Second, a large amount of transplants will have to be sourced from elsewhere. If they are transplanted from other Spratly reefs, this means considerable additional impact on the region's reefs, with uncertain prospects of success. If they are meant to be sourced from coral farms or reefs outside the region,

[298] Edwars & Gomez *op. cit.* ref. 293.
[299] See discussion under Section VIII above; McCook et al. *op. cit.* ref. 134.

there is a risk of introducing non-native species and genotypes, reduced genetic diversity, and non-compatibility in terms of environmental requirements[300]. Third, the affected area is on a scale that exceeds previous restoration efforts, and transplantation on such a large scale will be prohibitive in terms of labour and associated costs[301].

3. China State Oceanic Administration, "Construction Work at Nansha Reefs Will Not Harm Oceanic Ecosystems" (18 June 2015; Annex 821)

> "*The expansion of the Nansha reefs will abide rigorously by <u>the concept of "Green Construction, Eco-Friendly Reefs" in protecting the ecosystems</u>. This protection of the ecosystems is integrated in the stages of planning, design, and construction. Based on the premise that <u>the affected area, duration of construction, effects on the environment, and the ecological recovery time will be kept to a minimum</u>, and through thorough research, rigorous logic, and dynamic protective measures, we strive to minimize the ecological effects during construction, heeding the requirements of engineering as well as ecological protection, in realizing the goal of sustainable development of the Nansha reefs.*"

Comment: Without access to further background documents on the planning and execution of construction work, it is not clear what the concept of "Green Construction, Eco-Friendly Reefs" means. As discussed in Sections VI, VII and VIII, and in the comments to other statements above, the affected area is substantial, with up to 60% of the reef flat area of affected reefs immediately destroyed by dredging and land reclamation. The time of construction, lasting several months for the phase of active land reclamation, included peak spawning times of several species, and peak times of coral growth. Construction activities have led to extensive impacts, in large parts permanent, on the reef environment, and large sediment plumes could be observed in connection with construction activities. Lastly, as discussed extensively in Section VIII, the ecological time of recovery for the affected reefs will be considerably longer than for healthy reefs, partly as a result of construction activities.

> "*The expansion of the Nansha reefs uses the "nature simulation" method as its comprehensive technical concept. <u>This method simulates the displacement of bioclasts such as corals and sands during wind storms and high waves; this biological detritus settles on the combined equilibrium points of the shallow reef flats to form stable supratidal zones which then evolve into oceanic oases</u>. Big cutter suction dredgers are used <u>to collect the loose coral fragments and sands in the lagoon</u> and deposit them on bank-inset reefs to form supratidal platform foundation on which certain kinds of facilities can be built. Through the natural functions of the air, the rain, and the sun, paving it with some quick man-made material, <u>the land reclamation area will produce the ecological effects by going</u>*

[300] Edwards & Clark *op. cit.* ref. 292; Zimmer, B. (2006) "Coral reef restoration: an overview," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press/Taylor and Francis.
[301] Edwards & Gomez *op. cit.* ref. 293; Zimmer *op. cit.* ref. 300.

from desalination, solidification, efflorescence, to a green coral reef ecological environment."

Comment: This statement misses one critical aspect of reef island formation and maintenance: the role and importance of biogenic sediment production (i.e. sediment production stemming from the activities of living organisms)[302], described in Section III.4. While the construction activities utilise carbonate fragments and sands that were produced biologically, they simultaneously impact the very biota that are the basis for sediment generation in the first place (mostly corals, foraminifera, and calcareous algae). Rather than simulating the natural process of island development, the construction process increases the erosion of the reefs by shifting the balance between carbonate accretion and erosion, and thus increases the risk of drowning the reef as sea levels continue to rise.

"*The construction work adopts the measures of ecological protection.*

a. To plan construction projects on bank-inset reefs made of basically dead corals: use a cutter suction dredger to collect loose coral fragments and sands from flat lagoon basins, which do not constitute hospitable environment for corals, to fill the land reclamation areas.

Comment: While the deep lagoon basins contained less live corals than other reef habitats, they nonetheless constituted a vital habitat for benthic macrofauna, such as molluscs, echinoderms and crustaceans. On the reefs lacking a deep lagoon (Hughes, Cuarteron, Gaven and Johnson Reef), material for land reclamation was gathered by excavating parts of the shallow reef flat habitat with the use of cutter suction dredgers. In all cases, land reclamation targeted shallow reef flat habitat, which (as outlined in Section IV) contained higher amounts of live coral, is the habitat with the highest primary productivity, and likely constitutes an important nursery for juvenile fishes. Furthermore, sediment plumes from dredging have affected both lagoon and outer reef slope habitats. Thus, the dredging impacts were not confined to the deep lagoon basins.

b. We used a new "dig, cutter suction, blow, and fill" land reclamation method to integrate digging, transporting, and filling into the construction work; this results in the least ecological impact to the coral reefs.

Comment: To our knowledge, the cutter suction dredge operation employed by China does, if employed correctly, create less of a plume than other forms of dredging (see Section V above). In terms of the relative impact on coral reefs, this statement may thus be accurate (although an engineer would be better qualified to judge the accuracy of this statement).

c. At the same time that the land reclamation work is in progress, use slope model of concrete to build permanent protective banks and walls around the land area to

[302] Perry, C. T., Kench, P. S., Smithers, S. G., Riegl, B., Yamano, H., & O'Leary, M. J. (2011) "Implications of reef ecosystem change for the stability and maintenance of coral reef islands," *Global Change Biology,* 17: 3679-3696.

fend off waves. We have to enclose, to fill, and to protect at the same time, and also to contain floating substances.

Comment: Sloping concrete banks are visible from a number of aerial photographs of construction activities[303]. Such sloping surfaces are important to dissipate wave energy and provide a stable substrate for the recruitment of benthic biota[304]. However, the aerial and satellite images also show that a systematic bunding of reclamation areas did not take place, and that even in areas where concrete banks were constructed, significant sediment plumes extended from the area of reclamation into the surrounding reefs and waters[305]. Further, as noted above, one (non-official) Chinese-language description of the construction activities underlines that damming facilities were not necessary and "minor losses through drifts" accepted during the dredging activities in the Spratly Islands[306].

d. The construction embraces the concepts of containment of scope, high efficiency, and sustainability. The duration of construction for every land reclamation project on the reefs will only be about several months."

"*The construction work on the Nansha reefs stresses ecological protection. Many protection measures were adopted in the stages of planning, design, and construction. Good results have been obtained, and the ecological impact on the coral reefs is partial, temporary, controllable, and recoverable.*"

Comment: Summing up the responses to the previous statements, ecological impacts from the construction activities affected large parts of the reefs and include permanent (for reclaimed reef flats and excavated channels) and long-lasting (for sediment resuspension in lagoons) effects. The extensive sediment plumes visible from aerial and satellite imagery that remained near the construction areas for several weeks to months render the amount of control over potential impacts doubtful. For large areas of reef affected by the construction activities, recovery is unlikely, or may take decades to centuries.

4. Statement by the president of the National Institute for South China Sea Studies, Wu Shicun

In an article of the ABC news of January 25, 2016, there was a statement by the president of the National Institute for South China Sea Studies, Wu Shicun, saying that strict ecological protection measures were guiding the construction China is carrying

[303] Annex 597, 783, 785.

[304] PIANC *op. cit.* ref. 134.

[305] Annex 597, 783, 785.

[306] Annex 737.

out on seven reefs[307]. Although not an official spokesman, Wu Shicun's organisation is overseen by the powerful State Council.

The "*green construction ethos*" of the project "*ensures the affected area is as small as possible, the time period [of construction] is as short as possible and the level of impact is minimal*", according to a translation of Mr. Wu's response to questions from the ABC. In a bid to allay environmental concerns, he said the construction was on reefs that are "*already dead*"[308].

Comment: Statements of 'as small as possible', 'as short as possible' and 'minimal' are, of course, relative and depend on the aims and requirements of construction. However, the extent of reclamation activities and their environmental impact are unprecedented for the region. As described in detail in Section IV, while none of the reefs were in a pristine state prior to construction activities, each of them hosted diverse habitats and coral communities, in some cases with coral cover up to 90%. However, there are indications of extensive damage to the shallow reef flat area on the seven reefs from clam shell dredging by Chinese fishermen preceding the onset of construction activities, and according to the ecologist Prof. John McManus this prior damage may be the foundation for the claim that construction took place on reefs that were "already dead"[309].

Mr. Wu said the material being dredged to reinforce the new facilities was "*dead coral debris*".[310]

Comment: While the material used in reclamation of the atolls (Mischief and Subi Reef) was apparently gathered from deep lagoon habitats which contain few, if any, live corals, on the other reefs, dredging activities targeted reef slopes or shallow reef flats, which based on available information (described in Section IV) contained diverse coral communities.

[307] Birtles, B. (2016) "South China Sea coral reef destruction 'recoverable', Chinese think-tank chief says," *ABC News* 25. January 2016.
[308] *Ibid.*
[309] McManus *op. cit.* ref. 41.
[310] *Ibid.*

XI. Conclusions

Based on the considerations and findings set out in this report, we conclude that:

- China's recent construction activities have and will cause environmental harm to coral reefs at Cuarteron Reef, Fiery Cross Reef, Gaven Reef, Johnson Reef, Hughes Reef, Mischief Reef, and Subi Reef; beyond the pre-existing damage to reefs that resulted from destructive fishing and the collection of corals and clams, storm damage, Crown-of-Thorns starfish, and the human presence on small garrisons on the reefs. The scale of these previous impacts generally cannot be compared with the environmental harm caused by the construction activities, both in terms of spatial extent and duration.

- The harm caused by direct burial of reef habitat during the construction of artificial islands is near-permanent. The duration of harm to areas affected by dredging and dredging-related release of sediments and nutrients and the prospects and likely rates for rejuvenation differ depending on the environmental setting of each particular affected habitat area. We expect that the harm to areas affected by dredging for navigable channels and basins will likely be near-permanent and that the prospects for rejuvenation are low, particularly as long as maintenance dredging for the use of the artificial islands continues. Second, where major geomorphological structures have been removed through dredging, such as large coral 'bommies' (accumulations of corals that typically stand several metres above the substrate), there is little prospect for recovery on ecological time scales. These structures constitute accumulated reef growth on geological time scales of centuries to millennia. This statement applies to much of the lagoon and deeper parts of the reef flat where these features (bommies or patch reefs) have been described in the Spratly Islands. Harm to areas affected by smothering of sediments and increased turbidity, which includes most of the lagoons at Mischief and Subi Reefs and parts of the outer reef slopes of all seven reefs, is likely to endure for years to decades within the lagoons (due to limited water exchange), and for weeks to months on the outer reef slopes. Rejuvenation of these areas is possible (provided chronic stressors such as sedimentation are removed and recurrent stressors such as bleaching events are infrequent), but will take several decades, and it will likely take centuries for large massive colonies to regrow.

- China's construction activities have led to reduced productivity and complexity of the affected reefs, with significant reductions of nursery habitat for a number of fish species. Therefore, not only will the reefs affected by construction have a greatly reduced capacity to sustain local fisheries but their ability to help replenish the fisheries of neighbouring jurisdictions will also be vastly diminished – at least threefold. The construction activities thus will have a broader impact on the marine ecosystem in and around the South China Sea and on fisheries resources. However, the magnitude of this impact will depend on the relative role of the seven affected reefs as critical habitat and source of larvae for fisheries resources compared to other reefs in the Spratly Islands, which is difficult to quantify due to a lack of empirical studies. On the basis of available information, cascading effects cannot be ruled out.

- The two expert reports presented by the Philippines are generally accurate, though occasionally overestimate or understate the damage, in respects that are set out in this report.

- The statements by Chinese officials and scientists about the environmental impact of the construction activities on the reefs were found to contradict the available information reviewed in this report. The statements underestimate the kind and extent of damage and the long-lasting environmental impact of its activities, with up to 60% of the shallow reef flat habitat permanently damaged, limited prospects of recovery in excavated channels, and a likely recovery time of decades to centuries in reef areas affected by increased sedimentation, turbidity and nutrients as a result of construction activities.

Dated: 26 April 2016

Dr. rer. nat. Sebastian Ferse

Prof. Peter Mumby, Ph.D.

Dr. Selina Ward, Ph.D.

ANNEX

ANNEX A: Curricula Vitae of the Authors

Leibniz Centre for Tropical Marine Ecology (ZMT)
Fahrenheitstraße 6
28359 Bremen
Germany

Office: +49 (0)421-2380028
Fax: +49 (0)421-2380030

Email: sebastian.ferse@leibniz-zmt.de

Educational History

PhD — Department of Chemistry and Biology, University of Bremen, Germany — 2008
Supervisors: Prof. Dr. Matthias Wolff, Dr. Andreas Kunzmann
Title of thesis: 'Artificial reef structures and coral transplantation: fish community responses and effects on coral recruitment in North Sulawesi/Indonesia',
Final grade: *magna cum laude*

MSc — Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany — 2004
Supervisors: Prof. Dr. Matthias Wolff, Dr. Andreas Kunzmann
Title of thesis: 'Growing corals in an ocean-based nursery: The use of cages'
Final grade: *A*

Vordiplom — Department of Biology, Georg August University Göttingen, Germany — 2001
Final grade: *A*

Research and Professional Experience

2014-15 *Visiting Scientist*, Geography Department, University of Hawaii Mānoa, USA. Host: Prof. Dr. Camilo Mora

2013 since September: *Junior Research Group Leader*, Human Agency, Resilience and Diversity in Coral Reefs, Leibniz Center for Tropical Marine Ecology, Bremen, Germany

2012-13 *Project Coordinator*, collaborative project in BMBF-funded SPICE III program (Science for the Protection of Indonesian Coastal Ecosystems), Topic 1 (MABICO - Impacts of marine pollution on biodiversity and coastal livelihoods)

2012-13 *Post-doctoral Researcher*, Coastal Social-Ecological Systems, Leibniz Center for Tropical Marine Ecology, Bremen, Germany. Advisor: PD Dr. Marion Glaser

2011 September – December: *Post-doctoral Researcher*, Coral Reef Ecology, Leibniz Center for Tropical Marine Ecology, Bremen, Germany. Advisor: Prof. Dr. Christian Wild

2011 January – August: *Post-doctoral Researcher*, Coastal Social-Ecological Systems, Leibniz Center for Tropical Marine Ecology, Bremen, Germany. Advisor: PD Dr. Marion Glaser

2008-10 *Post-doctoral Researcher*, SPICE II project, Coastal Social-Ecological Systems, Leibniz Center for Tropical Marine Ecology, Bremen, Germany. Advisor: PD Dr. Marion Glaser

2005-07 *Field Research*, North Sulawesi/Indonesia as guest scientist at Sam Ratulangi University (UNSRAT), Manado (Ecological effects of coral transplantation and artificial reefs)

2003-04 *Guest Student*, Bogor Agricultural University (IPB), Java, Indonesia

2003-04 *Field Research*, Sambangan Island, Karimunjawa National Park, Central Java, Indonesia (Use of cages in ocean-based farming of coral fragments)

2003-04 *Research Assistant*, Leibniz Centre for Tropical Marine Ecology, Bremen, Germany,MADAM (Mangrove Dynamics and Management) project, Dr. Marion Glaser

2002 *Research Assistant*, Moorea, French Polynesia (Population regulation in a mutualistic reef fish [*Ctenogobiops feroculus*]), Andrew Thompson, University of California, Santa Barbara (UCSB)

2001-02 *Guest Student*, Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara (UCSB), USA

Teaching Experience

2016-19 *Additional supervisor* [member of PhD panel], PhD thesis of Jennifer Bachmann, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2016 *External supervisor*, Sarjana 1 thesis (BSc equivalent) of Yuda Perdana, Department of Marine Science and Technology, Bogor Agricultural University, Bogor, Indonesia

2016 *Supervisor*, MSc thesis of Élyne Dugény, Msc SDUEE Oceanography and Marine Environments, Pierre and Marie Curie University, Paris, France

2016 *Supervisor*, MSc thesis of Robin Gauff, Msc SDUEE Oceanography and Marine Environments, Pierre and Marie Curie University, Paris, France

2015-18 *External Supervisor*, PhD thesis of Beginer Subhan, Department of Marine Science and Technology, Bogor Agricultural University, Bogor, Indonesia

2015-16 *Co-Supervisor*, MSc thesis of Emmanuella Orero, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-16 *Co-Supervisor*, MSc thesis of Isabell Kittel, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-16 *Co-Supervisor*, MSc thesis of Tobias Schneider, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-16 *Supervisor*, MSc thesis of Andreas Eich, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-16 *Supervisor*, MSc thesis of Ryan McAndrews, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-16 *Supervisor*, MSc thesis of Steven Lee, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015-18 *Additional supervisor* [member of PhD panel], PhD thesis of Stefan Partelow, Leibniz Center for Tropical Marine Ecology/Jacobs University, Bremen, Germany

2015 *External Examiner*, PhD thesis of Wahyu Nugraha, Newcastle University, UK

2015 *Examiner*, MSc thesis of Lena Heel, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2015 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis)

2014-17 *Co-Supervisor*, PhD thesis of Janne Rohe, Leibniz Center for Tropical Marine Ecology/Jacobs University, Bremen, Germany

2014-17 *Additional supervisor* [member of PhD panel], PhD thesis of Katie Nelson, Leibniz Center for Tropical Marine Ecology/Jacobs University, Bremen, Germany

2014-15 *Co-Supervisor*, MSc thesis of Jan-Claas Dajka, Marine Biology, University of Bremen, Germany

2014 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis)

2014 *Assistant Instructor,* German Scientific Diver Training, ZMT Bremen

2013-16 Co-*Supervisor*, PhD thesis of Akuila Cakacaka, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2013-16 *Supervisor*, PhD thesis of Amanda Ford, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2013-16 *Additional supervisor* [member of PhD panel], PhD thesis of Claudia Pogoreutz, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2013-14 *Co-Supervisor*, MSc thesis of Steffi Meyer, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2013-14 *Supervisor*, MSc thesis of Pilar Velásquez Jofre, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2013-14 *Supervisor*, MSc thesis of Riki Nakajima, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2013-14 *Co-Supervisor*, MSc thesis of Mary Namukose, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2013-14 *Supervisor*, MSc thesis of Nur Garcia Herrera, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2013 *Lecturer*, Marine Ecology Summer Training, Center for Coral Reef Research, Hasanuddin University, Makassar, Indonesia (A social-ecological systems approach to coral reef fisheries in Spermonde)

2013 *Lecturer*, MPA Summer School of the SUTAS (Sustainable Use of Tropical Aquatic Systems) Graduate School, Leibniz Center for Tropical Marine Ecology, Bremen, Germany (Interdisciplinary approaches for Marine Protected Area research and creation: what role for (tropical) coastal communities?)

2013 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis)

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Jeremiah Plass-Johnson, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Gunilla Baum, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Pia Kegler, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Roger Spranz, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Thomas Mann, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-15 *Additional supervisor* [member of PhD panel], PhD thesis of Anke Mösinger, Leibniz Center for Tropical Marine Ecology/University of Lucerne, Germany

2012-13 *Additional supervisor* [member of PhD panel], PhD thesis of Szilvi Cseke, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2012-13 *Supervisor*, MSc thesis of Nicole Herz, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2012-13 *Supervisor*, MSc thesis of Godfrey Fabiani, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2012-13 *Supervisor*, MSc thesis of Ima Kusumanti, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2012 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis; Interdisciplinarity between natural & social sciences in coastal management)

2011-14 *Additional supervisor* [member of PhD panel], PhD thesis of Maren Kruse, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2011-14 *Additional supervisor* [member of PhD panel], PhD thesis of Daniella Ferrol-Schulte, Leibniz Center for Tropical Marine Ecology/University of Bremen, Germany

2011-14 *Additional supervisor* [member of PhD panel], PhD thesis of Philipp Gorris, Leibniz Center for Tropical Marine Ecology/Jacobs University, Germany

2012 *Examiner*, MSc thesis of Bishwajit Kumar Dev, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2011-12 *Supervisor*, MSc thesis of Marisol Beltran Gutierrez, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2011-12 *Supervisor*, MSc thesis of John Sebit Benansio, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2011-12 *Supervisor*, MSc thesis of Nancy Gikonyo, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2011-12 *Co-Supervisor*, Diploma thesis of Jana Holler, Marine Biology, University of Bremen, Germany

2011 *Lecturer*, Marine Conservation Workshop, joint workshop of the ISOS and GLOMAR graduate schools, AWI Wadden Sea Station, List/Sylt, Germany (Marine Protected Areas (MPAs) and other forms of marine conservation: what role for (tropical) coastal communities?)

2011 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis; Interdisciplinarity between natural & social sciences in coastal management)

2010-14 *Supervisor*, MSc thesis of Coen Bosboom, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2010-12 *External Supervisor*, Sarjana 2 thesis (MSc equivalent) of Sainab Husain, Department of Fisheries and Marine Science, Hasanuddin University, Makassar, Indonesia

2010-11 *Supervisor*, MSc thesis of Ario Putra, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2010 *Lecturer*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Participatory techniques & stakeholder analysis; Interdisciplinarity between natural & social sciences in coastal management)

2009-10 *Supervisor*, MSc thesis of Marielle Dumestre, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2009-10 *Supervisor*, MSc thesis of Liesa-Marlena von Essen, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2009 *Lecturer*, DKP/IPB Coastal and Marine Management Sandwich Program, Leibniz Centre for Tropical Marine Ecology, Bremen, Germany (Counteracting degradation of reefs: conservation, management and restoration)

2009 *Co-Supervisor*, MSc thesis of Wasistini Baitoningsih, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany

2009 *Lecturer*, Marine Ecology Summer Training, Center for Coral Reef Research, Hasanuddin University, Makassar, Indonesia (Social-Ecological Systems and MPA design)

2009 *Lecturer,* International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Interdisciplinarity between natural & social sciences in coastal management)

2009 *Teaching Assistant*, International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Introduction to systems analysis)

2008 *Lecturer,* International Studies in Tropical Aquatic Ecology (ISATEC), University of Bremen, Germany (Approaches to coastal planning and management)

2007 *Trainer*, Workshop on coral farming for villagers, Pulau Badi, Sulawesi, Indonesia, in co-operation with PT Effem Mars

2006-07 *Volunteer*, Environmental education for guests of Gangga Island Resort, North Sulawesi, Indonesia

2006 *Lecturer*, Short course on coral reef ecology for students from Southern Adventist University, Bunaken, North Sulawesi, Indonesia

2001 *Teaching Assistant*, Botany Department, Georg August University, Göttingen, Germany (Taxonomy and identification of plants, including field excursions)

Scholarships and Grants

2014 *Research Grant*, "Contributing to Coral Commons – Assessing multilevel drivers of reef health" (Leibniz Society), Grant No. SAW-2014-ZMT-1, **116,964 Euro**

2013 *Research Grant*, "Resilience of Pacific Island coral reef social-ecological systems in times of global change" (BMBF), Grant No. 01LN1303A, **1,205,349 Euro**

2013 *Networking Grant*, "PACE-Net Plus" (EU), FP7-INCO-2013-1, Grant No. 609490 (co-authors Kathleen Schwerdtner Máñez and Corinna Harms), **274,615.5 Euro**

2012 *Robert Bosch Junior Professorship 'Sustainable Use of Renewable Natural Resources'*, Robert Bosch Foundation, 2nd place

2012 *Travel Grant*, German Academic Exchange Service (DAAD), **2,500 Euro**

2012 *Research Grant*, SPICE III Topic 3, "The social drivers of coral reef resilience and their social-ecological repercussions" (BMBF), Grant No. 03F0643A (co-authors Marion Glaser and Kathleen Schwerdtner Máñez), **257,210 Euro**

2012 *Research Grant*, SPICE III Topic 1, "Impacts of marine pollution on biodiversity and coastal livelihoods" (BMBF), Grant No. 03F0641A (co-authors Marion Glaser and Andreas Kunzmann), **304,573 Euro**

2010 *Publication Grant*, History of Marine Animal Populations (HMAP) Project, **1,350 US$**

2009 *Travel Grant*, German Academic Exchange Service (DAAD), **1,400 Euro**

2008 *Mentoring Program, Initiative Scientific Journalism*, Robert Bosch Stiftung, Stifterverband für die Deutsche Wissenschaft and BASF, finalist (application withdrawn)

2008 *Travel Grant*, Leibniz Center for Tropical Marine Ecology, **1,200 Euro**

2005-08 *Doctorate Fellowship*, German National Academic Foundation, **~36,000 Euro**

2001-02 *Study Abroad Scholarship*, German National Academic Foundation, **~3,300 Euro**

2001-02 *Student Scholarship*, University of California Education Abroad Program, waiver of tuition fee

1999-2004 *Scholarship*, German National Academic Foundation

Awards and Appreciations

2006 *Young Scientist Award,* best poster presentation, International Society for Reef Studies (ISRS), European Meeting, Bremen

1998 *Award*, Hamburg chapter of the Society of German School Geographers (VDSG), for an exceptional Abitur examination in geography (topic: The sinking of water masses in the Northern Polar Sea and its influence on global climate)

1998 *Hans-Henny-Jahn Award*, Gymnasium Kaiser-Friedrich-Ufer, Hamburg, Germany for several years of committed work as student president and member of the school conference

Further Qualifications

2014 Special training in communication and conflict management, ISAS/ZWM

2014 Training as Dive Mission Leader

2013 European Scientific Diver (ESD)

2008 Training course 'Socio-Economic and Institutional Dimensions of Global Change in the Marine Realm', MARUM/University of Bremen

2008 Special training in efficient lecturing, didactics and presentation design during the course 'presenting science', MARUM/University of Bremen

2008 Special training in project planning, supervision and execution during the course 'project management', MARUM/University of Bremen

2007 Open Water SCUBA Instructor (PADI)

2007 Emergency First Response Instructor

2002 Research Diving Certification, American Association of Underwater Scientists (AAUS), University of California, Santa Barbara, USA

Symposia, Workshops and Conferences

- Science for the Protection of Indonesian Coastal Marine Ecosystems (SPICE) Final Conference, Udayana University, Denpasar, Indonesia, 20-21. January 2016
- Small Islands Research in Tropical Regions (SIRTRE): The Spermonde Archipelago and other Case Studies, Hasanuddin University (UNHAS), Makassar, Indonesia, 15-16. September 2015
- PACE-Net+ Bi-regional Platform, Brussels, Belgium, 23-24. June 2015
- 5th Coral Reef Ecology Symposium, Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany, 22. May 2015 (organizer)
- Reef Conservation UK Symposium, Zoological Society London (ZSL), UK, 06. December 2014
- PACE-Net+ Conference 'Coastal ecosystem disturbances, fish and shellfish poisoning and their socio-economic implications', Noumea, New Caledonia, 18-20. November 2014
- PACE-Net+ Key Stakeholder Conference, Bremen, Germany, 9-11. September 2014 (organizer)
- 4th COral Reef Ecology (CORE) Symposium, Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany, 13. June 2014
- 'Climate Change, Marine Life, and Livelihoods in the Center of the Coral Triangle', International Conference, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, Indonesia, 10-11. September 2013
- 7th Meeting of the European Association of South East Asian Studies, Lisbon, Portugal, 2-5. July 2013
- 12th International Coral Reef Symposium, Cairns, Australia, 9-13. July 2012
- Study Group on Socio-Economic Dimensions of Aquaculture (SGSA) Annual Meeting, Beijer Institute for Ecological Economics, Stockholm, Sweden, 23-26. April 2012
- PACE-Net Key Stakeholder Conference, Brussels, Belgium, 20-23. March 2012
- YOUMARES 2.0. Oceans amidst science, innovation and society. 2nd Young Marine Research network meeting. Session chair "Living with the sea: Coastal livelihoods and management". Bremerhaven, Germany, 7-9. September 2011
- Marine Conservation Workshop, joint workshop of the ISOS and GLOMAR graduate schools, AWI Wadden Sea Station, List/Sylt, Germany, 19-21. August 2011
- Study Group on Socio-Economic Dimensions of Aquaculture (SGSA) Annual Meeting, Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany, 12-14. April 2011
- Resilience 2011. Resilience, Innovation and Sustainability: Navigating the Complexities of Global Change. Second International Science and Policy Conference, Tempe, AZ, USA, 11-16. March 2011
- 2010 European Meeting of the International Society for Reef Studies (ISRS), Wageningen, The Netherlands, 13-17. December 2010

- 11th Biennial Conference of the International Society for Ecological Economics (ISEE): ‘Advancing Sustainability in a Time of Crisis’, Oldenburg & Bremen, Germany, 22-25. August 2010
- International Seminar on Small Islands and Coral Reef Management, Ambon, Indonesia, 04-06. August 2010
- *Young* marine research: Diversity and similarities. 1. German Young Marine Scientist Meeting, ZMAW Hamburg, Germany, 12. June 2010
- International SPICE Workshop “Developing theory and supporting policy through multi-level socio-ecological analysis in the context of coastal and marine resources governance”, Bogor, Indonesia, 14-15. April 2010
- 12. Fish International, Bremen, Germany, 21-23. February 2010
- ‘Building Indonesia’s status as a maritime continent’, Seminar at Hasanuddin University, Makassar, Indonesia, 12. January 2010
- International Ocean, Science and Policy Symposium at the World Ocean Conference 2009, Manado, Indonesia, 12-14. May 2009
- 3rd Coral Reef Ecology (CORE) working group Mini Symposium, Munich, Germany, 4. May 2009
- 11th International Coral Reef Symposium, Fort Lauderdale, Florida, USA, 7-11. July 2008
- Sustainable Mariculture Meeting & Workshop, Makassar, Indonesia, 27-30. November 2007
- 1st International Symposium for Occupational Scientific Diving, AWI, Bremerhaven, Germany, 15-16. October 2007
- SPICE/LOICZ/ATSEF/SEACORM (SLAS) Southeast Asia Coastal Governance and Management Forum: Science Meets Policy for Coastal Management and Capacity Building, Bali, Indonesia, 14-16. November 2006
- International Society for Reef Studies European Meeting 2006, Bremen, Germany, 19-22. September 2006
- International Workshop-cum-Training Course on Coastal Ecosystem: Hazards Management and Rehabilitation, UNSOED, Purwokerto, Indonesia, 8-17. August 2006
- 3rd BioRock Workshop, Bali, Indonesia, 21-28. November 2005
- 7. Internationales Meerwasser-Symposium, Lünen, Germany, 11-13. March 2005
- Coral Reef Conservation Symposium, Zoological Society London (ZSL), UK, 16-17. December 2004

Memberships

- Head of Scientific Council of the ZMT
- International Society for Reef Studies
- International Society for Ecological Economics
- Deutsche Gesellschaft für Meeresforschung (DGM)
- ICES Working Group on Socio-Economic Dimensions of Aquaculture (WGSA)
- Word-Wide Fund for Nature (WWF) Indonesia
- Professional Association of Dive Instructors (PADI)
- Alumni der Studienstiftung e.V.

Reviewing and Evaluation

Scientific publications

Reviewer for AMBIO, Aquatic Biology, Aquatic Conservation: Marine and Freshwater Ecosystems, Coastal Management, Coral Reefs, Ecological Engineering, Ecology and Society, Environmental Conservation, Global Environmental Change, Frontiers in Marine Science, Journal of Experimental Marine Biology and Ecology, Journal of Marine Science and Engineering, Marine Pollution Bulletin, Ocean & Coastal Management, Oceanologia, Pacific Science, PeerJ, PLoS ONE, Regional Environmental Change, Restoration Ecology, Science of the Total Environment, Sustainability

Member of the Editorial Board of PLoS ONE

Grant and funding evaluation

Studienstiftung des deutschen Volkes (German National Academic Foundation)

National Geographic Society

Publications

Peer-reviewed journals

Plass-Johnson J.G., M.H. Taylor, A.A.A. Husain, M.C. Teichberg & S.C.A. **Ferse** (2016): Non-random variability in functional composition of coral reef fish communities along an environmental gradient. *PLoS ONE* 11(4): e0154014. doi:10.1371/journal.pone.0154014.

Dsikowitzky L., S.C.A. **Ferse**, J. Schwarzbauer, T.S. Vogt & H.E. Irianto (in press): Impacts of megacities on tropical coastal ecosystems — The case of Jakarta, Indonesia. *Marine Pollution Bulletin*. doi:10.1016/j.marpolbul.2015.11.060.

Namukose M., F.E. Msuya, S.C.A. **Ferse**, M.J. Slater & A. Kunzmann (in press): Growth performance of the sea cucumber *Holothuria scabra* and the seaweed *Eucheuma denticulatum*: integrated mariculture and effects on sediment organic characteristics. *Aquaculture Environment Interactions*. doi:10.3354/aei00172.

Puk L., S.C.A. **Ferse** & C. Wild (2016): Patterns and trends in coral reef macroalgae browsing – a review of browsing herbivorous fishes of the Indo-Pacific. *Reviews in Fish Biology and Fisheries* 26(1): 53-70. doi:10.1007/s11160-015-9412-z.

Beltran-Gutierrez M., S.C.A. **Ferse**, A. Kunzmann, S. Stead, F. Msuya, T. Hoffmeister & M. Slater (2016): Co-culture of sea cucumber *Holothuria scabra* and red seaweed *Kappaphycus striatum*. *Aquaculture Research* 47(5): 1549-1559. doi:10.1111/are.12615.

Baum G., H.I. Januar, S.C.A. **Ferse** & A. Kunzmann (2015): Local and regional impacts of pollution on coral reefs along the Thousand Islands north of the megacity Jakarta, Indonesia. *PLoS ONE* 10(9): e0138271. doi:10.1371/journal.pone.0138271.

Krause G., C. Brugere, A. Diedrich, M.W. Ebeling, S.C.A. **Ferse**, E. Mikkelsen, J.A. Pérez Agúndez, S.M. Stead, N. Stybel & M. Troell (2015): A revolution without people? Closing the people-policy gap in aquaculture development. *Aquaculture* 447: 44-55. doi:10.1016/j.aquaculture.2015.02.009.

Glaser M., A. Breckwoldt, R. Deswandi, I. Radjawali, W. Baitoningsih & S.C.A. **Ferse** (2015): Of exploited reefs and fishers - a holistic view on participatory coastal and marine management in an Indonesian Archipelago. *Ocean & Coastal Management* 116: 193-213. doi:10.1016/j.ocecoaman.2015.07.022.

Plass-Johnson J.G., S.C.A. **Ferse**, J. Jompa, C. Wild & M. Teichberg (2015): Fish herbivory as key ecological function in a heavily degraded coral reef system. *Limnology & Oceanography* 60(4): 1382-1391. doi:10.1002/lno.10105.

Plass-Johnson J.G., H. Schwieder, J. Heiden, L. Weiand, C. Wild, J. Jompa, S.C.A. **Ferse** & M. Teichberg (2015): A recent outbreak of the crown-of-thorns starfish (*Acanthaster planci*) in the Spermonde Archipelago, Indonesia. *Regional Environmental Change* 15(6): 1157-1162. doi:10.1007/s10113-015-0821-2.

Naumann M.S., V.N. Bednarz, S.C.A. **Ferse**, W. Niggl & C. Wild (2015): Monitoring of coastal coral reefs near Dahab (Gulf of Aqaba, Red Sea) indicates local eutrophication as potential cause for change in benthic communities. *Environmental Monitoring and Assessment* 187(2): 44. doi:10.1007/s10661-014-4257-9.

Ferrol-Schulte D., P. Gorris, W. Baitoningsih, D.S. Adhuri & S.C.A. **Ferse** (2015): Coastal livelihood vulnerability to marine resource degradation: a review of the Indonesian national coastal and marine policy framework. *Marine Policy* 52: 163-171. doi:10.1016/j.marpol.2014.09.026.

Ferrol-Schulte D., S.C.A. **Ferse** & M. Glaser (2014): Patron-client relationships, livelihoods and natural resource management in tropical coastal communities. *Ocean & Coastal Management* 100: 63-73. doi:10.1016/j.ocecoaman.2014.07.016.

Plass-Johnson J.G., S.C.A. **Ferse**, C. Wild & M. Teichberg (2014): Observation of macroalgal browsing in juvenile humphead parrotfish, *Bolbometopon muricatum*, in the Spermonde Archipelago, Indonesia. *Bulletin of Marine Science* 90(3): 763-764. doi:10.5343/bms.2014.1006.

Madduppa H.H., N.P. Zamani, B. Subhan, U. Aktani & S.C.A. **Ferse** (2014): Feeding behavior and diet of the eight-banded butterflyfish *Chaetodon octofasciatus* in the Thousand Islands, Indonesia. *Environmental Biology of Fishes* 97(12): 1353-1365. doi:10.1007/s10641-014-0225-z.

Ferse S.C.A., M. Glaser, M. Neil & K. Schwerdtner Máñez (2014): To cope or to sustain? Eroding long-term sustainability in an Indonesian coral reef fishery. *Regional Environmental Change* 14(6): 2053-2065. doi:10.1007/s10113-012-0342-1.

Ferrol-Schulte D., M. Wolff, S.C.A. **Ferse** & M. Glaser (2013): Sustainable Livelihoods Approach in tropical coastal and marine social-ecological systems: a review. *Marine Policy* 42: 253-258. doi:10.1016/j.marpol.2013.03.007.

von Essen L.-M., S.C.A. **Ferse**, M. Glaser & A. Kunzmann (2013): Attitudes and perceptions of villagers towards community-based mariculture in Minahasa, North Sulawesi, Indonesia. *Ocean & Coastal Management* 73: 101-112. doi:10.1016/j.ocecoaman.2012.12.012.

Ferse S.C.A., M.M. Nugues, S.B.C. Romatzki & A. Kunzmann (2013): Examining the use of mass transplantation of brooding and spawning corals to support natural coral recruitment in Sulawesi/Indonesia. *Restoration Ecology* 21(6): 745-754. doi:10.1111/rec.12004.

Schwerdtner Máñez K., S. Husain, S.C.A. **Ferse** & M. Máñez-Costa (2012): Water scarcity in the Spermonde Archipelago, Sulawesi, Indonesia: past, present and future. *Environmental Science and Policy* 23: 74-84. doi:10.1016/j.envsci.2012.07.004.

Glaser M., P. Christie, K. Diele, L. Dsikowitzky, S.C.A. **Ferse**, I. Nordhaus, A. Schlüter, K. Schwerdtner Máñez & C. Wild (2012): Measuring and understanding sustainability-enhancing processes in tropical coastal and marine social-ecological systems. *Current Opinion in Environmental Sustainability* 4(3): 300-308. doi:10.1016/j.cosust.2012.05.004.

Ferse S.C.A., L. Knittweis, G. Krause, A. Maddusila & M. Glaser (2012): Livelihoods of ornamental coral fishermen in South Sulawesi/Indonesia: implications for management. *Coastal Management* 40(5): 525-555. doi:10.1080/08920753.2012.694801.

Madduppa H.H., S.C.A. **Ferse**, U. Aktani & H.W. Palm (2012): Seasonal trends and fish-habitat associations around Pari Island, Indonesia: setting a baseline for environmental monitoring. *Environmental Biology of Fishes* 95(3):383-398. doi:10.1007/s10641-012-0012-7.

Mora C., O. Aburto-Oropeza, A. Ayala Bocos, P.M. Ayotte, S. Banks, A.G. Bauman, M. Beger, S. Bessudo, D.J. Booth, E. Brokovich, A. Brooks, P. Chabanet, J. Cinner, J. Cortés, J.J. Cruz-Motta, A. Cupul Magaña, E. DeMartini, G.J. Edgar, D.A. Feary, S.C.A. **Ferse**, A. Friedlander, K.J. Gaston, C. Gough, N.A.J. Graham, A. Green, H. Guzman, M. Hardt, M. Kulbicki, Y. Letourneur, A. López Pérez, M. Loreau, Y. Loya, C. Martinez, I. Mascareñas-

Osorio, T. Morove, M.-O. Nadon, Y. Nakamura, G. Paredes, N.V.C. Polunin, M.S. Pratchett, H. Reyes Bonilla, F. Rivera, E. Sala, S. Sandin, G. Soler, R. Stuart-Smith, E. Tessier, D.P. Tittensor, M. Tupper, P. Usseglio, L. Vigliola, L. Wantiez, I. Williams, S.K. Wilson &. F.A. Zapata (2011): Global human footprint on the linkage between biodiversity and ecosystem functioning in reef fishes. *PLoS Biology* 9(4): e1000606. doi:10.1371/journal.pbio.1000606.

Glaser M., I. Radjawali, S.C.A. **Ferse** & B. Glaeser (2010): "Nested" community participation in hierarchical societies? Lessons for social-ecological research and management. International *Journal of Society Systems Science* 2(4): 390-414. doi:10.1504/IJSSS.2010.035571.

Glaser M., W. Baitoningsih, S.C.A. **Ferse**, M. Neil & R. Deswandi (2010): Whose sustainability? Top-down participation and emergent rules in marine protected area management in Indonesia. *Marine Policy* 34(6): 1215-1225. doi:10.1016/j.marpol.2010.04.006.

Ferse S.C.A. (2010): Poor performance of corals transplanted onto substrates of short durability. *Restoration Ecology* 18(4): 399-407. doi:10.1111/j.1526-100X.2010.00682.x.

Schwerdtner Máñez K. & S.C.A. **Ferse** (2010): The history of Makassan trepang fishing and trade. *PLoS ONE* 5(6): e11346. doi:10.1371/journal.pone.0011346

Ferse S.C.A., M. Máñez Costa, K. Schwerdtner Máñez, D.S. Adhuri & M. Glaser (2010): Allies, not aliens – increasing the role of local communities in MPA implementation. *Environmental Conservation* 37(1): 23-34. doi:10.1017/S0376892910000172.

Borell E.M., S.B.C. Romatzki & S.C.A. **Ferse** (2010): Differential physiological responses of two congeneric scleractinian corals to mineral accretion and an electric field. *Coral Reefs* 29: 191-200. doi:10.1007/s00338-009-0564-y.

Ferse S.C.A. & A. Kunzmann (2009): Effects of concrete-bamboo cages on coral fragments: evaluation of a low-tech method used in artisanal ocean-based coral farming. *Journal of Applied Aquaculture* 21: 31-49. doi:10.1080/10454430802694538.

Books, theses and proceedings

Glaser M., A. Breckwoldt, D. Henke, S.C.A. **Ferse**, S. Husain & M. Neil (2015): Perceptions of the reef and behaviour towards it: Differentials between divers and non-divers in Spermonde reef fisheries. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde Archipelago and other Case Studies. 15-16. September 2015, Hasanuddin University, Makassar, Indonesia. Book of Abstracts: 19.

Glaser M., A. Breckwoldt, S.C.A. **Ferse**, R. Deswandi, I. Radjawali & W. Baitoningsih (2015): Of exploited reefs and fishers: A holistic view on participatory coastal and marine management in the Spermonde Archipelago. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde Archipelago and other Case Studies. 15-16. September 2015, Hasanuddin University, Makassar, Indonesia. Book of Abstracts: 54.

Kegler P., H. Schwieder, A. Gärdes, S.C.A. **Ferse**, Y.R. Alfiansah, M. Lukman & A. Kunzmann (2015): Identifying correlations of scleractinian coral larvae settlement with bacterial biofilm communities and dominant environmental parameters in Spermonde, Indonesia. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde Archipelago and other Case Studies. 15-16. September 2015, Hasanuddin University, Makassar, Indonesia. Book of Abstracts: 30.

Plass-Johnson J.G., S.C.A. **Ferse**, J. Jompa, C. Wild & M. Teichberg (2015): Fish herbivory as key ecological function in a heavily degraded coral reef system. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde Archipelago and other Case Studies. 15-16. September 2015, Hasanuddin University, Makassar, Indonesia. Book of Abstracts: 39.

Teichberg M., J.G. Plass-Johnson, H. Schwieder, V. Bednarz, J. Heiden, A. Gärdes, S.C.A. **Ferse**, M. Lukman & C. Wild (2015): Linkages between water quality and coral reef benthic and pelagic communities along a nearshore to offshore gradient in the Spermonde Archipelago, Indonesia. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde

Archipelago and other Case Studies. 15-16. September 2015, Hasanuddin University, Makassar, Indonesia. Book of Abstracts: 49.

Bejarano Chavarro S., G. Roff, A. Marshall, I. Chollet-Ordaz, J.-B. Jouffray, R. Steneck, S.C.A. **Ferse** & P. Mumby (2014): Wave exposure a bidirectional force structuring herbivorous fish communities. Reef Conservation UK 2014, 6. December 2014, London, UK. Book of Abstracts: 2.

Schwerdtner Màñez K. & S.C.A. **Ferse** (2013): A window into the past – the role of historical material in reconstructing marine resource use over time. 7th Meeting of the European Association of South East Asian Studies, 2-5. July 2013, Lisbon, Portugal. Book of Abstracts: 366.

Deswandi R., M. Glaser & S.C.A. **Ferse** (2012): What makes a Social System Resilient? Two Fishing Communities in Indonesia. In A.-K. Hornidge & C. Antweiler (eds.) Environmental Uncertainty and Local Knowledge. Southeast Asia as a Laboratory of Global Ecological Change. transcript Verlag, Bielefeld. pp. 243-272.

Ferse S.C.A., M. Glaser, C. Schultz & J. Jompa (2012): Linking research to Indonesia's CTI Action Plan: the SPICE Program. *Proceedings of the 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia*. 17A-1.

Glaser M., W. Baitoningsih, S.C.A. **Ferse**, M. Neil & R. Deswandi (2012): Whose sustainability? Top-down participation in MPA management in Indonesia. *Proceedings of the 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia*. 22A-2.

Nugues M. & S.C.A. **Ferse** (2011): Maßnahmen zum Schutz von Korallenriffen. Chapter 5.5 in J.L. Lozán, H. Graßl, L. Karbe & K. Reise (eds.) Warnsignal Klima: Die Meere – Änderungen und Risiken. Wissenschaftliche Auswertungen, Hamburg. pp. 330-336. [in German]

Ferse S.C.A., L. Knittweis, A. Maddusila, M. Glaser & G. Krause (2010): Livelihood diversity of ornamental fishermen and implications for management in South Sulawesi/Indonesia. In J. Kaandorp, E. Meesters, R. Osinga, J. Verreth & T. Wijgerde (eds.) Euro ISRS Symposium 2010. Reefs in a changing environment. 13-17. December, Wageningen, The Netherlands. Book of Abstracts: 146.

Glaser M. & S.C.A. **Ferse** (2010): Towards a strong basis for coastal conservation: building upon emergent rules and institutions to increase management effectiveness. In J. Kaandorp, E. Meesters, R. Osinga, J. Verreth & T. Wijgerde (eds.) Euro ISRS Symposium 2010. Reefs in a changing environment. 13-17. December, Wageningen, The Netherlands. Book of Abstracts: 142.

Ferse S.C.A., K. Schwerdtner Màñez & A. Kunzmann (2010): Gems of the sea – Assessing the economic potential of ornamental coral reef fishes. Advancing Sustainability in a Time of Crisis. ISEE Conference, 22-25. August 2010, Oldenburg, Germany. Programme and Abstracts: 131.

Ferse S.C.A. (2009): Multivariate responses of the coral reef fish community to artificial structures and coral transplants. *Proceedings of the 11th International Coral Reef Symposium, 6-11 July 2008, Fort Lauderdale, FL, Vol. II*: 1230-1234.

Ferse S.C.A. (2008): Artificial Reefs and Coral Transplantation. Fish Community Responses and Effects on Coral Recruitment in North Sulawesi/Indonesia. VDM Verlag Dr. Müller, Saarbrücken, Germany. 244 p.

Ferse S.C.A. (2008): Reef rehabilitation and natural recovery: does transplantation of coral fragments increase natural recruitment? 11th International Coral Reef Symposium, 6-11 July 2008, Fort Lauderdale, FL. Abstracts: 531.

Ferse S.C.A. & S.B.C. Romatzki (2006): Effects of an electric field on the growth and survival of two *Acropora* species. ISRS European Meeting, 19-22 September 2006, Bremen. Programme and Abstracts: 279.

Ferse S.C.A. (2006): Coral transplantation increases fish abundance and diversity on artificial reefs. ISRS European Meeting, 19-22 September 2006, Bremen. Programme and Abstracts: 278.

Ferse S.C.A. (2004): Growing corals in an ocean-based nursery: The use of cages. MSc Thesis, Zentrum für Marine Tropenökologie (ZMT), Universität Bremen. 64 p.

Other publications

Ferse S.C.A. (2014): Fischerpaten und Seegurken – komplexe Mensch-Natur-Beziehungen im indonesischen Archipel. *KITA, das Magazin der deutsch-indonesischen Gesellschaft* 23(2): 24-29.

Bell J., M. Batty, P. Lehodey, K. Brander, S.C.A. **Ferse**, J.E. Rogier & G. Rücker (2012): Climate Change, Fisheries and Aquaculture in the Pacific. PACE-NET Key Stakeholder Conference 'Strengthening Pacific-European Collaboration in Research, Development and Innovation', Brussels, 20-23 March 2012. Policy Brief #4, Working Draft, July 2012. 24 p.

Ferse S.C.A., H. Asmus, D. Kneer, M. Kochzius, Y. Sawall, S. Schiel & M. Schulz (2011): Wissenschaftlicher Abschlussbericht für das Vorhaben Dynamik und wechselseitige Verknüpfung der Prozesse in Korallenriffen, tropischen Seegraswiesen und der Wassersäule. Science for the Protection of Indonesian Coastal Ecosystems Phase II, Cluster 1: Coral-Reef Based Ecosystems and Resources, FK 03F0472A-C. Leibniz-Center for Tropical Marine Ecology (ZMT), Bremen, Germany. 241 p. [in German]

Glaser M., S.C.A. **Ferse**, M. Flitner, G. Krause, M. Lukas, & K. Schwerdtner Máñez (2011): Wissenschaftlicher Abschlussbericht für das Vorhaben SPICE II, Cluster 6: Governance und Management sozial-ökologischer Küstensysteme, FK 03F0474A. Leibniz-Center for Tropical Marine Ecology (ZMT), Bremen, Germany. 92 p. [in German]

Schwerdtner Máñez K, M. Glaser, S.C.A. **Ferse**, H. Wiederhold, H. Sulzbacher (2011): Danger from below: Groundwater protection on small islands- its importance must not be underestimated. In: Water – Beware! Zwischenruf 1/2011. Leibniz-Gemeinschaft e.V., Berlin, Germany: 42-46.

Ferse S.C.A. (2011): Regenwälder der Meere. Sozioökonomische Ansätze zur Rettung indonesischer Korallenriffe. *labor&more* 1.11: 44-47. [in German]

Glaser M., S.C.A. **Ferse** & K. Schwerdtner Máñez (2009): Wissenschaftlicher Zwischenbericht 2008 für das Vorhaben SPICE II, Cluster 6: Governance und Management sozial-ökologischer Küstensysteme, FK 03F0474A. Leibniz-Center for Tropical Marine Ecology (ZMT), Bremen, Germany. 32 p. [in German]

Ferse S.C.A. (2008): Electrifying North Sulawesi. *X-ray mag* 24: 38-43.

Ferse S.C.A. (2006): Coral growth. *What's Happening* 11(1): 3-5.

Oral Presentations

Ferse S.C.A. Coral reef fish surveys. Marine Ecology Summer Training, Hasanuddin University, Makassar, Indonesia, 21. September 2015

Ford A.K., N. Van Hoytema, B. Moore, L. Pandihau, C. Wild & S.C.A. **Ferse**. Sedimentary oxygen consumption rates indicate local anthropogenic organic matter input drives coral reef community shifts. SIRTRE 2015: Small Islands Research in Tropical Regions – The Spermonde Archipelago and other Case Studies. Hasanuddin University, Makassar, Indonesia, 16. September 2015.

Ferse S.C.A. A social-ecological systems approach to coral reef fisheries in Spermonde. Marine Ecology Special Training. Hasanuddin University, Makassar, Indonesia, 13. September 2013

Ferse S.C.A., M. Glaser, M. Neil & K. Schwerdtner Màñez. Resilient communities in an unsustainable system? Coping strategies and social-ecological traps in the Spermonde coral reefs fishery. Invited plenary presentation. International Conference on Climate Change, Marine Life, and Livelihoods in the Center of the Coral Triangle. Hasanuddin University, Makassar, Indonesia, 11. September 2013

Ferse S.C.A. Interdisciplinary approaches for Marine Protected Area research and creation: what role for (tropical) coastal communities? SUTAS Summer School on Marine Protected Areas, ZMT Bremen GmbH, Bremen, Germany, 26. August 2013

Ferse S.C.A., M. Glaser, M. Neil & K. Schwerdtner Màñez. Resilient communities in an unsustainable system? Coping strategies and social-ecological traps in the Spermonde coral reefs fishery. 7th Meeting of the European Association of South East Asian Studies, Lisbon, Portugal, 4. July 2013

Ferse S.C.A. An interdisciplinary approach to coastal issues: coral reef fisheries in Spermonde. Marine Ecology Summer Training, Hasanuddin University, Makassar, Indonesia, 26. September 2012

Ferse S.C.A. Marine Protected Areas and other forms of marine conservation: what role for (tropical) coastal communities? ISOS/GLOMAR Marine Conservation Workshop, AWI Wadden Sea Station, List/Sylt, Germany, 21. August 2011

Ferse S.C.A. Fische im Strom: Was Ernährung, Strom und Kunst mit Fischen zu tun haben [public presentation at opening ceremony of art exhibition, in German]. Atelierhaus Roter Hahn, Bremen, Germany, 08. April 2011

Ferse S.C.A., G. Krause, M. Glaser, I. Radjawali, R. Deswandi & L. Knittweis. Global markets, local livelihoods – the marine ornamental fishery in South Sulawesi/Indonesia at the interface of international and regional drivers. Resilience 2011. Second International Science and Policy Conference, Tempe, AZ, USA, 15. March 2011

Ferse S.C.A. Riffvielfalt: Erhaltung und Nutzung. Projekte zur Restauration und nachhaltigen Nutzung von Korallenriffen in Indonesien [public lecture organized by the University of Bremen, in German]. Überseemuseum, Bremen, Germany, 07. February 2011

Ferse S.C.A., L. Knittweis, A. Maddusila, G. Krause & M. Glaser. Livelihood diversity of ornamental fishermen - implications for management of an emergent fishery in South Sulawesi/Indonesia. 2010 European Meeting of the International Society for Reef Studies, Wageningen, The Netherlands, 15. December 2010

Ferse S.C.A., K. Schwerdtner Màñez & A. Kunzmann. Gems of the sea – Assessing the economic potential of ornamental coral reef fishes. 11th Biennial ISEE Conference, Oldenburg, Germany, 24. August 2010

Ferse S.C.A., M. Glaser, I. Radjawali & B. Glaeser. "Nested" community participation in hierarchical societies? Lessons for social-ecological research and management. International Seminar on Small Islands and Coral Reef Management, Ambon, Indonesia, 05. August 2010

Ferse S.C.A. Untying the Gordian Knot? Challenges and approaches in marine coastal resource management and research in Indonesia. Keynote at *Young* marine research: Diversity and similarities. 1. German Young Marine Scientist Meeting, ZMAW Hamburg, Germany, 12. June 2010

Ferse S.C.A. Trends in coastal resource use in the Spermonde Archipelago. International SPICE Cluster 6 Workshop, Bogor Agricultural University (IPB) Bogor, Indonesia, 15. April 2010

Ferse S.C.A. Coral reefs – endangered wilderness of the tropical oceans [public lecture, in German]. International Maritime Museum, Hamburg, Germany, 25. February 2010

Ferse S.C.A. Coastal management in Indonesia: Some issues and challenges. Colloquium on Challenges of Integrated Coastal Management, Bogor Agricultural University (IPB), Bogor, Indonesia, 8. January 2010

Ferse S.C.A. Coral reef restoration – background and approaches [in Indonesian]. Training workshop on coral transplantation, North Sulawesi Fisheries Department (DKP SulUt), Manado, Indonesia, 13. November 2009

Ferse S.C.A. MPAs: Concepts and implementation. Marine Ecology Summer Training, Hasanuddin University, Makassar, Indonesia, 26. October 2009

Ferse S.C.A. Analysis of coastal Social-Ecological Systems in the frame of the SPICE program. Marine Ecology Summer Training, Hasanuddin University, Makassar, Indonesia, 26. October 2009

Ferse S.C.A. Multivariate similarity of fish communities ‑ a potential indicator of reef recovery? PhD and Post-Doc Minisymposium on Coral Reefs, Leibniz Centre for Tropical Marine Ecology, Bremen, Germany, 14-15. September 2009

Ferse S.C.A., A. Maddusila, S. Husain & M. Glaser. Mariculture as livelihood option for coastal communities: Investigating the potential for reef resource users in Spermonde/South Sulawesi. International Ocean, Science and Policy Symposium at the World Ocean Conference 2009, Manado, Indonesia, 12-14. May 2009

Ferse S.C.A. Linking People and the Reefs: The quest for sustainable forms of usage. 3rd Coral Reef Ecology (CORE) working group Mini Symposium, Munich, Germany, 4. May 2009

Ferse S.C.A. Migrant predatory exploitation patterns of coral reefs – The Roving Bandit Syndrome. Seminar in Tropical Ecology, Leibniz Centre for Tropical Ecology (ZMT), Bremen, Germany, 10. December 2008

Ferse S.C.A. Multivariate responses of the coral reef fish community to artificial structures and coral transplants. 11th International Coral Reef Symposium, Fort Lauderdale, Florida, USA, 7-11. July 2008

Ferse S.C.A. Wiederaufbau im Riff: Kabel, Keramik und Kugelkonstruktionen – Schäden in einem der ältesten Ökosysteme der Erde und wie der Mensch versucht, sie zu reparieren [public lecture, in German]. House of Science, Bremen, Germany, 24. November 2007

Ferse S.C.A. Artificial reefs and coral transplantation: Ichthyofaunal responses at three locations in North Sulawesi, Indonesia. Seminar in Tropical Ecology, Leibniz Centre for Tropical Ecology (ZMT), Bremen, Germany, 31. October 2007

Poster Presentations

Ford A., N. van Hoytema, B. Moore, C. Wild & S.C.A. **Ferse**. Sedimentary oxygen consumption as an effective process indicator of organic matter stress on coral reefs. Reef Conservation UK 2014, London, UK, 6. December 2014.

Ferrol-Schulte D., J. Cinner, N. Jiddawi & S.C.A. **Ferse**. Livelihood diversification and food security in coastal communities on Zanzibar. 8th Western Indian Ocean Marine Science Association (WIOMSA) Symposium, Maputo, Mozambique, 27. October-1. November 2013

Ferrol-Schulte D., S.C.A. **Ferse** & M. Glaser. Exploring drivers of natural resource exploitation in tropical coastal communities: patron-client systems. International Conference on Conservation Biology (ICCB), Baltimore, USA, 21-25. July 2013

Ferse S.C.A., M. Glaser, C. Schultz & J. Jompa. Linking research to Indonesia's CTI Action Plan: the SPICE Program. 12th International Coral Reef Symposium, Cairns, Australia, 9-13. July 2012

Husain, S., S.C.A. **Ferse** & M. Glaser. Analysis of factors affecting resilience towards climate change on several islands in the Spermonde Archipelago, Sulawesi, Indonesia. Storm Surges Congress 2010, Hamburg, Germany, 13-17. September 2010

Glaser, M. & S.C.A. **Ferse**. The Governance and Management of Indonesian Coastal Social-Ecological Systems. A cross-regional & interdisciplinary approach. International Ocean, Science and Policy Symposium at the World Ocean Conference 2009, Manado, Indonesia, 12-14. May 2009

Ferse S.C.A., K. Schwerdtner Máñez, M. Neil & M. Glaser. Trends in coral reef fisheries of the Spermonde Archipelago, South Sulawesi, Indonesia. Oceans Past II, University of British Columbia, Vancouver, Canada, 26-28. May 2009

Ferse S.C.A., K. Schwerdtner Máñez, M. Neil & M. Glaser. Socio-economic drivers in the coral reef fishery of Spermonde, South Sulawesi/Indonesia. Oceans Past II, University of British Columbia, Vancouver, Canada, 26-28. May 2009

Ferse S.C.A. Reef rehabilitation and natural recovery: Does transplantation of coral fragments increase natural recruitment? 11th International Coral Reef Symposium, Fort Lauderdale, Florida, USA, 7-11. July 2008

Borell E.M., S.B.C. Romatzki & S.C.A. **Ferse**. Biorock Corals – Backtracking the notion of enhanced growth and prosperity. 11th International Coral Reef Symposium, Fort Lauderdale, Florida, USA, 7-11. July 2008

Ferse S.C.A. Coral farming and reef management. Sustainable Mariculture Meeting & Workshop, Makassar, Indonesia, 27-30. November 2007

Blankenhorn S.U. & S.C.A. **Ferse**. Integrated culture of corals and seaweeds. Optimizing the sustainable use of reef resources. Sustainable Mariculture Meeting & Workshop, Makassar, Indonesia, 27-30. November 2007

Ferse S.C.A., S. Bröhl & A. Kunzmann. Coral reef research. Methods for ecological research in tropical environments using SCUBA. 1st International Symposium for Occupational Scientific Diving, AWI, Bremerhaven, Germany, 15-16. October 2007

Ferse S.C.A., A. Kunzmann & L. Knittweis. Coral reefs are more than fishes. Towards the sustainable use of non-fish reef resources. SPICE/LOICZ/ATSEF/SEACORM (SLAS) Southeast Asia Coastal Governance and Management Forum: Science Meets Policy for Coastal Management and Capacity Building, Bali, Indonesia, 14-16. November 2006

Ferse S.C.A. & S.B.C. Romatzki. Effects of an electric field on the growth and survival of two Acropora species. International Society for Reef Studies European Meeting 2006, Bremen, Germany, 19-22. September 2006

Ferse S.C.A. Coral transplantation increases fish abundance and diversity on artificial reefs. International Society for Reef Studies European Meeting 2006, Bremen, Germany, 19-22. September 2006

Media outreach

My work and publications have been featured in several dozen online and print newspaper articles in Europe and Indonesia. I have written several popular science articles for magazines, making my work accessible to the wider public. Furthermore, I have been interviewed over a dozen times by radio and television stations, including major national German TV channels. The reports covered a range of topics, from my work on coral reef ecology and reef restoration to research on coastal resource use and management in Indonesia, the International Year of the Reef in 2008, marine conservation in the Pacific, and coral bleaching and destruction in Southeast Asia and Australia.

Address School of Biological Sciences
Goddard Bldg
University of Queensland
St. Lucia, Brisbane
Qld, 4072, Australia

Tel: +61 (0)7 3365 1686

E-mail: p.j.mumby@uq.edu.au

Qualifications PhD University of Sheffield, 1997 'Remote sensing of coral reefs and seagrass beds: an ecological perspective'

B.Sc.(Hons) Marine Biology, First Class, Liverpool University, June 1992

Appointments

Professor & Vice-Chancellor's Fellow, School of Biological Sciences, University of Queensland (*present*)
April 2010 – Dec 2015 *ARC Laureate Fellow*, School of Biological Sciences, UQ

Professor and Royal Society University Research Fellow - University of Exeter
November 2000 - 2008 (8 year fellowship), Professor 2006 -,

Natural Environment Research Council (NERC) Post-doc Research Fellow - University of Newcastle
November 1997 - October 2000

Research Associate - University of Sheffield (DfID funded)
September 1994 - August 1997

Science Coordinator - Coral Cay Conservation, Belize, Central America
June 1992 - September 1994

A Research

(a) Before embarking on a research career I spent two years attempting to design marine reserves in Belize. I experienced the limited scientific basis for such planning first hand and have subsequently aimed to conduct basic and applied science in support of the management of coral reefs. My first research goal was to develop remote sensing methods that provide ecologically-relevant data on tropical coastal environments. Using state-of-the-art airborne instruments, we have doubled the accuracy with which reef habitats can be mapped and even progressed to assessing the health of reefs (Mumby et al 2001 *Nature*). Our research into coral reef remote sensing remains the most highly-cited on the topic and in 2000 we published the book *Remote Sensing Handbook for Tropical Coastal Management* which is the second-highest selling book of UNESCO's Coastal & Small Islands series. Since 2000, I have focused on the ecology and ecosystem science of coral reefs.

My goal is to provide the ecology and tools needed to manage coral reefs. This involves (i) empirical studies, (ii) ecosystem modelling and theory, and (iii) creation of management tools. Empirical studies, be they experimental or macro-ecological, focus on quantifying the ecological impacts of human behaviour, including the deforestation of mangroves which provide nurseries for reef fish (Mumby et al 2004 *Nature*), the impacts of marine reserves (e.g, Mumby et al 2006 *Science*), and a wealth of experiments needed to parameterise ecological processes (e.g., Mumby et al 2007 *PNAS*). I have used these empirical studies to build spatially-realistic models of coral reefs and quantify the resilience of an ecosystem for the first time (Mumby et al 2007 *Nature*). The models have also been used to study the effects of climate policy on future reef function (Kennedy et al 2013 *Current Biology*) and understand the future fisheries productivity of coral reefs (Rogers et al 2014 *Current Biology*). Ecological models, theory, and remote sensing have been combined to provide management tools include (i) reserve design tools that account for climate change impacts (Mumby et al 2012

Ecology Letters), (ii) mapping of the effects of management actions on future reef resilience and help target interventions where they can have maximal benefit (Mumby et al 2014 *Conservation Letters*), and (iii) develop fisheries regulations that explicitly account for ecological needs of reefs experiencing climate change (Bozec et al 2016 *PNAS*).

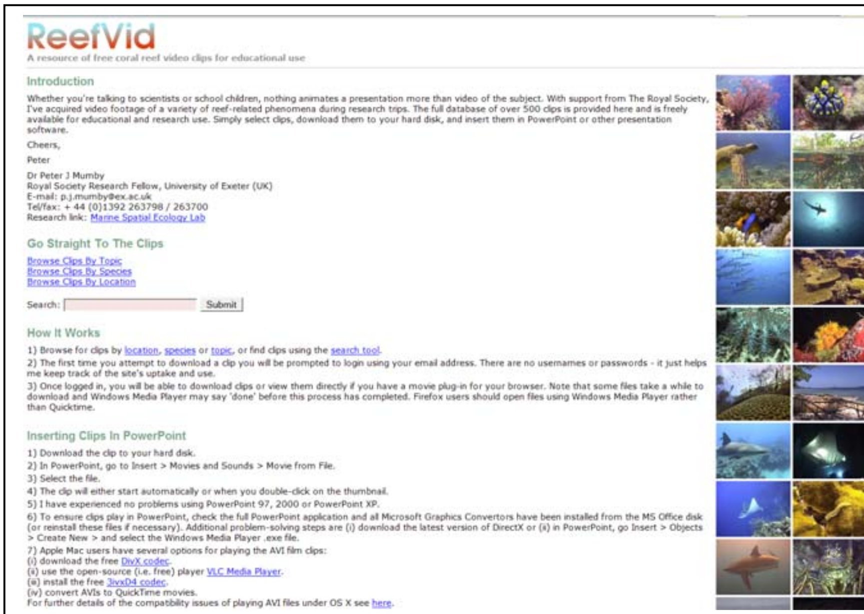
Outcomes of this research have been used explicitly in the setting of new fisheries policies in Belize and Bonaire (bans on parrotfish exploitation), and in providing supporting case to a successful lawsuit against the US Government for the inadequacy of their efforts to protect corals (Earth Justice 2013).

(b) Grants (external only)

In the last five years I have generated over **AU$30m** in direct research income which includes a fairly diverse range of streams including the ARC, NERC, EU, World Bank, US Environmental Protection Agency and US National Science Foundation.

1. **ARC Linkage Project**, 2015-2017, Effects of Palm Oil agriculture on reef fisheries, $400,000
2. **ARC Centre of Excellence for Coral Reef Studies**, $24m (among multiple faculty, personal grant of $1.5m), 2014-2021
3. **Qld Government Accelerate Project**, Solving the crown-of-thorns starfish problem on the Great Barrier Reef, $500,000 (2014-2016)
4. **Great Barrier Reef Foundation**, Modelling reef connectivity, $60,000 2015-2016
5. **The Nature Conservancy**, Mapping fisheries ecosystem values, $110,000, 2015-2016
6. **World Bank / Global Environmental Facility,** Capturing coral reef ecosystem services, $8m, 2013-2018
7. **ARC Linkage Project**, 2012-2015, Marine reserve design, AU$340,000
8. **UQ Collaboration and Industry Engagement Fund**, 2012-2013, Seagrass modelling, AU$95,000
9. **Stocker Industrial Endowment Fund**, 2012-2013, Fellowship in connectivity, AU$270,000
10. **National Environment Research Programme**, 2011-2015, Mapping vulnerability of the Great Barrier Reef, AU$517,000
11. **World Bank Grant to Maldivian Government,** 2013-2014, Climate change risk mapping, $100,000
12. **Australian Research Council**, 2012-2015, Climate change impacts on coral-algal interactions, $300,000
13. **The Nature Conservancy**, 2014-2016, Modelling global fisheries productivity, $110,000
14. **Global Environmental Facility / The Nature Conservancy**, 2011-2012, AUS$105,000 Demonstration project of marine reserve benefits
15. **Australian Research Council Laureate Fellowship**, 2010-2015, AUS$4,500,000
16. **Pew Charitable Trusts,** Pew Fellowship in Marine Conservation, 2010-2013 though fellowship indefinite, US$150,000.
17. **Australian Research Council,** Super Science Initiative, Sea-level impacts on tropical coastal areas (2010-2014, $1.8m)
18. **Global Environmental Facility**, Partner in research award to The Nature Conservancy, Bahamas National Trust, and Government of the Bahamas. My component US$107,000 (2010-2012)
19. **Natural Environment Research Council**, Climate change and the fragmentation of coral reef habitats, PI, 2010-2013, £388,000
20. **European Union**, Future of Coral Reefs in a Changing Environment, Lead and Coordinator, 2010-2014 €6.7m involving 18 partners from the Caribbean, Europe and US. It is currently the largest coral reef project in the world.
21. **Natural Environment Research Council**, Global analysis of temperature regimes to stratify the management of coral reefs for climate change, PI, 2009-2010, £53,000
22. **National Geographic Society**, Coral recruitment in Pacific systems, PI, 2009-2010, US$22,500
23. **US National Fish and Wildlife Foundation**, Effects of herbivore exploitation in Micronesia, PI, 2008-2010, US$85,000
24. **Natural Environment Research Council**, Generic model of aquatic remote sensing that includes ecological inputs and a Bayesian framework. PI, 2007-2010, £310,000

25. **Natural Environment Research Council**, Modelling fishing impacts on the resilience of Caribbean coral reefs. PI, 2007-2010, £330,000
26. **Living Oceans Foundation**, GIS analyses to incorporate climate impacts into the design of reserve networks in the Bahamas, PI, 2007-8, US$180,000
27. **Alumni Fund**, Widening participation in Bahamas field course, 2007, £20,000
28. **Natural Environment Research Council**, Gene flow in Caribbean corals, PI, 2007, £52,000
29. **Natural Environment Research Council,** Optical properties of coral reefs, PI, 05-06, £30,380.
30. **US Environmental Protection Agency,** Modelling effects of climate change on Caribbean coral reefs and mangroves. Start 2004 (3 years), US$750,000 (Exeter component $210,000 with colleagues at Stanford)
31. **The Royal Society,** Summer studentship 2006, £2,500
32. **National Geographic Society**, Dynamics of coral reef algae, PI, 2005/6, $19,000
33. **World Bank/Global Environment Facility**, Targeted coral reef research (remote sensing) 2004 (5 years), US$1,600,000
34. **European Union, Marie-Curie Fellowship,** March 05, £157,000
35. **The Royal Society,** 3 year extension to Royal Society Fellowship, £165,000
36. **Khaled bin Sultan Living Oceans Foundation**, Mapping beta diversity of coral reefs, 2004 (1 year), US$35,000
37. **Wildlife Conservation Society**, Spatial database and ecology of Glovers Atoll, Belize. 2003 (3 years) US$90,000
38. **Natural Environment Research Council,** Spectral unmixing in aquatic environments and the design of hyperspectral sensors, PI, 2002 (3 years) £158,217
39. **Natural Environment Research Council,** Modelling community dynamics of reef corals, PI, 2002 (3 years), £154,130
40. **National Geographic Society,** Redundancy in ecosystem functions, 2002 (1 year), US$15,000
41. **PADI Aware Foundation,** £4000, 2002
42. **National Science Foundation (US),** Design of marine protected areas, 2001 (5 years), US$2,500,000 (with US colleagues, Exeter budget $160,000)
43. **Darwin Initiative,** Dynamics of juvenile corals in Honduras, £30,000, 2001 (1 year)
44. **Khaled Bin Sultan Living Oceans Foundation,** Hierarchical structure in coral reefs, 2001, US$70,000
45. **World Wildlife Fund,** Connectivity of coral-seagrass –mangroves, 2001, US$5000
46. **The Royal Society**, Spatial reef ecology, 2000 (5 years), £500,000 (US$850,000)
47. **Natural Environment Research Council**, Remote sensing of reefs & diversity assessment, 1997, £120,000 (US$186,000)



Snapshot of my website www.reefvid.org which is a free repository of video clips of marine life that is fully searchable by behaviour, species, and location and used by more than 30,000 people, including school curricula

B Teaching

(a) Courses

1) Coordinate and co-teach the third year 'Marine Ecology & Conservation' course
2) Provide the marine conservation component of the MSc in Conservation Biology
3) Tropical Marine Ecosystems MOOC (Edx, UQ)
4) Guest lectures on third year Tropical Coastal Ecosystems course
5) Discussion on careers with Masters students in Conservation Biology

(b) Teaching excellence

I have pioneered the use of video in teaching and presentation methods. Over the past 10 years I have edited a library of more than 1000 video clips ranging from hurricane disturbance to generic biological behaviours of reef organisms. These clips are routinely used to illustrate (and animate) lectures and I have recently launched a website (www.reefvid.org) to make them available to students at Exeter and the wider, international user community. Non-commercial users can search for clips and download them in PowerPoint format. The site was featured in *Science* Magazine, has more than 30,000 registered users, and clips were used in the DVD version of the Oscar winning documentary, 'An Inconvenient Truth' by Al Gore. My latest average teaching evaluation from students is 4.8/5.

C External examining and journal reviewing

Examiner of academic courses:

MSc Tropical Coastal Management, University of Newcastle 2008-2011

Examiner of theses:

Simon Albert, PhD, University of Queensland, 2008
Fiona Webster, PhD, Murdoch University, 2007
Sonia Cardoso, MPhil, University of East Anglia, 2007
Valeria Pizarro, PhD, University of Newcastle, 2006
Bernardo Blanco-Martin, PhD, James Cook University, Australia, 2006
Ben Radford, PhD, University of Western Australia, Australia, 2005
Fiona Manson, PhD, University of Queensland, Australia, 2004
Vanessa Karpoulzi, PhD, University of Edinburgh, 2004
Mark Vermeij, PhD, University of Amsterdam, Holland, 2003
Abdulla Naseer, PhD, Dalhousie University, Canada, 2003
Peter Collins, MPhil, University of Plymouth, 2002

I regularly review for the following journals: Nature, Science, Proceedings of the National Academy of Sciences, Current Biology, Trends in Ecology and Environment, Ecology, Ecology Letters, Global Change Biology, Marine Ecology Progress Series, Coral Reefs, Marine Biology, Aquatic Biology, Marine and Freshwater Research, Marine Pollution Bulletin, Ambio, Conservation Biology, Biological Conservation, International Journal of Remote Sensing, Remote Sensing of Environment, Limnology and Oceanography, Coastal Management, Journal of Environmental Management, Botanica Marina, Marine Ecology, Bulletin of Marine Science.

D Postgraduate personnel

(a) Postgraduate

John Hedley, PhD, started 1999, Spectral unmixing of remotely-sensed data. Passed
Clare Muller, PhD, 1999, Impact of mangroves on larval reef fish. Passed
Alastair Harborne, 2002, PhD, Beta diversity of coral reefs. Passed & merit recommendation
Stephen Box, PhD, 2002, Effect of benthic algae on the survival of coral recruits. Passed.
Nicola Foster, PhD, 2003, Clonality in the coral, *Montastraea annularis*, Passed.
Hendrik Renken, PhD, 2003, Modelling the dynamics of macroalgae. Passed.
Ellen Husain, PhD, 2005, Ecological role of damsefishes on coral reefs.
Sonia Bejarano, PhD, 2005, Modelling parrotfish grazing on Pacific coral reefs.
Iliana Chollet, PhD, 2007, Remote sensing of the physical environment of coral reefs.
Shay O'Farrell, PhD, 2007, Effects of climate change on the population dynamics of Caribbean parrotfishes.
Manuel Gonzalez, PhD, 2007, The effects of phase shifts on coral reef sponges.
Susan Kay, PhD, 2008, Radiative transfer modelling of sunglint
Robert Canto, PhD, 2008, Algal dynamics on the Great Barrier Reef
Lyndsey Holland, PhD, 2008, Genetics and dispersal of temperate sea fans.
Renata Ferrari, PhD, 2008, Parrotfish grazing and coral dynamics in the Caribbean.
Emma Kennedy, PhD, 2008, Ecosystem processes on Pacific coral reefs.
Alyssa Marshell, PhD, 2010, Acanthurid grazing.
Lester Kwaitowski, PhD, 2010, Climate change and coral reefs
Chico Birrell, PhD, 2010, Pacific algal dynamics
Chris Doropoulos, PhD, 2010, Ocean acidification and coral recruitment
Jimena Samper, PhD, 2012, Dynamics of seagrass beds and carbon sequestration
Tries Razak, PhD, 2012, Response of coral calcification to climate change
Carolina Castro, PhD, 2012, Effects of habitat loss on *Halimeda*
Eleanor Aurellado, PhD, 2012, Predator-prey interactions of coral reef fish
Vivian Lam, PhD, 2013, Operationalising resilience of coral reefs
Nick Wolff, PhD, 2013, Modelling vulnerability of the Great Barrier Reef
Mark Priest, PhD, 2014, Spawning aggregations of coral reef fish.
Nicholas Evenson, PhD, 2015, Coral-algal interactions
Laura Puk, PhD, 2016, Herbivory on coral reefs
Abdi Priyanto, PhD, 2016, Marine Spatial Planning in Indonesia

(b) Post-docs and research associates

Dr Kamila Zychaluk (jointly with Prof Paul Blackwell, Sheffield), started 2002-2004
Dr Helen Edwards, 2005-2007
Dr Karen Brady, 2005-2008
Dr John Hedley, 2002-2009
Dr Alastair Harborne, 2002-present
Mr Ian Gillett, 2007-2010
Dr Yves-Marie Bozec, 2010-present
Dr Juan-Carlos Ortiz, 2010-present
Dr George (Jez) Roff, 2010-present
Dr Sonia Bejarano, 2010-2013
Dr Laith Yacob, 2010-2011
Mr Nick Wolff, 2011-present
Dr Chris Brown, 2011-present
Dr Megan Saunders, 2011-present

Dr Karlo Hock, 2012-present
Dr Alice Rogers, 2012-present
Dr Iliana Chollett, 2012-2014
Dr Shay O'Farrell 2012-2014
Dr Santiago Bucarum, 2012-2013
Dr Cheryl Knowland, 2012-2013
Mr Jason Flower, 2012-2015
Dr Chris Doropoulos, 2012-2015
Dr Sabah Abdulla, 2012-2015
Dr Nils Kruenk, 2013-present
Dr Jessica Stella, 2014-2015

E Administration

(a) School committees

University of Queensland:
Research Committee, OH&S Committee, Professorial Promotions Committee (UQ Central)

I have been running courses for staff, post-docs and PhD students on proposal writing and advice on getting published. I also organize an annual research retreat for the School.

F External recognition

(a) Awards

1. Inaugural Award of the International Society for Reef Studies for outstanding contributions of a mid-career scientist (2015)
2. Rosenstiel Award for Contributions to Marine Science, University of Miami, 2011
3. Pew Fellowship in Marine Conservation (2010-)
4. Marsh Award for Marine Conservation, Zoological Society of London (2010)
5. ARC Laureate Fellowship (the highest-level fellowship in Australia) (2009-2014)
6. Royal Society University Research Fellowship (with extension and two merit increments)
7. NERC Post-doctoral fellowship
8. Winner of Best Paper at the 4th Int. Conf. Remote Sensing of Marine and Coastal Environments, Orlando, March 1997.

(b) Participation in professional bodies and working groups

1. *Member*, Reef Integrated Monitoring & Reporting Working Group, Australian Government 2015-2018
2. *Member*, Review Panel of Great Barrier Reef Task Force, Queensland Government, 2015-2017
3. *Member*, Powell Working Group on Coral Reef Resilience, USGS 2016-2018
4. *Member*, US National Socio-Environmental Synthesis Center, MPA Mysteries 2014-2017
5. *Member*, US National Socio-Environmental Synthesis Center, Time scales and decisions, 2014-2016
6. *Member,* IUCN Reef Resilience Working Group, 2014-present
7. *President,* Australian Coral Reef Society, 2012-2014
8. *Co-Chair* (with Prof Jane Lubchenco), Climate changes and the oceans working group, Pew Charitable Trusts / Hoover Foundation, 2014
9. *Chief Scientist,* World Bank / GEF Capturing Coral Reef Ecosystem Services project, 2013-2018
10. *Member*, UNESCO Intergovernmental Platform on Biodiversity and Ecosystem Services, 2012-2014

11. *Coordinator*, Future of Reef Ecosystems (FORCE), 2010-2015, currently the largest collaborative research initiative on coral reefs involving more than 50 scientists and funded by the EU. The project focuses on the drivers of change in the Caribbean and opportunities to improve reef health and management.
12. *Chair*, World Bank / Global Environmental Facility Targeted Research Group on Coral Reef Remote Sensing
13. Member, GLOBE Marine Advisory Panel, advising legislators on fisheries and marine reserve issues
14. Advisory Committee, Natural Environment Research Programme, Australian Government
15. Member, NERC Ecosystem Synthesis Working Group on Effects of Reserve Networks (2006-08), with Mark Johnson, Bill Kunin, Kevin Gaston, Robert Whittaker and others.
16. Elected *Corresponding Secretary* (2002-2006) International Society for Reef Studies
17. Member of IOC-UNEP Coral Reef Theme for the Integrated Global Observing Strategy
18. Member of Advisory Group to World Bank/GEF Mesoamerican Barrier Reef System Project
19. Scientific Council, Living Oceans Foundation, Washington DC
20. Adjunct Professor, University of Maine, Darling Marine Science Center
21. Review Panelist to *NASA Global Interdisciplinary Science Initiative*
22. Scientific advisor to *Coral Cay Conservation*, London

(c) Media and serious journalism (Public Understanding of Science; examples from 2008 and earlier, not managed to keep up with updates since then)

1. Participated as panelist in 'Science vs. Media Awareness Workshop' organized by SeaWeb in Florida 08
2. BBC Radio 4, interview on Leading Edge 8th July 08
3. BBC World Service, Discovery Series on effects of climate change on reefs, June 9th 08
4. BBC Radio 4, in the field contributing to 'Frontiers' science programme May 26th 08
5. *The Times*, Coverage of Science article from December 07
6. *The Independent*, Coverage of Science article from December 07
7. *The Guardian*, Coverage of Science article from December 07
8. *NERC Planet Earth* Winter 2007, news item on our research published in Nature
9. *The Times*, Coverage of Nature article from November 07
10. *The Independent*, Coverage of Nature article from November 07
11. *BBC Online* (6th most frequently viewed news story of the day), Coverage of Nature article from Nov 07
12. *Express & Echo*, Coverage of our study in PNAS, May 07
13. *ITV Western News*, Television interview about our research, May 07
14. *Western Morning News*, Coverage of our study in PNAS, May 07
15. Perspectives of climate change, interview for *The Royal Society* http://www.royalsoc.ac.uk/ May 06
16. *The Economist*, coverage of our study of marine reserves, Jan 06
17. *ITV Western News*, Television interview about our research, Jan 06
18. *The Independent*, coverage of our study of marine reserves Jan 06
19. *The Times*, coverage of our study of marine reserves Jan 06
20. *New York Times*, coverage of our study of marine reserves Jan 06
21. *Western Morning News*, coverage of our study of marine reserves Jan 06
22. *Nature*, coverage of our study of marine reserves Jan 06
23. *New Scientist*, coverage of our study of marine reserves, Jan 06
24. *The Yorkshire Post*, coverage of our study of marine reserves, Jan 06
25. *National Geographic Society* online, coverage of our study of marine reserves Jan 06
26. *Discovery Channel* online, coverage of our study of marine reserves Jan 06
27. *BBC* online, Effects of marine reserves on coral reefs, January 2006
28. *Royal Society Education Programme,* Sc1 Website, Interactive module on coral reefs http://www.sc1.ac.uk/interactive/deep
29. *Exeter Express & Echo,* Impact of coral bleaching in the Caribbean, October 2005
30. *BBC World Service "Science in Action",* February 2004
31. *CBC Canada*, Radio interview about mangroves and coral reefs, Feb 2004

32. *Liberacion*, Importance of mangroves for coral reefs, Feb 2004
33. *BBC Online*, coverage of our study of marine reserves Jan 06
34. *National Geographic Society News*, Linkages coverage of our study of marine reserves Jan 06
35. *Science News*, “Aircraft spies on health of coral reefs”, 160 (10), September 2001 & “Mangroves story” Feb 2004
36. *National Geographic Society* News, “Coral reef health & climate change”, September 2001
37. *New York Times*, “Surveying the coral”, September 11th 2001
38. *BBC World Service*, radio interview, September 2001
39. *The Daily Express* “Coral Reefs Wrecked”, July 23rd 2001
40. *Radio Australia* Interview on coral bleaching & climate change, July 24th 2001
41. Interactive presentation on the health of coral reefs, Café Scientifique, Nottingham, May 2001
42. Reporting impacts of dynamite on the Belize barrier reef; television interviews in Belize, August 1992

(d) Invitations to give papers at international meetings

*** = **keynote or plenary**, **= invited (expenses paid)

1. **13th International Coral Reef Symposium, Honolulu, June 2016*****
2. **Brazilian International Marine Biology Congress, April 2015****
3. **Mexican Coral Reef Society Annual Meeting, April 2015****
4. **University of Amsterdam, Netherlands, December 2014****
5. **University of Hawaii, Hawaii, November 2014****
6. NOAA (US Government), Florida, April 2014**
7. Sesync working group on protected areas (with Helen Fox), Baltimore October 2013**
8. **Conference on reef fisheries and habitat, Tampa, Florida, May 2013*****
9. Sesync working group on timescales (with Alan Hastings), Baltimore June 2013**
10. UNESCO IBPES working group, Paris, October 2012**
11. IUCN meeting on Caribbean reef health, Panama, May 2012**
12. Georgia Tech University, April 2012**
13. Royal Society, Biodiversity thresholds meeting, April 2012**
14. **2nd International Conference on Coral Reef Resilience, Florida, October 2011*****
15. **Association of Marine Scientists of Australia, Annual conference, Perth, July 2011*****
16. **Association of Marine Labs of the Caribbean, San Jose, Costa Rica May 2011*****
17. Stanford University, March 2011**
18. **85th Australian Coral Reef Symposium,** Coffs Harbour, September 2010***
19. Florida International University, March 2009**
20. University of Florida / Florida Sea Grant, January 2009**
21. International Coral Reef Symposium, Florida, July 2008
22. **Kathryn Fuller Invited Seminar**, World Wildlife Fund, Washington DC, Jan 08***
23. Plymouth University, February 2008**
24. National Center for Ecological Analysis and Synthesis (NCEAS), University of California, Santa Barbara, 2007**
25. **Colloquium on coral reef conservation**, University of Queensland, Australia 2007***
26. Westden Seminars on Climate Change, Plymouth, 2007**
27. University of Sheffield (Animal & Plant Sciences), 2007**
28. University of California, Davis, USA**
29. Institute for Marine Science and Engineering, invited seminar, Plymouth 2007
30. University of East Anglia, 2007**
31. Caribbean & Gulf Caribbean Fisheries Institute, 59th Annual meeting, Belize 2006**
32. **International Society for Reef Studies, Bremen 2006*****
33. Challenges for conservation biology, Heron Island, Australia, 2005**

34. Coastal Zone Management Institute, Belize, 2005**
35. University College Belfast (Marine Science), 2005**
36. **Coral Reef Conservation, Zoological Society of London, 2004*****
37. **Western Society of Naturalists, California, USA 2004*****
38. Stanford University (Hopkins Marine Station), USA 2004**
39. Marine Biological Association of the United Kingdom, 2004**
40. University of Melbourne (Zoology), Australia, 2004**
41. University of Queensland, Australia, 2004**
42. Australian Institute of Marine Science, Australia, 2004**
43. James Cook University (Marine Science), Australia, 2004**
44. Great Barrier Reef Marine Park Authority, Australia, 2004**
45. Southampton Oceanography Centre, 2004**
46. University of Edinburgh (Geography), 2004**
47. University of Newcastle (Marine Science), 2004**
48. University of Plymouth (Marine Science) 2003**
49. Plymouth Marine Laboratory, 2003**
50. IOC-UNESCO/World Bank Coral Bleaching Workshop, Heron Island, 2002**
51. AIMS/NOAA Satellite Remote Sensing for Coral Bleaching, Townsville, 2002**
52. **NASA/Conservation Workshop on Biological Fingerprinting (topic leader for marine**
53. **applications of remote sensing for biodiversity research, New York, 2001*****
54. **NCORE workshop on Caribbean reef research, Miami, 2001 (topic leader)*****
55. Bahamas workshop on design of Marine Protected Areas, Bahamas, 2000**
56. 9th International Coral Reef Symposium, Bali, Indonesia, 2000**
57. University of the Virgin Islands, St. Thomas, 2000**
58. First Biennial Science Meeting on the Intra-Americas Seas: connectivites between coastal zones, Panama 1999**
59. **International Workshop on the Use of Remote Sensing Tools for Mapping and Monitoring Coral Reefs. NOAA / ICLARM, Honolulu, Hawaii, 1999*****
60. International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration. National Coral Reef Institute, Nova Southeastern Oceanographic Center, Florida 1999**
61. **Workshop to assess NASA's remote sensing capabilities to map and monitor the health of coral reefs: present status and future needs. St. Petersburg, Florida 1999*****
62. NOAA Seagrass and Aquatic Habitat Assessment Workshop, St. Petersburg, 1998**
63. Atlantic Gulf Reef Assessment Workshop on coral reef condition, Miami, 1998**
64. **International Symposium on Mangrove Biology & Ecology, Kuwait, 1998.*****
65. VIII Pacific Science Inter-Congress, University of the South Pacific, Fiji, 1997.**
66. East African Workshop on Environmental Monitoring in the Coastal Zone, Mombasa, Kenya, 1997**
67. Tropical Marine Research Unit, University of York, 1997.**
68. International Centre for Living Aquatic Resources Management, Manila, Philippines, 1996.**
69. Smithsonian / University College of Belize Training Course in Mangrove Management, Belize, 1996**
70. Department of Marine Sciences, Bangor University (N. Wales), 1996**
71. Centre for Marine Sciences, University of the West Indies, Jamaica, 1995**
72. 1994 Site Directors meeting of the CARICOMP programme, Florida Institute of Oceanography, 1994.**
73. Symposium on Research Conducted in Belize, Scottish Natural History Museum, 1993.**
74. Marine Conservation Society (UK); Muffles college, Belize; University College of Belize, 1993.**

(e) Other conferences attended (abstracts submitted rather than invited)

1. International Marine Conservation Congress, DC 2009
2. 11th International Coral Reef Symposium, Florida, 2008
3. 3rd International Tropical Coastal Management Symposium, Cozumel 2006

4. 10th International Coral Reef Symposium, Okinawa, Japan 2004
5. Climate change and coral reefs, Hawaii, 2003
6. 9th International Coral Reef Symposium, Bali, Indonesia, 2000
7. 4th European Meeting of the International Society for Reef Studies, Perpignan, 1998
8. VIII Pacific Science Inter-Congress, University of the South Pacific, Fiji, 1997
9. 4th International Conference on Remote Sensing for Marine and Coastal Environments, Orlando, 1997
10. 8th International Coral Reef Symposium, Panama City, Panama. 1996
11. 3rd European Meeting of the International Society for Reef Studies, Newcastle, 1995
12. 2nd European meeting of the International Society for Reef Studies, Luxembourg, 1994
13. Marine Biodiversity: Causes & Consequences, University of York, 1994
14. Joint Scientific Meeting on Science, Management & Sustainability of Marine Habitats in the 21st Century, Townsville, Australia, 1994
15. 6th Pacific Congress on Marine Science & Technology (PACON), Townsville, Australia, 1994
16. 2nd Thematic Conference for Remote Sensing of Marine and Coastal Environments, New Orleans, 1994.
17. 1st European Meeting of the International Society for Reef Studies, Vienna, 1993
18. Global Aspects of Coral Reefs, Colloquium & Forum, University of Miami, 1993

(f) Consultative work

1. Tribunal at Permanent Court of Arbitration; Philippines vs. China on development of the Spratly Island (Independent Expert), 2016
2. Great Barrier Reef Foundation, Review of resilience mapping feasibility study 2010
3. European Space Agency, Demonstration of satellite remote sensing for managing the impacts of climate change on coral reefs, 2009, €50,000 (industrial contractual research)
4. Kerzner Marine Foundation, Mapping Bahamian coral reefs, 2009, ($20,000)
5. European Space Agency, *Capacity of ESA data for assessing coral reefs*, 2006/7
6. Khaled bin Sultan Living Oceans Foundation – *Mapping reefs of Bermuda*, 2005
7. The Nature Conservancy / Conservation International – *Preparation of research proposal for targeted research into the management of coral bleaching risks through Marine Protected Areas.* 2002
8. Joint Nature Conservation Committee - *Monitoring methods for coastal biotopes,* 1999
9. UNEP-IOC UNESCO - *Training Workshop for Mapping Seagrass Beds using Remote Sensing,* 1997
10. The World Bank - *Training in Remote Sensing for Coastal Zone Management*, 1997
11. UNDP / GEF Coastal Zone Management Project, Belize - *Coastal Habitat Classification,* 1997
12. UNDP / GEF Coastal Zone Management Project, Belize – *Coastal habitat mapping*, 1996

(g) Editorial boards and conference organisation

1. **Editorial Board**, *Ecology Letters* (2012-present)
2. **Editorial Board,** *Current Biology* (2014-present)
3. **Editorial Board**, *Philosophical Transactions of the Royal Society, Series B* (2010-2014)
4. **Ecological Editor** of the journal *Coral Reefs* 2006-2010
5. **Review Editor** of *Marine Ecology Progress Series* (2004-present)
6. Edited **Special Issue** of the *International Journal of Remote Sensing* on coastal environments
7. International organising committee for the **11th International Coral Reef Symposium**, Florida, 2008
8. Organised mini-symposium entitled "Large scale reef ecology" at the **10th International Coral Reef Symposium**, Japan 2004
9. Organised mini-symposium entitled "Large scale reef ecology: linking biogeography, metacommunites and local population dynamics" at the **9th International Coral Reef Symposium**, Bali 2000
10. Organised workshop entitled "The Use of Non-Professionals in Applied Marine Science and Coastal Zone Management" which was held at the Second Regional Meeting of the International Society for Reef Studies, Luxembourg, September 1994

G International uptake of research for marine policy

My research is targeted to management questions on coral reefs and it's therefore essential that I communicate my results to local stakeholders and decision-makers. During several field trips I have organised local stakeholder meetings to share our research and the attendance and feedback has been great. Locations include: San Salvador (Bahamas) where the local community reinvigorated their plans to set up their own protected areas; Fisheries Department (Belize) which resulted in me being invited to discuss my work with fishermen; Koror (Palau, Micronesia) which was attended by the State Governor. The most positive outcome of communicating science took place in Belize when I was invited to present the results of my modelling work to 170 Belizean fishermen. The talk was illustrated using video and dealt with the importance of mangroves and parrotfishes in building resilience in coral reefs. The fishermen were apparently unaware of the functions of parrotfishes and launched their own initiative to ban the exploitation of this species (which has been a rising concern). In 2009 the Ministry of Agriculture and Fisheries passed legislation banning the harvesting of herbivorous fish. Other forms of engagement included providing the biological rationale for declaration of the Conception Island Marine Park (Bahamas). More recently my research has been used to support a successful legal suit against the US Government (NOAA) for the inadequacy of their management of coral reefs.

I have provided advice to various governments including Indonesia (Marine Spatial Planing), the Bahamas (design of MPAs), Belize (MPA design, herbivore fisheries), Maldives (managing the effects of climate change), and Palau (effects of fishing on reefs). Advice to other management agencies includes the Great Barrier Reef Marine Park Authority (resilience mapping, control of crown-of-thorns starfish), the Caribbean Fisheries Management Council (herbivore fisheries), and NOAA (herbivore fisheries).

H Publications

Since 1995 I have published >215 journal articles, 7 book chapters and 5 books. My H-score is 60 and my total number of citations is >15,000. My research on reef remote sensing is the most highly cited on the topic and three papers have made the Thompson ISI Highly Cited list in their field with Mumby et al (2004) *Nature* being the most highly-cited recent paper on mangroves, Mumby and Edwards (2002) *Remote Sensing of Environment* amongst the top 3 most highly-cited papers in aquatic remote sensing, and Hoegh-Guldberg, Mumby et al (2007) *Science* being the most highly-cited paper on coral reefs since publication. According to a Thompson-Reuters analysis of coral reef papers in the last five years, I rank #1 in number of publications.

(i) Books

1. **Mumby PJ**, et al (2014) Towards Reef Resilience and Sustainable Livelihoods. University of Exeter, 180 pp. *Foreword by **Sir Richard Branson***
2. Day JC, Laffoley D, Zischka K (2015) Marine protected area management. In Worboys GL, Lockwood M, Kothari A, Feary S, Pulsford I (eds) Protected Area Governance and Management pp 609-650, ANU Press, Canberra (Contributing author).
3. Leadley, P.W., Krug, C.B., Alkemade, R., Pereira, H.M., Sumaila U.R., Walpole, M., Marques, A., Newbold, T., Teh, L.S.L, van Kolck, J., Bellard, C., Januchowski-Hartley, S.R. and **Mumby, P.J.** (2014): Progress towards the Aichi Biodiversity Targets: An Assessment of Biodiversity Trends, Policy Scenarios and Key Actions. **Secretariat of the Convention on Biological Diversity**, Montreal, Canada Technical Series 78, 500 pages.
4. Secretariat of the Convention on Biological Diversity (2014) Global Biodiversity Outlook 4. Montréal, 155 pages. (*Contributor*)
5. Green EP, **Mumby PJ**, Edwards AJ, Clark CD (Ed. A.J. Edwards) (2000). *Remote Sensing Handbook for Tropical Coastal Management*. *Coastal Management Sourcebooks 3*. **UNESCO, Paris. x + 316 pp. + 24 colour plates. ISBN 92-3-103736-6**

6. Edwards AJ, **Mumby PJ** (1997) Applications of Marine and Coastal Image Data to Coastal Management. Seventh Computer-based learning module, UNESCO-CSI *Bilko for Windows* distance-learning software for remote sensing and coastal management. UNESCO, Paris 173 pp.

(ii) Chapters in books and proceedings of conferences

1. Yakob L & **Mumby PJ** (2013) Infectious disease and the novel Caribbean coral reef. In: Novel Ecosystems: intervening in the new ecological world order. RJ Hobbs, Higgs ES, Hall CM (eds). John Wiley & Sons, Chichester pp 114-123
2. **Mumby PJ** & Steneck RS (2011) The resilience of coral reefs and its implications for reef management. In: Dubinsky Z, Stambler N. (eds.) Coral Reefs. Springer, Amsterdam 509-519
3. **Mumby PJ** (2009) Grazing and the resilience of coral reefs. In: Sheppard CRC (ed). *The Biology of Coral Reefs*, Oxford University Press, 186-188
4. **Mumby PJ**, Harborne AR (2006) A seascape-level perspective of coral reef ecosystems. In: Cote IM, Reynods JD (eds) *Coral Reef Conservation*, Cambridge University Press, Cambridge, pp 78-114.
5. **Mumby PJ**, Dytham C (2006) Metapopulation dynamics of hard corals. In: *Marine Metapopulations* (Eds J Kritzer, PF Sale), Elsevier, USA pp 157-203
6. **Mumby PJ** (2001) A synopsis of mangrove remote sensing. In *Mangrove ecosystems: natural distribution, biology and management* (Eds. Bhat NR, Taha FK, Al-Naseer AY), Kuwait Institute for Scientific Research, Kuwait pp. 3-6.
7. **Mumby PJ** (2000) Remote sensing of tropical coastal resources: progress and fresh challenges for the new Millennium. In. *Seas at the Millennium* (Ed. CRC Sheppard), Elsevier Science, London III: 283-291
8. **Mumby PJ,** Green EP, Clark CD, Edwards AJ (1997) Reefal habitat assessment using CASI airborne remote sensing. *Proceedings of the 8th Int.Coral Reef Symp*., Panama City, Panama. 2: 1499-1502
9. Green EP, **Mumby PJ**, Edwards AJ, Clark CD (1997) Mapping reefal habitats using remotely sensed data: exploring the relationship between cost and accuracy. *Proceedings of the 8th Int. Coral Reef Symp*. Panama City, Panama. 2: 1503-1506
10. Green EP, **Mumby PJ**, Clark CD, Edwards AJ, Ellis AC (1997). A comparison between satellite and airborne multispectral data for the assessment of mangrove areas in the Eastern Caribbean. Proceedings 4th Int. Conf. on Remote Sensing of Marine and Coastal Environments, Orlando, March 1997. 1: 168-176.
11. Harborne AR, **Mumby PJ**, Raines PS, Ridley JM (1995) The Bacalar Chico Marine Reserve: a case study in government and NGO collaboration in conservation projects In. *The Peaceful Management of Transboundary Resources* (Eds. Blake GH, Hildesley WJ, Pratt MA, Ridley RJ, Schofield CH) Graham and Trotman, London. pp 301-306.
12. **Mumby PJ**, Baker MA, Raines PS (1994) The potential of SPOT Panchromatic imagery as a tool for mapping coral reefs. *Proceedings of the Second Thematic Conference for Remote Sensing of Marine and Coastal Environments*, New Orleans 1: 259-267.
13. Raines PS, McCorry D, **Mumby PJ**, Ridley JM (1992) Coral Cay Conservation: survey techniques and their application in Belize. *Proceedings of 7th International Coral Reef Symposium*, Guam. 1:122-126.

(iii) Journals

1. Ainsworth TD, Heron SF, Ortiz JC, **Mumby PJ**, Grech A, Ogawa D, Eakin CM, Leggat WL (2016) Climate change disables coral bleaching protection on the Great Barrier Reef. **Science** (*in press*), accepted 1/3/16.
2. Bozec YM, O'Farrell S, Bruggemann JH, Luckhurst BE, **Mumby PJ** (2016) Tradeoffs between fisheries harvest and the resilience of coral reefs. **Proceedings of the National Academy of Sciences** (*in press*) (accepted Feb 2016)
3. **Mumby PJ**, Steneck RS, Adjeroud M, Arnold SN (2016) High resilience masks underlying sensitivity to algal phase shifts of Pacific coral reefs. **Oikos** (*in press*) Accepted 24/7/15

4. Doropoulos CD, Roff G, Bozec YM, Zupan M Werminghausen, **Mumby PJ** (2016) Characterising the ecological trade-offs throughout the early ontogeny of coral recruitment. **Ecological Monographs** 86: 20-44
5. Roff G, Doropoulos C, Rogers A, Bozec Y-M, Kruck N, Aurellado E, Priest M, Birrell C, **Mumby PJ** (2016) The ecological role of sharks on coral reefs. **Trends in Ecology & Evolution** (*in press*), accepted 28/1/15
6. Castro-Sanguino C, Lovelock C, **Mumby PJ** (2016) The effect of structurally complex corals and herbivory on the dynamics of *Halimeda*. **Coral Reefs** (*in press*) Accepted 29/1/16
7. Hock K, Wolff NH, Beedon R, Hoey J, Condie SA, Anthony KRN, Possingham HP, **Mumby PJ** (2016) Controlling range expansion in habitat networks by adaptively targeting source populations. **Conservation Biology** (*in press*) Accepted 29/11/15
8. Harborne AR, Nagelkerken I, Wolff NH, Bozec YM, Dorenbosch M, Grol MGG, **Mumby PJ** (2016) Direct and indirect effects of nursery habitats on coral-reef fish assemblages, grazing pressure, and benthic dynamics. **Oikos** (*in press*) Accepted 8/9/15
9. Ford AK, Bejarano S, Marshell A, **Mumby PJ** (2016) Linking the biology and ecology of key herbivorous unicornfish to fisheries management in the Pacific. **Aquatic Conservation: Marine and Freshwater Ecosystems** (*in press*) Accepted 14/12/15
10. Wolff NH, Wong A, Vitolo R, Stolberg K, Anthony KRN, **Mumby PJ** (2016) Temporal clustering of tropical cyclones on the Great Barrier Reef and its ecological importance. **Coral Reefs** (*in press*), accepted 11/1/16
11. O'Farrell S, Luckhurst BE, Box SJ, **Mumby PJ** (2016) Parrotfish sex ratios recover rapidly in Bermuda following a fishing ban. **Coral Reefs** (*in press*), accepted 8/12/15
12. Bayraktarov E, Saunders MI, Abdulla S, Mills M, Beher J, Possingham HP, **Mumby PJ**, Lovelock CE (2016) The cost and feasibility of marine coastal restoration. **Ecological Applications** (*in press*), accepted 14/10/15
13. Mills M, Leon JX, Saunders MI, Bell J, Liu Y, O'Mara J, Lovelock CE, **Mumby PJ**, Phinn SR, Possingham HP, Tulloch V, Mutafoglu K, Morrison T, Callaghan D, Baldock T, Klein CJ, Hoegh-Guldberg O (2016) Reconciling development & conservation under coastal squeeze from rising sea-level. **Cons. Letters** (*in press*) Accepted 28/10/15
14. Gonzalez-Rivero M, Bozec Y-M, Chollett I, Ferrari R, Schonberg CHL, **Mumby PJ** (2016) Asymmetric competition prevents the outbreak of an opportunistic species after coral reef degradation. **Oecologia (***in press*) Accepted 22/12/15
15. **Mumby PJ** (2016) Stratifying herbivore fisheries by habitat to avoid ecosystem overfishing of coral reefs. **Fish and Fisheries** 17: 266-278
16. Hughes TP, Cameron DS, Chin A, Connolly SR, Day JC, Jones GP, McCook L, McGinnity P, **Mumby PJ**, Pears RJ, Pressey RL, Russ GR, Tanzer J, Tobin A, Young MAL (2016) A critique of claims for negative impacts of Marine Protected Areas on Fisheries. **Ecological** Applications 26: 1-5
17. Chollett I, Box SJ, **Mumby PJ** (2016) Quantifying the squeezing or stretching of fisheries as they adapt to displacement by marine reserves. **Conservation Biology** 30: 166-175
18. Roff G, Zhao J-x, **Mumby PJ** (2016) Decadal-scale rates of reef erosion following El Niño related mass coral mortality. **Global Change Biology** 21: 4415-4424
19. Saunders MI, Albert S, Roelfsema CM, Leon JX, Woodroffe CD, Phinn SR, **Mumby PJ** (2016) Tectonic subsidence provides insight into possible coral reef futures under rapid sea-level rise. **Coral Reefs** 35: 155-167
20. Hedley JD, Roelfsema CM, Chollett I, Harborne AR, Heron SF, Weeks SJ, Skirving WJ, Strong AE, Eakin CM, Christensen TRL, Ticzon V, Bejarano S & **Mumby PJ** (2016) Remote Sensing of Coral Reefs for Monitoring and Management: A Review. **Remote Sensing** 8: 118.
21. Wilson R, Hardisty D, Epanchin-Niell R, Runge M, Cottingham K, Urban D, Maguire L, Hastings A, **Mumby PJ**, Peters D (2016) A typology of timescale mismatches and behavioral interventions to diagnose and solve conservation problems. **Conservation Biology** 30: 42-49
22. Ferrari R, McKinnon D, He H, Smith RN, Corke P, Gonzalez-Rivero M, **Mumby PJ** & Upcroft B (2016) Quantifying Multiscale Habitat Structural Complexity: A Cost-Effective Framework for Underwater 3D Modelling. **Remote Sensing** 8: 113.

23. **Mumby PJ**, Anthony KRN (2015) Resilience metrics to inform ecosystem management under global change with application to coral reefs. **Methods in Ecology and Evolution** 6: 1088-1096
24. Kwiatowski L, Cox P, Halloran P, **Mumby PJ**, Wiltshire A (2015) Coral bleaching under novel scenarios of warming and ocean acidification. **Nature Climate Change** 5: 777-781
25. Beger M, McGowan J, Treml EA, Green AL, White AT, Wolff NH, Klein CJ, **Mumby PJ**, Possingham HP (2015) Integrating regional conservation priorities for multiple objectives into national policy. **Nature Communications** doi:10.1038/ncomms9208
26. Brown CJ, White C, Beger M, Grantham HS, Halpern BS, Klein CJ, **Mumby PJ**, Tulloch VJD, Ruckelshaus M, Possingham HP (2015) Fisheries and biodiversity benefits of using static versus dynamic models for designing marine reserve networks. **Ecosphere** 6(10): 182
27. Newman SP, Meesters EH, Dryden CS, Williams SM, Sanchez C, **Mumby PJ**, Polunin NVC (2015) Reef flattening effects on total richness and species responses in the Caribbean. **J Anim. Ecol**. 84: 1678-1689
28. Ticzon VS, Foster G, David LT, **Mumby PJ**, Samaniego BR, Randolf Madrid V (2015) Delineating optimal settlement areas of juvenile reef fish in Ngederrak Reef, Koror State, Republic of Palau. **Environmental Monitoring and Assessment** 187(1):4089
29. Wolff NH, Donner SD, Lao L, Iglesias-Prieto, R, Sale PF, **Mumby PJ** (2015) Global inequities between polluters and the polluted: climate change impacts on coral reefs. **Global Change Biology** 21: 3982-3994
30. Marshell A, **Mumby PJ** (2015) The role of surgeonfish (Acanthuridae) in maintaining algal turf biomass on coral reefs. **Journal of Experimental Marine Biology and Ecology** 473: 152-160
31. O'Farrell S, Salguero-Gomez R, van Rooij JM, **Mumby PJ** (2015) Disentangling trait-based mortality in species with decoupled size and age. **Journal of Animal Ecology** 84: 1446-1456
32. Aswani S, **Mumby PJ**, Baker AC, Christie P, McCook LJ, Steneck RS, Richmond RH (2015) Scientific frontiers in the management of coral reefs. **Frontiers in Marine Science** doi: 10.3389/fmars.2015.00050
33. Doropoulos C, Ward S, Roff G, Gonzalez-Rivero M, **Mumby PJ** (2015) Linking demographic processes of juvenile corals to benthic recovery trajectories in two common reef habitats. **PloS One** 0128535
34. Baldock TE, Golshani A, Atkinson A, Shimamoto T, Wu S, Callaghan DP **Mumby PJ** (2015) Impact of sea-level rise on cross-shore sediment transport on fetch-limited barrier reef island beaches under modal and cyclonic conditions. **Marine Pollution Bulletin** 97: 188-198
35. Linnenluecke MK, Griffiths A, **Mumby PJ** (2015) Executives' engagement with climate science and perceived need for business adaptation to climate change. **Climatic Change** 131: 321-333
36. Williams SM, Mumby PJ, Chollett I, Cortes J (2015) The importance of differentiating *Orbicella* reefs from gorgonian plains for ecological assessments of Caribbean reefs. **Mar Ecol Prog Series** 530: 93-101
37. Williams SM, Chollett I, Roff G, Cortes J, Dryden CS, **Mumby PJ** (2015) Hierarchical spatial patterns in Caribbean reef benthic assemblages. **Journal of Biogeography** 42: 1327–1335
38. Roff G, Doropoulos C, Zupan M, Rogers A, Steneck RS, Golbuu Y, **Mumby PJ** (2015) Phase shift facilitation following cyclone disturbance on coral reefs. **Oecologia** 178: 1193-1203
39. Roff, G, Chollett I, Doropoulos D, Golbuu Y, Steneck RS, **Mumby PJ** (2015) Exposure-driven phase shift following catastrophic disturbance on coral reefs. **Coral Reefs** (*in press*)
40. Kennedy EV, Foster NL, **Mumby PJ**, Stevens JR (2015) Widespread prevalence of cryptic Symbiodinium D in the key Caribbean reef builder, *Orbicella annularis*. **Coral Reefs** 34: 519-531
41. Green A, Maypa A, Almany G, Rhodes K, Abesamis R, Gleason M, **Mumby PJ**, White A (2014) Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. **Biological Reviews** 90: 1215-1247
42. Bozec YM, **Mumby PJ** (2015) Synergistic impacts of global warming on the resilience of coral reefs. **Philosophical Transactions of the Royal Society B** 370: 20130267
43. Hock K, **Mumby PJ** (2015) Quantifying the reliability of dispersal paths in connectivity networks. **J. Royal Soc. Interface** 12: 20150013
44. Conversi A, Dakos V, Gardmark A, Ling S, Folke C, **Mumby PJ**, Greene C, Edwards M, Blenckner T, Casini M, Pershing A, Mollman C (2015) A holistic view of marine regime shifts. **Phil Trans. Royal Society B.** 370: 20130279

45. Allgeier JE, Layman CA, **Mumby PJ**, Rosemond AD (2015) Biogeochemical implications of biodiversity and community structure across multiple coastal ecosystems. **Ecological Monographs** 85: 117-132
46. Igulu MM, Nagelkerken I, Dorenbosch M1, Grol MGG, Harbone AR, Kimirei IA, **Mumby PJ**, Olds AD, Mgaya YD (2015) Mangrove habitat use by juvenile reef fish: meta-analysis reveals that tidal regime matters more than biogeographic region. **PloS One** 9:e114715
47. Saunders MI, Bakraktarov E, Roelfsema CM, Leon JX, Samper-Villarreal J, Phinn SR, Lovelock CE, **Mumby PJ** (2015) Spatial and temporal variability of seagrass at Lizard Island, Great Barrier Reef. **Botanica Marina** 58: 35-48
48. Dıaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR, Arico S, Ba´ldi A, Bartuska A, Baste IA, Bilgin A, Brondizio E, Chan KMA, Figueroa VE, Duraiappah A, Fischer M, Hill R, Koetz T, Leadley P, Lyver P, Mace GM, Martin-Lopez B, Okumura M, Pacheco D, Pascual U, Perez ES, Reyers B, Roth E, Saito O, Scholes RJ, Sharma N, Tallis H, Thaman R, Watson R, Yahara T, Hamid ZA, Akosim C, Al-Hafedh Y, Allahverdiyev R, Amankwah E, Asah ST, Asfaw Z, Bartus G, Brooks LA, Caillaux J, Dalle G, Darnaedi D, Driver A, Erpul G, Escobar-Eyzaguirre P, Failler P, Fouda AMM, Fu B, Gundimeda H, Hashimoto S, Homer F, Lavorel S, Lichtenstein G, Mala WA, Mandiveny W, Matczak P, Mbizvo C, Mehrdadi M, Metzger JP, Mikissa JP, Moller H, Mooney HA, **Mumby P**, Nagendra N, Nesshover C, Oteng-Yeboah AA, Pataki G, Roue M, Rubis J, Schultz M, Smith P, Sumaila R, Takeuchi K, Thomas S, Verma M, Yeo-Chang Y, Zlatanova D (2015) The IPBES conceptual framework – connecting nature and people. **Current Opinion in Environmental Sustainability** 14: 1-16
49. O'Farrell S, Harborne AR, Bozec Y-M, Luckhurest BE, **Mumby PJ** (2015) Protection of functionally important parrotfishes increases their biomass but fails to deliver enhanced recruitment. **Marine Ecology Progress Series** 522: 245-254
50. Ainsworth, C, **Mumby PJ** (2015) Coral-algal phase shifts alter fish communities and reduce fisheries production. **Global Change Biology** 21: 165-172
51. Bozec YM, Alvarez-Filip L, **Mumby PJ** (2015) The dynamics of architectural complexity on coral reefs. **Global Change Biology** 21: 223-235
52. Anthony KRN, Marshall PA, Abdulla A, Beeden R, Bergh C, Black R, Eakin CM, Game ET, Gooch M, Graham NAJ, Green A, Heron SF, van Hooidonk R, Knowland C, Mangubhai S, Marshall N, Maynard JA, McGinnity P, McLeod E, **Mumby PJ**, Nystrom M, Obura D, Oliver J, Possingham HP, Pressey RL, Rowlands GP, Tamelander J, Wachenfeld D, Wear S (2015) Operationalising resilience for adaptive coral reef management under global environmental change. **Global Change Biology** 21:48-61
53. Perry CT, Murphy GN, Kench PS, Edinger EN, Smithers SG, Steneck RS, **Mumby PJ** (2015) Evidence for the regional scale dominance of weedy coral taxa on Caribbean coral reefs: impacts on reef carbonate production and implications for future reef growth. **Global Change Biology** 21: 1153-1164
54. Brown CJ, Abdulla S, **Mumby PJ** (2015) Minimizing the short-term impacts of marine reserves on fisheries while meeting long-term goals for recovery. **Conservation Letters** 8: 180-189
55. **Mumby PJ** and van Woesik R (2014) Consequences of ecological, evolutionary, and biogeochemical uncertainty on the response of coral reefs to climatic stress. **Current Biology** 24: R413-R423
56. Rogers A, Blanchard JL, **Mumby PJ** (2014) Vulnerability of coral reef fisheries to a loss of structural complexity. **Current Biology** 24: 1000-1005
57. Tittensor DP, Walpole M, Hill SLL, Boyce DG, Britten GL, Burgess ND, Butchart SHM, Leadley PW, Regan EC, Alkemade R, Baumung R, Bellard C, Bouwman L, Bowles-Newark NJ, Chenery AM, Cheung WWL, Christensen V, Cooper HD, Crowther AR, Dixon MJR, Galli A, Gaveau V, Gregory RD, Gutierrez NL, Hirsch TL, Höft R, Januchowski-Hartley SR, Karmann M, Krug CB, Leverington FJ, Loh J, Lojenga RK, Malsch K, Marques A, Morgan DHW, **Mumby PJ**, Newbold T, Noonan-Mooney K, Pagad SN, Parks BC, Pereira HM, Robertson T, Rondinini C, Santini L,Scharlemann JPW, Schindler S, Sumaila UR, Teh LSL, van Kolck J, Visconti P, Ye Y (2014) A mid-term analysis of progress towards international biodiversity targets. **Science** 346: 241-244
58. Brown CJ, **Mumby PJ** (2014) Trade-offs between fisheries and the conservation of ecosystem function are defined by management strategy. **Frontiers in Ecology and Evolution** 12: 324-329

59. **Mumby PJ**, Wolff NH, Bozec YM, Chollett I, Halloran P (2014) Operationalising the resilience of coral reefs in an era of climate change. **Conservation Letters 7: 176-187 (Feature Article)**
60. Perry CT, Murphy GN, Kench PS, Edinger EN, Smithers SG, Steneck RS, **Mumby PJ** (2014) Changing dynamics of Caribbean reef carbonate budgets: emergence of reef bioeroders as critical controls on present and future reef growth potential. **Proceedings of the Royal Society B** http://dx.doi.org/10.1098/rspb.2014.2018
61. Ortiz JC, Bozec Yves-Marie, Wolff NH, Doropoulos C, **Mumby PJ** (2014) Global disparity in the ecological benefits of reducing carbon emissions for coral reefs. **Nature Climate Change** 4: 1090-1094
62. O'Farrell S, Bearhop S, McGill RAR, Dahlgren CP, Brumbaugh DR, **Mumby PJ** (2014) Habitat and body size effects on the isotopic niche space of invasive lionfish and endangered Nassau grouper. **Ecosphere** 5(10):123 http://dx.doi.org/10.1890/ES14-00126.1
63. Rogers A, Harborne AR, Brown CJ, Bozec Y-M, Castro C, Chollett I, Hock K, Knowland C, Marshell A, Ortiz JC, Razak T, Roff G, Samper-Villarreal J, Saunders MI, Wolff N, **Mumby PJ** (2015) Anticipative management for coral reef ecosystem services in the 21st century. **Global Change Biology** 21: 504-514
64. Bell J, Saunders M, Patino JL, Mills M, Kythreotis A, Phinn S, **Mumby PJ**, Lovelock CE, Hoegh-Guldberg O, Morrison T (2014) Maps, laws and planning policy: working with biophysical and spatial uncertainty in the case of sea level rise. **Environmental Science and Policy** 44: 247-257
65. Mace GM, Reyers B, Alkemade R, Biggs R, Stuart Chapin II F, Cornell SE, Diaz S, Jennings S, Leadley P, **Mumby PJ**, Purvis A, Scholes RJ, Seddon AWR, Solan M, Steffen W, Woodward G (2014) Approaches to defining a planetary boundary for biodiversity. **Global Environmental Change** 28: 289-297
66. Steneck RS, Arnold SN, **Mumby PJ** (2014) Cascading processes on recruitment may limit coral reef recovery and drive alternate attractors. **Marine Ecology Progress Series** 506: 115-127
67. Vergés A, Steinberg PD, Hay ME, Poore AGB, Campbell AH, Ballesteros E, Heck, Jr KI, Booth DJ, Coleman MA, Feary DA, Figueira W, Langlois T, Marzinelli EM, Mizerek T, **Mumby PJ**, Nakamura Y, Roughan M, Sebille EV, Gupta AS, Smale DA, Tomas F, Wernberg T, Wilson SK (2014) The tropicalisation of temperate marine ecosystems: climate-mediated changes in herbivory and community phase shifts. **Proceedings of the Royal Society B** http://dx.doi.org/10.1098/rspb.2014.0846
68. Saunders MI, Leon JX, Callaghan DP, Roelfsema CM, Hamylton S, Brown CJ, Baldock T, Golshani A, Phinn SR, Lovelock CE, Hoegh-Guldberg O, Woodroffe CD, **Mumby PJ** (2014) Interdependency of tropical marine ecosystems in response to climate change. **Nature Climate Change** 4: 724-729
69. Hock K, Wolff NH, Condie SA, Anthony KRN, **Mumby PJ** (2014) Connectivity networks reveal the risks of crown-of-thorns starfish outbreaks on the Great Barrier Reef. **J. Applied Ecology** 51: 1188-1196
70. Baldock TE, Karampour H, Sleep R, Vyltla A, Albermani F, Golshani A, Callaghan DP, Roff G, **Mumby PJ** (2014) Resilience of branching and massive corals to wave loading under sea level rise - a coupled computational fluid dynamics-structural analysis. **Marine Pollution Bulletin** 82: 91-101
71. Baldock TE, Golshani A, Callaghan DP, Saunders M, **Mumby PJ** (2014) Impact of sea-level rise and coral mortality on wave dynamics on barrier reefs. **Marine Pollution Bulletin** 83: 155-164
72. Sale PF, Agardy T, Ainsworth CH, Feist BE, Bell JD, Christie P, Hoegh-Guldberg O, **Mumby PJ**, Feary DA, Saunders MI, Daw TM, Foale SJ, Levin PS, Lindeman KC, Lorenzen K, Pomeroy RS, Allison EH, Bradbury RH, Corrin J, Edwards AJ, Obura DO, Sadovy de Mitcheson YJ, Samoilys MA, Sheppard CRC (2014) Transforming management of tropical coastal seas to cope with challenges of the 21st century. **Marine Pollution Bulletin** 85: 8-23
73. Doropoulos C, Zupan M, Roff G, Nestor V, Isechal AL, **Mumby PJ** (2014) Reef-scale failure of coral settlement following typhoon disturbance and macroalgal bloom in Palau, Western Pacific. **Coral Reefs** 33: 613-623
74. Roff G, Bejarano S, Bozec Y-M, Nugues M, Steneck RS, **Mumby PJ** (2014) *Porites* and the Phoenix effect: unprecedented recovery after a mass coral bleaching event at Rangiroa Atoll, French Polynesia. **Marine Biology** 161: 1385-1393
75. Chollett I, Canty SWJ, Box SJ, **Mumby PJ** (2014) Adapting to the impacts of global change on an artisanal coral reef fishery. **Ecological Economics** 102: 118-125

76. Allgeier JE, Layman CA, **Mumby PJ**, Rosemond AD (2014) Consistent nutrient storage and supply mediated by diverse fish communities in coral reef ecosystems. **Global Change Biology** 20: 2459-2472
77. Christianen MJA, Herman PMJ, Bouma TJ, Lamers LPM, van Katwijk MM, van der Heide T, **Mumby PJ**, Silliman BR, Engelhard SL, van de Kerk M, Kiswara W, van de Koppel J (2014) Habitat collapse due to overgrazing threatens turtle conservation in marine protected areas. **Proceedings of the Royal Society B** http://dx.doi.org/10.1098/rspb.2013.2890
78. **Mumby PJ**, Chollett I, Wolff NW, Bozec YM (2014) Ecological resilience, robustness and vulnerability: how do these concepts benefit ecosystem management? **Current Opinions in Environmental Sustainability** 7: 22-27
79. Chollett I, Enriquez S, **Mumby PJ** (2014) Redefining thermal regimes to design reserves for climate change. **PloS One** 9: e110634
80. Micheli F, **Mumby PJ**, Brumbaugh DR, Broad K, Dahlgren CP, Harborne AR, Holmes KE, Kappel CV, Litvin SY, Sanchirico JN (2014) High vulnerability of ecosystem function and services to diversity loss in Caribbean coral reefs. **Biological Conservation** 171: 186-194
81. Kwiatkowski L, Halloran PR, **Mumby PJ**, Stephenson DB (2014) What spatial scales are believable for climate model projections of sea surface temperature? **Climate Dynamics** 43: 1483-1496
82. Holstein DM Paris CB, **Mumby PJ** (2014) Consistency and inconsistency in multispecies population network dynamics of coral reef ecosystems. **Marine Ecology Progress Series** 499:1-18 **(Feature Article)**
83. Ortiz JC, Gonzalez-Rivero M, **Mumby PJ** (2014) An ccosystem-level perspective on the host and symbiont traits needed to mitigate climate change impacts on Caribbean coral reefs. **Ecosystems** 17:1-13
84. Ticzon VS, Foster G, David LT, **Mumby PJ**, Samaniego BR, Randolf Madrid V (2015) Delineating optimal settlement areas of juvenile reef fish in Ngederrak Reef, Koror State, Republic of Palau. **Environmental Monitoring and Assessment** 187:4089 DOI 10.1007/s10661-014-4089-7
85. Chollett I, **Mumby PJ** (2013) Reefs of last resort: Locating and assessing thermal refugia in the wider Caribbean. **Biological Conservation** 167: 179-186
86. **Mumby PJ**, Steneck RS, Hastings A (2013) Evidence for and against the existence of alternate attractors on coral reefs. **Oikos** 122: 481-491
87. Bejarano S, Golbuu Y, Sabolu T, **Mumby PJ** (2014) Changes in the herbivore spear fishery associated with the grouper closure in Palau. **Animal Conservation** 17:133-143
88. Kennedy EV, Perry CT, Halloran PR, Iglesias-Prieto R, Schonberg CH, Wisshak M, Form AU, Carricart-Ganivet JP, Fine M, Eakin CM, **Mumby PJ** (2013) Avoiding coral reef functional collapse requires local and global action. **Current Biology** 23: 912-918
89. Tomimatsu H, Sasaki T, Kurokawa H, Bridle JR, Fontaine C, Kitano J, Stouffer DB, Vellend M, Martijn Bezemer T, Fukami T, Hadly EA, van der Heijden MGA, Kawata M, Kefi S, Kraft NJB, McCann KS, **Mumby PJ**, Nakashizuka T, Petchey OL, Romanuk TN, Suding KN, Takimoto G, Urabe J, Yachi S (2013) Sustaining ecosystem functions in a changing world: a call for an integrated approach. **J Appled Ecol** 50: 1124-1130
90. Kwaitkowski L, Cox PM, Economou T, Halloran PR, **Mumby PJ**, Booth BB, Carilli J, Guzman HM (2013) Caribbean coral growth influenced by anthropogenic aerosol emissions. **Nature Geoscience** 6: 362-366
91. Bejarano S, Golbuu Y, Sabolu T, **Mumby PJ** (2013) Ecological risk and the exploitation of herbivorous fish across Micronesia. **Marine Ecology Progress Series** 482:197-215
92. Perry CT, Murphy GN, Kench PS, Smithers SG, Edinger EN, Steneck RS, **Mumby PJ** (2013) Caribbean-wide decline in carbonate production threatens coral reef growth. **Nature Communications** 4: 1402
93. Foster NL, Baums IB, Sanchez JA, Agudelo CL, Vermeij MJA, Chollett I, **Mumby PJ** (2013) Hurricane-driven patterns of clonality in an ecosystem engineer: The Caribbean coral *Montastraea annularis*. **PLoS One** 8:e53283
94. González-Rivero M, Ereskovsky AV, Schönberg CHL, Ferrari R, Fromont J, **Mumby PJ** (2013) Life-history traits of a common Caribbean coral-excavating sponge, Cliona tenuis (Porifera: Hadromerida). **Journal of Natural History** 47(45-46):2815-2834
95. Sanders MI, Leon J, Phinn SR, Callaghan DP, O'Brien KR, Roelfsema CM, Lovelock CE, Lyons MB, **Mumby PJ** (2013) Coastal retreat and improved water quality mititgate losses of seagrass from sea level rise. **Global Change Biology** 19: 2569-2583

96. Roff G & **Mumby PJ** (2012) Global disparity in the resilience of coral reefs. **Trends in Ecology & Evolution** 27: 404-413
97. Ortiz JC, Gonzalez M, **Mumby PJ** (2012) Can a thermally tolerant symbiont improve the future of Caribbean coral reefs? **Global Change Biology** 19: 273-281
98. **Mumby PJ**, Bejarano S, Golbuu Y, Steneck RS, Arnold SN, van Woesik R, Friedlander AM (2013) Empirical relationships among resilience indicators on Micronesian reefs. **Coral Reefs** 32: 213-226
99. Dornelas M, Magurran AE, Buckland ST, Chao A, Chazdon RL, Colwell RK, Curtis T, Gaston KJ, Gotelli NJ, Kosnik MA, McGill B, McCune JL, Morlon H, **Mumby PJ**, Ovreas L, Studeny A, Vellend M (2013) Quantifying temporal change in biodiversity: challenges and opportunities. **Proc Royal Society** B 280 (1750): DOI:10.1098/rspb.2012.1931
100. Roff G, Wabnitz CCC, Harborne AR, **Mumby PJ** (2013) Macroalgal associations of motile epifaunal invertebrate communities on coral reefs. **Marine Ecology** 34: 409-419
101. Doropoulos C, Ward S, Marshell A, Diaz-Pulido G, **Mumby PJ** (2012) Interactions among chronic and acute impacts on coral recruits: the importance of size-escape thresholds. **Ecology** 93: 2131-2138
102. Perry CT, Edinger EN, Kench PS, Murphy GN, Smithers SG, Steneck RS, **Mumby PJ** (2012) Estimating rates of biologically driven coral reef framework production and erosion: a new census-based carbonate budget methodology and applications to the reefs of Bonaire. **Coral Reefs** 31: 853-868
103. Marshell A, **Mumby PJ** (2012) Revisiting the functional roles of the surgeonfish *Acanthurus nigrofuscus* and *Ctenochaetus striatus*. **Coral Reefs** 31: 1093-1101
104. Doropoulous C, Ward S, Diaz-Pulido G, Hoegh-Guldberg O, **Mumby PJ** (2012) Ocean acidification reduces coral recruitment by disrupting intimate larval-algal settlement interactions. **Ecology Letters** 15: 338-346
105. Bozec YM, Yakob L, Bejarano S, **Mumby PJ** (2013) Reciprocal facilitation and non-linearity maintain habitat engineering on coral reefs. **Oikos** 122: 428-440
106. Ferrari R, Gonzalez M, **Mumby PJ** (2012) Size matters in the competition between corals and macroalgae. **Marine Ecology Progress Series** 467: 77-88
107. Chollett I, **Mumby PJ**, Muller-Karger FE, Hu C (2012) Physical environments of the Caribbean Sea. **Limnology & Oceanography** 57: 1233-1244
108. McClanahan TR, Donner S, Maynard JA, MacNeil MA, Graham NAJ, Maina JM, Baker AC, Alemu JB, Beger M, Campbell SJ, Darling ES, Eakin CM, Heron SF, Jupiter SD, Lundquist CJ, McLeod E, **Mumby PJ**, Paddack MJ, Selig ER, van Woesik R (2012) Evidence-based resilience assessments support coral reef management in a changing climate. **PLoS One** 7:e42884
109. Foster NL, Paris CB, Kool JT, Baums IB, Stevens JR, Sanchez JA, Bastidas C, Agudelo C, Bush P, Day O, Ferrari R, Gonzalez P, Gore S, Guppy R, McCartney M, McRoy CP, Mendes JM, Srinivasan A, Steiner S, Vermeij MAJ, Weil E, **Mumby PJ** (2012) Connectivity of Caribbean coral populations: complementary insights from empirical and modelled gene flow. **Molecular Ecol.** 21:1143-1157
110. Yakob L, **Mumby PJ** (2012) Life histories offer a clue to the future of infectious disease on coral reefs. **ANZIAM Journal** 54: 64-73
111. Harborne AR, **Mumby PJ**, Ferrari R (2012). The effectiveness of different meso-scale rugosity metrics for predicting intra-habitat variation coral-reef fish assemblages. **Environmental Biology of Fishes** 94: 431-442
112. Nagelkerken I, Grol MGG, **Mumby PJ** (2012) Effects of marine reserves versus nursery habitat availability on the structure of reef fish communities. **PLoS One** 7(6):e36906
113. Ticzon VS, **Mumby PJ**, Samaniego BR, Bejarano-Chavarro S, David LT (2012) Microhabitat use of juvenile coral reef fish in Palau. **Environmental Biology of Fishes** 95: 355-370
114. Ferrari R, Gonzalez M, Ortiz JC, **Mumby PJ** (2012) Interaction of herbivory and seasonality on the dynamics of Caribbean macroalgae. **Coral Reefs** 31: 683-692
115. Chollett I, **Mumby PJ** (2012) Predicting the distribution of *Montastraea* reefs using wave exposure. **Coral Reefs** 31: 493-503

116. Chollett I, Müller-Karger FE, Heron SF, Skirving W, **Mumby PJ** (2012) Seasonal and spatial heterogeneity of recent sea surface temperature trends in the Caribbean Sea and southeast Gulf of Mexico. **Marine Pollution Bulletin** 64: 956-965
117. Hedley JD, Roelfsema C, Phinn SR, **Mumby PJ** (2012) Environmental and sensor limitations in optical remote sensing of coral reefs: Implications for monitoring and sensor design. **Remote Sensing** 4:271-302
118. **Mumby PJ**, Steneck RS, Edwards AJ, Ferrari R, Harborne AR, Coleman R, Gibson J (2012) Fishing down a Caribbean food web relaxes trophic cascades. **Marine Ecology Progress Series** 445: 13-24
119. Blackwood J, Hastings A, **Mumby PJ** (2012) The effect of fishing on hysteresis in Caribbean coral reefs. **Theoretical Ecology** 5: 105-114
120. **Mumby PJ**, Vitolo R, Stephenson DB (2011) Temporal clustering of tropical cyclones and its ecosystem impacts. **Proceedings of the National Academy of Sciences USA** 108: 17626-17630
121. **Mumby PJ**, Harborne AR, Brumbaugh DR (2011) Grouper as a natural biocontrol of invasive lionfish. **PLoS One** 6(6): e21510
122. Harborne AR, **Mumby PJ** (2011) Novel ecosystems: altering fish assemblages in warming waers. **Current Biology** 21: R822-R824
123. Foster NL, Paris CB, Kool JT, Baums IB, Stevens JR, Sanchez JA, Bastidas C, Agudelo C, Bush P, Day O, Ferrari R, Gonzalez P, Gore S, Guppy R, McCartney M, McRoy CP, Mendes JM, Srinivasan A, Steiner S, Vermeij MAJ, Weil E, **Mumby PJ** (2012) Connectivity of Caribbean coral populations: complementary insights from empirical and modelled gene flow. **Molecular Ecol.** 21: 1143-1157
124. Harborne AR, **Mumby PJ**, Ferrari R (2011) The effectiveness of different meso-scale rugosity metrics for predicting intra-habitat variation coral-reef fish assemblages. ***Environmental Biology of Fishes*** *(in press)*
125. Roff G, Ortiz JC, Ledlie M, **Mumby PJ** (2011) Spatial Patterns of Parrotfish Corallivory in the Caribbean: the Importance of Coral Taxa, Density and Size. **PLoS One** 6(12): e29133
126. Harborne AR, **Mumby PJ**, Kennedy EV, Ferrari R (2011) Effect on coral reef fishes of biotic ad multi-scale abiotic controls of habitat quality. **Marine Ecology Progress Series** 437: 201-214
127. Yakob L, **Mumby PJ** (2011) Climate change induces demographic resistance to disease in novel coral assemblages. **Proceedings of the National Academy of Sciences USA** 108: 1967-1969
128. Yakob L, **Mumby PJ** (2011) Reply to Jordan-Garza et al: Demographic dynamism as an additional mechanism of coral disease resistance. **Proceedings of the National Academy of Sciences USA 108: E112-E112**
129. Gonzalez-Rivero M, Yakob L, **Mumby PJ** (2011) The role of sponge competition on coral reef alternative steady states. **Ecological Modelling** 222: 1847-1853
130. **Mumby PJ**, Elliott IA, Eakin CM, Skirving W, Paris CP, Edwards HJ, Enriquez S, Iglesias-Prieto R, Cherubin L, Stevens JR (2011) Reserve design for uncertain responses of coral reefs to climate change. **Ecology Letters** 14: 132-140
131. Blackwood JC, Hastings A, **Mumby PJ** (2011) A model-based approach to determine the long term effects of multiple interacting stressors on coral reefs. **Ecological Applications** 21: 2722-2733
132. Edwards HJ, Elliott IA, Eakin CM, Irikawa A, Madin JS, McField M, Morgan JA, van Woesik R, **Mumby PJ** (2011) How much time can herbivore protection buy for coral reefs under realistic regimes of hurricanes and coral bleaching? **Global Change Biology** 17: 2033-2048
133. **Mumby PJ**, Iglesias-Prieto R, Hooten AJ, Sale PF, Hoegh-Guldberg O, Edwards AJ, Harvell CD, Gomez ED, Knowlton N, Hatziolos ME, Kyewalyanga MS, Muthiga N (2011) Revisiting climate thresholds and ecosystem collapse. **Frontiers in Ecology & Environment** 9: 94-96
134. Bejarano S, **Mumby PJ**, Sotheran IS (2011) Predicting the structural complexity of reefs and fish abundance using RoxAnn. **Marine Biology** 158: 489-504
135. Kellner JB, Sanchirico HN, Hastings A, **Mumby PJ** (2011) Optimizing for multiple species and multiple values: tradeoffs inherent in ecosystem-based fisheries management. **Conservation Letters** 4: 21-30
136. Anthony K, Maynard J, Diaz-Pulido G, **Mumby PJ**, Cao L, Hoegh-Guldberg O (2011) Ocean acidification and warming will lower coral reef resilience. **Global Change Biology** 17: 1798-1808

137. Phinn SR, Roelfsema CM, **Mumby PJ** (2012) Multiscale, object-based image analysis for mapping geomorphic and ecological zones on coral reefs. **International Journal of Remote Sensing** 33: 3768-3797
138. Foster J, Ticzon V, Reigl B, **Mumby PJ** (2011) Detecting end-member structural and biological elements of a coral reef using a single-beam acoustic ground discrimination system. **International Journal of Remote Sensing** 32: 7749-7776
139. Hughes TP, Graham NAJ, Jackson JBC, **Mumby PJ**, Steneck RS (2010) Rising to the challenge of sustaining coral reef resilience. **Trends in Ecology & Evolution** 25: 633- 642
140. Arnold SN, Steneck RS, **Mumby PJ** (2010) Running the gauntlet to coral recruitment through a sequence of local multiscale processes. **Marine Ecology Progress Series** 414: 91-105
141. Chollett IC, **Mumby PJ**, Cortes J (2010) Upwelling regions: a refuge for coral reefs in a warming ocean? **Marine Ecology Progress Series** 416: 47-56
142. Bejarano S, **Mumby PJ**, Hedley JD, Sotheran IS (2010) Combining optical and acoustic data to enhance the detection of Caribbean forereef habitats. **Remote Sensing of Environment** 114: 2768-2778
143. Eakin CM, Nim C, Brainard RE, Aubrecht C, Elvidge C, Gledhill DK, Muller-Karger F, **Mumby PJ,** Skirving WJ, Strong AE, Wang M, Weeks S, Wentz F (2010) Monitoring coral reefs from space. **Oceanography** 23: 118-133
144. Kellner JB, Litvin SY, Hastings A, Micheli F, **Mumby PJ** (2010) Disentangling trophic interactions inside a Caribbean marine reserve. **Ecological Applications** 20: 1979-1992
145. **Mumby PJ**, Harborne AR (2010) Marine reserves enhance the recovery of corals on Caribbean reefs. **PloS One** 5: e8657
146. Wilson SK, Adjeroud M, Bellwood DR, Berumen ML, Booth D, Bozec Y-Marie, Chabanet P, Cheal A, Cinner J, Depczynski M, Feary DA, Gagliano M, Graham NAJ, Halford AR, Halpern BS, Harborne AR, Hoey AS, Holbook SJ, Jones GP, Kulbiki M, Letourneur Y, De Loma TL, McClanahan TM, McCormick MI, Meekan MG, **Mumby PJ**, Munday PL, Ohman MC, Pratchett MS, Riegl B, Sano M, Schmitt RJ, Syms C (2010) Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. **J Exp Biol** 213: 894-900.
147. Edwards HJ, Elliott IA, Pressey RL, **Mumby PJ** (2010) Incorporating ontogenetic dispersal, ecological processes, and conservation zoning into reserve design. **Biological Conservation** 143: 457-470
148. Renken H, **Mumby PJ**, Matsikis I, Edwards HJ (2010) Effects of physical environmental conditions on the patch dynamics of *Dictyota pulchella* and *Lobophora variegata* on Caribbean coral reefs. **Marine Ecology Progress Series** 403: 67-73
149. Beger M, Grantham HS, Pressey RL, Wilson KA, Peterson EL, Dorfman D, **Mumby PJ,** Lourival R, Brumbaugh DR, Possingham HP (2010) Conservation planning for connectivity across marine, freshwater, and terrestrial realms. **Biological Conservation** 143: 565-575
150. **Mumby PJ** (2009) Herbivory vs. corallivory: Are parrotfish good or bad for Caribbean reefs? **Coral Reefs** 28: 761-773
151. **Mumby PJ** (2009) Phase shifts and the stability of macroalgal communities on Caribbean coral reefs. **Coral Reefs** 28: 683-690
152. Baskett ML, Nisbet RM, Kappel CV, **Mumby PJ**, Gaines SD (2010) Conservation management approaches to protecting the capacity for corals to respond to climate change: a theoretical comparison. **Global Change Biology** 16: 1229-1246
153. Harborne AR, Renaud PG, Tyler EHM, **Mumby PJ** (2009) Reduced density of the herbivorous urchin *Diadema antillarum* inside a Caribbean marine reserve linked to increased predation pressure by fishes. Coral Reefs 28: 783-791
154. Paddack MJ, Reynolds JD, Aguilar C, Appeldoorn RS, Beets J, Burkett EW, Chittaro PM, Clarke K, Esteves R, Fonseca AC, Forrester GE, Friedlander AM, Garcia-Sais J, Gonzalez-Sanson G, Jordan LKB, McClellan DB, Miller MW, Molloy PP, **Mumby PJ**, et al (2009) Recent region-wide declines in Caribbean reef fish abundance. **Current Biology** 19: 1-6

155. Lim A, Hedley J, LeDrew E, **Mumby PJ**, Roelfsema C (2009) The effects of ecologically determined spatial complexity on the classification accuracy of simulated coral reef images. **Remote Sensing of Environment** 113: 965-978
156. Renken H, **Mumby PJ** (2009) Modelling the dynamics of coral reef macroalgae using a Bayesian Belief Network approach. **Ecological Modelling** 220: 1305-1314
157. Sanchirico JN, **Mumby PJ** (2009) Mapping ecosystem functions to the valuation of ecosystem services: Implications of species-habitat associations for coastal land-use decisions. **Theoretical Ecology** 2: 67-77
158. **Mumby PJ**, Steneck RS (2008) Coral reef management and conservation in the light of rapidly-evolving ecological paradigms. **Trends in Ecology and Evolution** 23: 555-563
159. Harborne AR, **Mumby PJ**, Kappel CV, Dahlgren CP, Micheli F, Holmes KE, Brumbaugh DR (2008) Tropical coastal habitats as surrogates of fish community structure, grazing and fisheries value. **Ecological Applications** 18: 1689-1701
160. Foster NL, Box SJ, **Mumby PJ** (2009) Competitive effects of macroalgae on the fecundity of the reef building coral, Montastraea annularis. **Marine Ecology Progress Series** 367: 143-152
161. **Mumby PJ**, Hastings A (2008) The impact of ecosystem connectivity on coral reef resilience. **Journal of Applied Ecology** 45: 854-862
162. **Mumby PJ**, Broad K, Brumbaugh DR, Dahlgren CP, Harborne AR, Hastings A, Holmes KE, Kappel CV, Micheli F, Sanchirico JN (2008) Coral reef habitats as surrogates of species, ecological functions and ecosystem services. **Conservation Biology** 22: 941-951
163. Harborne AR, **Mumby PJ**, Kappel CV, Dahlgren CP, Micheli F, Holmes KE, Sanchirico JN, Broad K, Elliott I, Brumbaugh DR (2008) Reserve effects versus natural variation in coral reef communities. **Journal of Applied Ecology** 45: 1010-1018
164. Hoegh-Guldberg O, **Mumby PJ**, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. **Science** 318: 1737-1742
165. **Mumby PJ**, Hastings A, Edwards HJ (2007) Thresholds and the resilience of Caribbean coral reefs. **Nature** 450: 98-101
166. **Mumby PJ**, Harborne AR, Williams J, Cappel CV, Brumbaugh DR, Micheli F, Holmes KE, Dahlgren CP, Paris CB, Blackwell PG (2007) Trophic cascade facilitates coral recruitment in a marine reserve. **Proceedings National Academy of Science** 104: 8362-8367
167. Hoegh-Guldberg O, **Mumby PJ**, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell DR, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2008) Coral adaptation in the face of climate change - response. **Science** 320: 315-316
168. Foster NL, Baums IB, **Mumby PJ** (2007) Sexual versus asexual reproduction in an ecosystem engineer: the massive coral Montastraea annularis. **Journal of Animal Ecology** 76: 384-391
169. Habeeb RL, Johnson CR, Wotherspoon S, **Mumby PJ** (2007) Optimal scales to observe habitat dynamics: A coral reef example. **Ecological Applications** 17: 641-647
170. Box SJ, **Mumby PJ** (2007) The effect of macroalgal competition on the growth and survival of juvenile Caribbean corals. **Marine Ecology Progress Series** 342: 139-149
171. Sanchirico, J.N. & **Mumby, P.J.** (2007) Economics, habitats, and biological populations: Finding the right value. **Resources** 165: 11-13
172. **Mumby PJ**, Micheli F, Dahlgren CP, Litvin SY, Gill AB, Brumbaugh DR, Broad K, Sanchirico JN, Kappel CV, Harborne AR, Holmes KE (2006) Marine parks need sharks: reply? **Science** 312: 526-528
173. **Mumby PJ**, Dahlgren CP, Harborne AR, Kappel CV, Micheli F, Brumbaugh DR, Holmes KE, Mendes JM, Broad K, Sanchirico JN, Buch K, Box S, Stoffle RW, Gill AB (2006) Fishing, trophic cascades, and the process of grazing on coral reefs. **Science** 311: 98-101 [Faculty1000 #8 in Ecology]
174. **Mumby PJ**, Harborne AR, Hedley JD, Zychualuk K, Blackwell P (2006) The spatial ecology of Caribbean coral reefs: revisiting the catastrophic die-off of the urchin *Diadema antillarum.* **Ecological Modelling** 196: 131-148

175. Harborne AR, **Mumby PJ**, Hedley JD, Zychaluk K, Blackwell PB (2006) Modelling the beta diversity of coral reefs. **Ecology** 87: 2871-2881
176. Harborne AR, **Mumby PJ**, Brumbaugh D, Micheli F, Holmes K, Perry C, Dahlgren CP (2006) Functions of Caribbean coral reef, seagrass and mangrove habitats. **Advances in Marine Biology** 50: 57-189
177. **Mumby PJ** (2006) The impact of exploiting grazers (Scaridae) on the dynamics of Caribbean coral reefs. **Ecological Applications** 16: 747-769
178. **Mumby PJ** (2006) Connectivity of reef fish between mangroves and coral reefs: algorithms for the design of marine reserves at seascape scales. **Biological Conservation** 128: 215-222
179. **Mumby PJ**, Foster NL, Glynn Fahy E (2005) The patch dynamics of coral reef macroalgae under chronic and acute disturbance. **Coral Reefs** 24: 681-692
180. Hedley JD, Harborne AR, **Mumby PJ** (2005) Simple and robust removal of sunglint for mapping shallow-water benthos. **International Journal of Remote Sensing** 26: 2107-2112
181. **Mumby PJ,** Edwards AJ, Arias-Gonzalez JE, Lindeman KC, Blackwell PG, Gall A, Gorczynska MI, Harborne AR, Pescod CL, Renken H, Wabnitz CCC, Llewellyn G (2004) Mangroves enhance the biomass of coral reef fish communities in the Caribbean. **Nature** 427: 533-536
182. **Mumby PJ**, Skirving W, Strong AE, Hardy JT, LeDrew EF, Hochberg EJ, Stumpf RP, David LT (2004) Remote sensing of coral reefs and their physical environment. **Marine Pollution Bulletin** 48: 219-228
183. McClanahan TR, Sala E, **Mumby PJ**, Jones S (2004) Phosphorus and nitrogen enrichment do not enhance brown frondose 'macroalgae'. **Marine Pollution Bulletin** 48: 196-199
184. **Mumby PJ**, Hedley JD, Chisholm JRM, Clark CD, Jaubert J (2004) The cover of living and dead corals using airborne remote sensing. **Coral Reefs** 23: 171-183
185. Hedley JD, **Mumby PJ**, Joyce KE, Phinn SR (2004) Spectral unmixing of coral reef benthos under ideal conditions. **Coral Reefs** 23: 60-73
186. Andréfouët S, Kramer P, Torres-Pulliza D, Joyce KE, Hochberg EJ, Garza-Perez R, **Mumby PJ**, Riegl B, Yamano H, White WH, Zubia M, Brock JC, Phinn SR, Naseer A, Hatcher BG, Muller-Karger FE (2003) Multi-sites evaluation of IKONOS data for classification of tropical coral reef environments. **Remote Sensing of Environment** 88: 128-143
187. Malthus TJ, **Mumby PJ** (2003) Remote sensing of the coastal zone: an overview and priorities for future research. **International Journal of Remote Sensing** 24: 2805-2815
188. Hedley JD, **Mumby PJ** (2003) Spectral unmixing and the resolution of depth from remotely sensed data of aquatic systems. **Limnology & Oceanography** 48: 480-488
189. **Mumby PJ,** Edwards AJ (2002) Mapping marine environments with IKONOS imagery: enhanced spatial resolution does deliver greater thematic accuracy. **Remote Sensing of Environment** 82: 248-257 [*In top 10 most cited coral reef papers on Web of Science*]
190. Andréfouët S, **Mumby PJ,** McField M, Hu C, Muller-Karger FE (2002) Revisiting coral reef connectivity. **Coral Reefs** 21: 43-48.
191. **Mumby PJ** (2002) Statistical power for non-parametric tests: a quick guide for designing sampling strategies. **Marine Pollution Bulletin** 44: 85-87
192. **Mumby PJ,** Wabnitz CCC (2002) Spatial patterns of aggression, territory size, and harem size in five sympatric Caribbean parrotfish species. **Environmental Biology of Fishes** 63: 265-279
193. Hedley JD, **Mumby PJ** (2002) Biological and remote sensing perspectives on pigmentation in coral reefs. **Advances in Marine Biology** 43: 277-317.
194. **Mumby PJ,** Chisholm JRM, Edwards AJ, Andréfouët S, Jaubert J (2001) Cloudy weather may have saved Society Islands coral reefs during the 1998 ENSO event. **Marine Ecology Progress Series** 222: 209-216
195. **Mumby PJ**, Chisholm JRM, Hedley JH, Clark CD, Jaubert J (2001) A bird's-eye view of the health of coral reefs. **Nature** 413 (6852): 36
196. **Mumby PJ** (2001) *Beta* and habitat diversity in marine systems: a new approach to measurement, scaling and interpretation. **Oecologia** 128: 274-280

197. **Mumby PJ**, Chisholm JRM, Edwards AJ, Clark CD, Jaubert J, Andrefouet A (2001) A quantitative assessment of mass bleaching-induced coral mortality at Rangiroa Atoll, French Polynesia. **Marine Biology** 139:183-189
198. Clark CD, **Mumby PJ,** Chisholm JRM, Jaubert J (2000) Spectral discrimination of coral mortality states following a severe bleaching event. **International Journal of Remote Sensing** 21: 2321-2327
199. **Mumby PJ** (1999) Bleaching and hurricane disturbances to populations of coral recruits in Belize. **Marine Ecology Progress Series** 190: 27-35
200. **Mumby PJ** (1999) Can Caribbean coral populations be modelled at metapopulation scales? **Marine Ecology Progress Series** 180: 275-288
201. **Mumby PJ** and Harborne AR (1999) Development of a systematic classification scheme of marine habitats to facilitate regional management of Caribbean coral reefs. **Biological Conservation** 88(2): 155-163
202. **Mumby PJ**, Green EP, Edwards AJ, Clark CD (1999) The cost-effectiveness of remote sensing for tropical coastal resources assessment and management. **Journal of Environmental Management** 55:157-166
203. **Mumby PJ**, Green EP, Clark CD, Edwards AJ (1998) Digital analysis of multispectral airborne imagery of coral reefs. **Coral Reefs** 17(1): 59-69
204. **Mumby PJ**, Clark CD, Green EP, Edwards AJ (1998) The practical benefits of water column correction and contextual editing for mapping coral reefs. **International Journal of Remote Sensing** 19: 203-210.
205. **Mumby PJ**, Edwards AJ, Clark CD, Green EP (1998) Managing tropical coastal habitats: should I use satellite or airborne sensors? **Backscatte***r* 9(2): 20-24.
206. Green EP, **Mumby PJ**, Edwards AJ, Clark CD, Ellis AC (1998) The assessment of mangrove areas using high resolution multispectral airborne imagery (CASI). **Journal of Coastal Research** 14: 433-443.
207. Green EP, **Mumby PJ**, Edwards AJ, Clark CD (1998) Cost-effective mapping of coastal habitats. **GIS Asia Pacific** August / September: 40-44.
208. Green EP, Clark CD, **Mumby PJ**, Edwards AJ, Ellis AC (1998) Remote sensing techniques for mangrove mapping. **International Journal of Remote Sensing** 19: 935-956.
209. **Mumby PJ**, Green EP, Edwards AJ, Clark CD (1997) Coral reef habitat mapping: how much detail can remote sensing provide? **Marine Biology** 130(2): 193-202.
210. **Mumby PJ,** Green EP, Edwards AJ, Clark CD (1997) Measurement of seagrass standing crop using satellite and digital airborne remote sensing. **Marine Ecology Progress Series** 159: 51-60.
211. **Mumby PJ**, Edwards AJ, Green EP, Anderson CW, Ellis AC, Clark CD (1997) A visual assessment technique for estimating seagrass standing crop. **Aquatic Conservation: marine and freshwater ecosystems** 7: 239-251.
212. Green EP, **Mumby PJ**, Ellis AC, Edwards AJ, Clark CD (1997) Estimating leaf area index of mangroves from satellite data. **Aquatic Botany**, 58: 11-19.
213. Clark CD, Ripley HT, Green EP, Edwards AJ, **Mumby PJ** (1997*)* Mapping and measurement of tropical coastal environments with hyperspectral and high spatial resolution data. **International Journal of Remote Sensing** 18: 237-242.
214. **Mumby PJ**, Clarke KR, Harborne AR (1996) Weighting species abundance estimates for marine resource assessment. **Aquatic Conservation: Marine and Freshwater Ecosystems** 6:115-120
215. Green EP, **Mumby PJ**, Edwards AJ, Clark CD (1996*)* A review of remote sensing for tropical coastal resources assessment and management. **Coastal Management** 24(1): 1-40
216. **Mumby PJ**, Gray DA, Gibson J, Raines PS (1995*)* Geographic Information Systems: A tool for integrated coastal zone management in Belize. **Coastal Management** 23(2): 111-121
217. **Mumby PJ**, Harborne AR, Raines PS, Ridley JM (1995) A critical assessment of data derived from Coral Cay Conservation volunteers. **Bulletin of Marine Science** 56(3): 742-756.

(iv) Book reviews

1. **Mumby PJ** (2001) Review of RH Karlson "Dynamics of Coral Reefs" ***Reef Encounter*** 29: 35-36

(v) Official reports

1. **Mumby PJ** (1998) Observations on the interaction of nutrient concentration, herbivore biomass, and wave energy on macroalgal cover at Glovers Atoll, Belize. Report to the Belize Department of Fisheries, October 1998, pp 8.
2. **Mumby PJ**, Harborne AR (1998) Classification scheme for marine habitats of Belize. Report to the UNDP/GEF Belize Coastal Zone Management Project. CCC Press.
3. **Mumby PJ** (1996) Remote sensing requirements for mapping the Belize Barrier Reef. Report to United Nations Development Programme for UNDP / GEF Coastal Zone Management Project, Belize. 15 pp.
4. McCorry D, **Mumby PJ**, Raines PS, Ridley JM (1993*)* Draft management plan for the South Water Cay Marine Reserve. Report for the Department of Fisheries & Agriculture, Government of Belize. 123pp .10 maps

(vi) Popular articles

5. Green EP, **Mumby PJ**, Edwards AJ, Clark CD (1997) A comparative assessment of remote sensing for mangroves. Intercoast Network, Special Edition 1: 19.
6. **Mumby PJ** (1995) Taking a critical look at remote sensing. *Reef Encounter* 17: 7-8.

Curriculum vitae for Selina Ward

Name: Dr Selina Ward

Address: 170 Indooroopilly Rd
St Lucia Qld 4068

Phone number: Work 07 3365 3307
Mobile 0434 011988

Email: selinaward@uq.edu.au

Date of birth: 22nd February 1963

Family: 3 children aged 28, 23 and 23

Tertiary Education:

PhD, Southern Cross University. Supervisor - Dr Peter Harrison
Thesis title: The effects of elevated nitrogen and phosphorus on the reproduction of three species of acroporid reef corals.

Master of Science, The University of Western Australia. Supervisor - Dr Robert Black
Thesis title: The effect of mechanical damage on allocation of energy to growth, reproduction and storage of lipids in the scleractinian coral *Pocillopora damicornis.*

Honours, University of Tasmania. Supervisor - Dr Alastair Richardson
Thesis title: The adaptations of the seasquirt *Pyura stolonifera praeputialis* (Heller 1878) at four sites of different exposure in Tasmania.

Bachelor of Science Degree (Zoology), The University of Western Australia

Awards and Grants:

Australian Research Council Discovery Grant 2009 – 2011
The impact of ocean acidification on the reproductive output, fertilisation, larval development and recruitment of key Australian marine organisms. Ove Hoegh-Guldberg, Jane Williamson, John Havenhand, Selina Ward, Guillermo Diaz-Pulido, David Kline and Vanessa Hernaman.

Australian Research Council Discovery Grant 2005
Microendoliths, coral bleaching and environmental change. Maoz Fine, Selina Ward, Michael Kuhl and Sophie Dove.

University of Queensland Womens' Postdoctoral Fellowship October 2002 – December 2005

Great Barrier Reef Marine Park Australian Research Grant for work on the effects of the 1998 GBR bleaching event on coral reproduction and physiology.
Australian Marine Science Association Travel Award to attend annual conference
Janice Klumpp Award from The University of Western Australia for Master of Science research

Recent Employment:

Senior Lecturer, School of Biological Sciences, The University of Queensland
January 2016 - current

Lecturer, School of Biological Sciences, The University of Queensland
January 2011 – December 2015

I have been coordinating the Stanford in Australia Program including two of the courses within it, Australia's Marine Environment and a Masters course – Marine Conservation. I also teach in to a number of other courses, supervise postgraduate students and conduct research.

Lecturer, Centre for Marine Studies, The University of Queensland (50%)
January 2006 – December 2010

I taught and coordinated courses, supervised postgraduate students and conducted research. My course coordination has included international programs such as the Stanford Program, a Masters course for Victoria University of Wellington (New Zealand) and Tropical Marine Invertebrates for the Great Barrier Reef Study Program. I also developed and coordinated the Rio Tinto Alcan Reef Searchers Employee Program which involved 10 courses between 2006 and 2009.

Program Convenor, International Riversymposium (50%)
January 2006 – December 2010

I created the program for the International Riversymposium, sourced sponsorship and created and maintain relationships and partnerships with international and national organisations and agencies.

Postdoctoral Fellow, The University of Queensland Postdoctoral Fellowship Scheme, Centre for Marine Studies, The University of Queensland – Prof Ove Hoegh-Guldberg
October 2002 – December 2005

I conducted research and lectured in our international programs. I was the Academic Coordinator of the Great Barrier Reef Study Program and worked with the development and promotion of the program. I also created a course within this program and taught on another in addition.

Riversymposium Convenor – (consultancy)
October 2002 – December 2005

I was employed by Riverfestival and the event was advised by a strategic planning committee chaired by Prof Paul Greenfield. My role was similar to that described in my 2006-2010 position.

Symposium Manager, Riverfestival.
January 2001 – October 2002

I managed the Riversymposium, Thiess Services International and National Riverprizes, Rivertalk and the Hypothetical. This role included creating the speaking and social programme for the symposium along with all the logistics, seeking and managing sponsorships and managing symposium staff and consultants. For the Riverprizes I oversaw the judging process (coordinating the judging panels, processing all the applications, collating all the material for the judges) and staging the award ceremony. I also created an exhibition for the Queensland Museum on the Riverprize, which was on display for 6 weeks. Rivertalk was a community forum for catchment groups and the Hypothetical was an event I created and ran for approximately 800 people.

Research Fellow, Centre for Marine Studies, The University of Queensland – Prof Ove Hoegh-Guldberg.
Jan 2000 – Jan 2001

This position involved research and creation of a program of excursions and field camps for high schools at Moreton Bay Research Station. The program was later taken over by the staff at the station and continues to run.

Advisory Editor, *Coral Reefs* (Journal of the International Society for Reef Studies).
2001 – 2004

Postdoctoral Fellow, Southern Cross University, in collaboration with The University of Sydney with Prof Ove Hoegh-Guldberg and Dr Peter Harrison. Funded by an ARC Collaborative grant (with the Great Barrier Reef Marine Park Authority).
1997 – 1999

The effects of elevated temperature on coral reproduction. Aside from running my own research program, I was in charge of setting up the temperature controlled aquarium system and coordinating the researchers' needs and timetables so that the program could run smoothly.

Lecturer, University of Hawaii Summer Program – Dr E Cox, Prof P Jokiel.
1997

Lectures for graduate students, assisted with student projects and ran my own research project.

Research Assistant - Griffith University – Prof Angela Arthington
1991– 1993

I ran experiments to investigate the effects of an organophosphate pesticide on the community structure of streams. This involved examining the fauna present in the different treatments over time, the decomposition of leaf material, changes in the organic material present and extracting the pesticide from the water samples. I was in charge of the running of this project and had a technical assistant on the project as well as a number of casual employees. I was responsible for planning, experimental design, conducting the experiments, processing and supervising the processing of sample material, the analysis of data and writing of papers.

Professional Memberships:

<u>Australian Coral Reef Society</u>
Councillor –May 2010 – to current
Immediate Past President - May 2008 – May 2010
President – May 2006 – May 2008
Vice President – May 2004 – May 2006
Treasurer - 2002 - 2004

Secretary - 1997 to 2001, member from 1988
Member of Australian Marine Science Association (from 1988)
Member of Australian Society for Limnology (from 1991)
Member of International Society for Reef Studies (from 1996)

Other qualifications:

A class drivers licence since 1980
Boating licence since 1994
Scientific Diver since 2000
Nitrox Diver since 2003
PADI Open Water Diver since June 1984 (due to onset of asthma can not dive at present).
Bronze Medallion, Bronze Cross and Instructors' – Royal Life Saving Society
St Johns Ambulance Senior First Aid Certificate
Radio licence

Media Experience

I have been interviewed and filmed by the following media teams:
France24
New York Times
Financial Times, London
The Guardian
CNN
BBC – many times, including Tropic of Capricorn
Quantum crew for both Quantum and A Question of Survival
Sydney Olympics Board (promotional material about research in Australia)
National Geographic
The Today Show (channel 9) Towards 2000 and Totally Wild
BBC (UK)
JP Exporer (Newspaper - Denmark)
Danish National Broadcaster (television)
The Sunshine Coast Daily (newspaper)
The Courier Mail (newspaper)
The Sunday Mail (newspaper)
Sydney Morning Herald
The Age
Channel seven
BBC World Service (radio)
Radio National (ABC radio)
Nature (journal)
Science (journal)
Living Planet
Baltimore Sun
Film-makers including David Hannan, Matt Tomaszewski, Richard Fitzpatrick (many years)
2SER radio, Sydney
Rueters
The Australian (newspaper)
Radio National and other ABC radio and TV channels

I have done paid work for:

NHK Television Network (Japan) (1999, 2007)
National Geographic (magazine) (1999)

Publications:

Ward S (1992) Evidence for broadcast spawning as well as brooding in the scleractinian coral *Pocillopora damicornis*. Marine Biology 112: 641-646.

Ward S (1995) The effect of damage on the growth, reproduction and storage of lipids in the scleractinian coral *Pocillopora damicornis* (Linnaeus). Journal of Experimental Marine Biology and Ecology 187:193-206.

Ward S (1995) Two patterns of energy allocation for growth, reproduction and lipid storage in the scleractinian coral *Pocillopora damicornis*. Coral Reefs 14: 87-90.

Ward S, Arthington AH, Pusey BJ (1995) The effects of a chronic application of chlorpyrifos on the macroinvertebrate fauna in an outdoor artificial stream system: species responses. Ecotoxicology and Environmental Safety 30: 2-23.

Ward S, Harrison PL (1997) The effects of elevated nutrients on settlement of coral larvae during the ENCORE experiment. Proceedings of the Eighth International Coral Reef Symposium, Panama 1:891-986.

Takabayashi, Misaki; Carter, Dee; Ward, Selina; Hoegh-Guldberg, Ove, (1998) Inter- and intra-specific variability in DNA sequence in the ITS region of corals. Proceedings of the 75th Conference of the Australian Coral Reef Society. 237-244

Harrison PL, Ward S (2000) Elevated levels of nitrogen and phosphorus reduce fertilization rates of gametes from scleractinian corals. Marine Biology 139:1057-1068

Jones, Ross J.; Ward, Selina; Yang Amri, Affendi; Hoegh-Guldberg, Ove (2000) Changes in photosynthetic efficiency of symbiotic dinoflagellates of corals after heat stress and during the 1998 Great Barrier Reef mass bleaching event. Mar Freshwater Res 51(1):63-71

Ward S (2000) Changes in gametogensis and fecundity of acroporid corals that were exposed to elevated nitrogen and phosphorus during the ENCORE experiment. J Exp Mar Biol Ecol 246:179-221

Ward S (2000) Changes in coral reproduction following slight changes in temperature. Proceedings of JAMSTEC International Coral Reef Symposium. Coral reef biodiversity and health as indicators of environmental change. Tokyo, Japan p94-111

Koop K, Booth D, Broadbent A, Brodie J, Bucher D, Capone D, Coll J, Dennison W, Erdmann M, Harrison P, Hoegh-Guldberg O, Hutchings P, Jones G B, Larkum A W D, O'Neil J, Steven A, Tentori E, Ward S, Williamson J, Yellowlees D (2001) ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. Mar Poll Bull 42:91-120

Cox E, Ward S (2002) Impact of elevated ammonium on reproduction in two Hawaiian scleractinian corals with different life history patterns. Mar Poll Bull 44:1230-1235

Greenfield P, Ward S (2002) (Eds) River*symposium* 2001 – Selected Proceedings of the Fourth International Riversymposium, Australia 29-31 August 2001. Water, Science and Technology Vol 45 (complete volume)

Hoegh-Guldberg O, Jones RJ, Ward S and Loh W (2002) Is coral bleaching really adaptive? Nature 415: 601-602

Ward S, Harrison P, Hoegh-Guldberg O (2002) Coral bleaching reduces reproduction of scleractinian corals and increases susceptibility to future stress. Proceedings of the Ninth International Coral Reef Symposium, Bali Vol 2:1123-1129

Greenfield P, Ward S (2003) (Eds) Riversymposium 2002 – Selected Proceedings of the Fifth International Riversymposium, Australia 3-6 September 2002. Water, Science and Technology Vol 48. (complete volume)

Gomez Cabrera M del C, Ortiz J C, Loh W K W, Ward S, Hoegh-Guldberg O (2007) Acquisition of symbiotic dinoflagellates (*Symbiodinium*) by juveniles of the coral *Acropora longicyathus.* Coral Reefs 27:219-226

Christiansen NA, Ward S, Harii S, Tibbetts IR (2009) Grazing by a small fish affects the early stages of a post-settlement stony coral. Coral Reefs 28:47-51

Kongjandtre N, Ridgway T, Ward S, Hoegh-Guldberg O (2010) Broadcast spawning patterns of *Favia* species on the inshore reefs of Thailand. Coral Reefs 29:227-234

Doropoulos, C., S. Ward, A. Marshell, G. Diaz-Pulido, and P. J. Mumby. (2012) Interactions among chronic and acute impacts on coral recruits: the importance of size-escape thresholds. Ecology.

Doropoulos, C., S. Ward, G. Diaz-Pulido, O. Hoegh-Guldberg, and P. J. Mumby. (2012). Ocean acidification reduces coral recruitment by disrupting intimate larval-algal settlement interactions. Ecology Letters 15:338-346.

Fellegara I, Baird AH and Ward S (2013) Coral reproduction in a high-latitude, marginal reef environment (Moreton Bay, south-east Queensland, Australia). Invertebrate Reproduction & Development

Hei Wa Ho, Rodney A Bray, Scott C Cutmore, Selina Ward and Thomas H Cribb (2014) Two new species of Phyllodistomum (Braun). 1899 (Trematoda:Gorgoderidae Looss 1899) from Great Barrier Reef fishes. Zootaxa 3779 (5): 551-562

Diaz PE, Bray RA, Cutmore SC, Ward S, Cribb TH (2015) A complex of species related to *Paradiscogaster glebulae* (Diagenea:Faustulidae) in Chaetodontidae fishes (Teleostei: Perciformes) of the Great Barrier Reef. Parasitology International 64:421-428

Nitschke MR, Davy SK, Cribb TH, Ward S (2015) The effect of elevated temperature and substrate on free-living *Symbiodinium* cultures. Coral Reefs 34:161 -171

Doropoulos C, Ward S, Roff G, Gonzalez-Rivero M, Mumby PJ (2015) Linking demographic processes of juvenile corals to benthic recovery trajectories in two common reef habitats. PLOSone 10(5):e0128535.doi:10.1371/journal. pone.0128535

Nitschke Matthew R, Davy Simon K, Ward Selina (2016) Horizontal transmission of *Symbiodinium* cells between adult and juvenile corals is aided by benthic sediment. Coral Reefs 35:335-344

Theses:

The effects of elevated nitrogen and phosphorus on the reproduction of three species of acroporid reef corals. PhD Thesis. Southern Cross University, 1997.

The effect of mechanical damage on allocation of energy to growth, reproduction and storage of lipids in the scleractinian coral *Pocillopora damicornis.* Master of Science thesis, The University of Western Australia, 1990

The adaptations of the seasquirt *Pyura stolonifera praeputialis* (Heller 1878) at four sites of different exposure in Tasmania. Honours Thesis, University of Tasmania, 1985

Conference presentations:

Papers were presented at the following conferences:

Temperate Reefs Conference - Melbourne 1989
Australian Marine Science Association - Brisbane 1991
Australian Society for Limnology - Sunshine Coast, Queensland 1993
Joint Australian Marine Science Association and Australian Coral Reef Society Conference (oral paper and poster) - Townsville 1994
Australian Marine Science Association - Sydney 1995
Australian Coral Reef Society Conference - Lismore, New South Wales 1995
Eighth International Coral Reef Symposium - Panama 1996
Australian Coral Reef Society Conference – Heron Island October 1997
Australian Coral Reef Society Conference – Port Douglas October 1998
Australian Coral Reef Society Conference - South Molle Island 1999
JAMSTEC International Coral Reef Symposium (Invited speaker) Tokyo 2000
Ninth International Coral Reef Symposium Bali 2000. (2 papers)
Australian Coral Reef Society Conference, Magnetic Island 2001.
Australian Coral Reef Society Conference, Stradbroke Island 2002
Australian Coral Reef Society Conference, Townsville 2003
Tenth International Coral Reef Symposium, Okinawa 2004
Focus on corals Conference, Bundaberg, 2005 keynote speaker
Australian Coral Reef Society Conference, Heron Island 2005
Australian Coral Reef Society Conference, Mission Beach 2006
Australian Coral Reef Society Conference, Perth 2007
Australian Coral Reef Society Conference,
Eleventh International Coral Reef Symposium, Fort Lauderdale, Florida 2008
Australian Coral Reef Society Conference, 2009 Darwin
Australian Coral Reef Society Conference, 2010 Coffs Harbour
Australian Coral Reef Society Conference, 2011 Twin Waters Maroochydore
Twelfth International Coral Reef Symposium, Cairns, Australia 2012
Australian Coral Reef Society Conference, 2013 Sydney

Australian Coral Reef Society Conference, 2014 Brisbane
Australian Coral Reef Society Conference, 2015 Daydream Island, Whitsundays

Editorship of scholarly journals

I am frequently asked to review manuscripts for international journals such as *Marine Biology, Marine Ecology Progress Series*, *Coral Reefs*, *Proceedings of the Royal Society B, Journal of Experimental Marine Biology* and *Ecology*. I have also examined PhD, Masters and honours theses. I am frequently asked to review grant applications for international granting bodies**.**
I was an advisory editor for *Coral Reefs* from 2001 to 2004.

Referees

Prof Kevin Arrigo
Department of Environmental Earth System Science
Stanford University
USA
Ph: + 1 650 723 3599
Email: arrigo@stanford.edu

Assoc Prof Simon Davy
School of Biological Sciences
Victoria University of Wellington
New Zealand
Ph + 64 4 463 5573
simon.davy@vuw.ac.nz

Prof Maoz Fine
The Interuniversity Institute for Marine Science
Bar-Ilan University
Israel
Ph +972 8 6360123
maoz.fine@biu.ac.il

ANNEX B: List of Cited Documents Provided by the PCA

A. Expert Reports submitted by the Philippines

Annex 240	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)
Annex 699	K.E. Carpenter & L.M. Chou, Environmental Consequences of Land Reclamation Activities on Various Reefs in the South China Sea (14 Nov. 2015)

B. Documents from the Record (cited by Annex number)

Philippine Government Documents	
Annex 28	Memorandum from Fact Finding Committee, National Police Commission, Republic of the Philippines, to Chairman and Members of the Regional Committee on Illegal Entrants for Region 1, Republic of the Philippines (28 Jan. 1998)
Annex 29	Memorandum from Assistant Secretary of the Department of Foreign Affairs, Republic of the Philippines to the Secretary of Foreign Affairs of the Republic of the Philippines (23 Mar. 1998)
Annex 30	People of the Philippines v. Shin Ye Fen, et al., Criminal Case No. RTC 2357-I, Decision, Regional Trial Court, Third Judicial Region, Branch 69, Iba, Zambales, Philippines (29 Apr. 1998)
Annex 31	People of the Philippines v. Wuh Tsu Kai, et al, Criminal Case No. RTC 2362-I, Decision, Regional Trial Court, Third Judicial Region, Branch 69, Iba, Zambales, Philippines (29 Apr. 1998)
Annex 32	People of the Philippines v. Zin Dao Guo, et al, Criminal Case No. RTC 2363-I, Decision, Regional Trial Court, Third Judicial Region, Branch 69, Iba, Zambales, Philippines (29 Apr. 1998)
Annex 41	Situation Report from Col. Rodrigo C. Maclang, Philippine Navy, to Chief of Staff, Armed Forces of the Philippines, No. 004-18074 (18 Apr. 2000)
Annex 45	Memorandum from Willy C. Gaa, Assistant Secretary of Foreign Affairs, Republic of the Philippines to Secretary of Foreign Affairs, Republic of the Philippines (14 Feb. 2001)
Annex 46	Office of Asian and Pacific Affairs, Department of Foreign Affairs, Republic of the Philippines, Apprehension of Four Chinese Fishing Vessels in the Scarborough Shoal (23 Feb. 2001)
Annex 49	Memorandum from Perfecto C. Pascual, Director, Naval Operation Center, Philippine Navy, to The Flag Officer in Command, Philippine Navy (11 Feb. 2002)
Annex 50	Letter from Victorino S. Hingco, Vice Admiral, Philippine Navy, to Antonio V. Rodriguez, Assistant Secretary, Office of Asia and Pacific Affairs, Department of Foreign Affairs, Republic of the Philippines (26 Mar. 2002)
Annex 51	Memorandum from Josue L. Villa, Embassy of the Republic of the Philippines in Beijing, to the Secretary of Foreign Affairs of the Republic of the Philippines (19 Aug. 2002)
Annex 52	Report from CNS to Flag Officer in Command, Philippine Navy, File No. N2D-0802-401 (1 Sept. 2002)
Annex 55	Report from Lt. Commander Angeles, Philippine Navy, to Flag Officer in Command, Philippine Navy, No. N2E-F-1104-012 (18 Nov. 2004)
Annex 57	Letter from George T. Uy, Rear Admiral, Armed Forces of the Philippines, to Assistant Secretary, Office of Asia and Pacific Affairs, Department of Foreign Affairs of the Republic of the Philippines (2006)

ANNEX B: List of Cited Documents Provided by the PCA

Annex 58	Memorandum from the Secretary of Foreign Affairs of the Republic of the Philippines to the President of the Republic of the Philippines (11 Jan. 2006)
Annex 59	Report from Commanding Officer, NAVSOU-2, Philippine Navy, to Acting Commander, Naval Task Force 21, Philippine Navy, No. NTF21-0406-011/NTF21 OPLAN (BANTAY AMIANAN) 01-05 (9 Apr. 2006)
Annex 77	Memorandum from Col. Nathaniel Y. Casem, Philippine Navy, to Chief of Staff, Armed Forces of the Philippines, No. N2E-0412-008 (11 Apr. 2012)
Annex 78	Report from Commanding Officer, SARV-003, Philippine Coast Guard, to Commander, Coast Guard District Northwestern Luzon, Philippine Coast Guard (28 Apr. 2012)
Annex 79	Memorandum from Andres R. Menguito, FRPLEU/QRT Chief, Bureau of Fisheries and Aquatic Resources, Republic of the Philippines, to Director, Bureau of Fisheries and Aquatic Resources, Republic of the Philippines (2 May 2012)
Annex 80	Report from Relly B. Garcia, et al., FRPLEU/QRT Officers, Bureau of Fisheries and Aquatic Resources, Republic of the Philippines, to Director, Bureau of Fisheries and Aquatic Resources, Republic of the Philippines (2 May 2012)
Annex 86	Armed Forces of the Philippines, Matrix of Events: Chigua (Kennan) Reef (2013)
Chinese Government Documents	
Annex 617	Permanent Mission of the People's Republic of China to the United Nations, Statement by H.E. Ambassador Wang Min, Head of the Chinese Delegation at the 25th Meeting of States Parties to the UN Convention on the Law of the Sea (12 June 2014)
Annex 624	Ministry of Foreign Affairs of the People's Republic of China, Foreign Ministry Spokesperson Hua Chunying's Regular Press Conference on April 9, 2015 (9 Apr. 2015)
Annex 625	Ministry of Foreign Affairs of the People's Republic of China, Foreign Ministry Spokesperson Hong Lei's Regular Press Conference on April 28, 2015 (28 Apr. 2015)
Annex 820	Embassy of the People's Republic of China in Canada, An Interview on China's Construction Activities on the Nansha Islands and Reefs (27 May 2015)
Annex 872	Article by Researcher Feng Aiping and Senior Engineer Wang Yongzhi from the First Ocean Research Institution of the State Oceanic Administration, 10 June 2015 (http://www.soa.gov.cn/xw/dfdwdt/jgbm_155/201506/t20150610_38318.html)
Annex 821	China State Oceanic Administration, "Construction Work at Nansha Reefs Will Not Harm Oceanic Ecosystems" (18 June 2015), available at http://www.soa.gov.cn/xw/hyyw_90/201506/t20150618_38598.html.
Photographs of Reclamation	
Annex 597	Center for Strategic & International Studies, Asia Maritime Transparency Initiative, "Island Tracker", available at http://amti.csis.org/island-tracker/ (last accessed 21 July 2015)
Annex 781	Center for Strategic & International Studies, Asia Maritime Transparency Initiative, Subi Reef Tracker, available at http://amti. csis.org/subi-reef-tracker/ (accessed 1 Nov. 2015)
Annex 782	Center for Strategic & International Studies, Asia Maritime Transparency Initiative, Mischief Reef Tracker, available at http:// amti.csis.org/mischief-reef-tracker/# (accessed 1 Nov. 2015)
Annex 783	Armed Forces of the Philippines, Aerial Photographs of On-Going Reclamation at Gaven Reef (2014)
Annex 784	Armed Forces of the Philippines, Aerial Photographs of Kennan Reef (2014-2015)
Annex 785	Armed Forces of the Philippines, Aerial Photographs of On-Going Reclamation at Fiery Cross Reef (2014-2015)

ANNEX B: List of Cited Documents Provided by the PCA

Annex 786	Armed Forces of the Philippines, Aerial Photographs of On-Going Reclamation at Subi Reef (Feb. 2015-Mar. 2015)
Annex 787	Compilation of Images of Cuarteron Reef (various sources) (compiled 13 Nov. 2015)
Annex 788	Compilation of Images of Fiery Cross Reef (various sources) (compiled 13 Nov. 2015)
Annex 789	Compilation of Images of Gaven Reef (various sources) (compiled 13 Nov. 2015)
Annex 790	Compilation of Images of Johnson Reef (various sources) (compiled 13 Nov. 2015)
Annex 791	Compilation of Images of McKennan (Hughes) Reef (various sources) (compiled 13 Nov. 2015)
Annex 792	Compilation of Images of Mischief Reef (various sources) (compiled 13 Nov. 2015)
Annex 795	Compilation of Images of Subi Reef (various sources) (compiled 13 Nov. 2015)
Annex 860	Annotated Satellite Image of Thitu Reefs (6 Mar. 2014)
News reports	
Annex 414	"Spratlys a Haven for Illegal Poachers-Mercado", Philippines Headline News Online (2 Dec. 1998)
Annex 737	Shi Yang, "Excellent Tool for Land Reclamation in Nansha", BBSBIAN (13 Sept. 2014)
Annex 862	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/m agazine-35l06631. Supplemental Submission of 18 December 2015
Annex 863	Video to 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/m agazine-35l 06631. Supplemental Submission of 18 December 2015
Miscellaneous	
Annex 796	Van Oord, "Cutter Suction Dredger Castor", Video (2012), available at http://www.vanoord.com/activities/cutter-suction-dredger (accessed 5 Nov. 2015)
Annex 799	Guangdong TV, "The Magic Dredge Pumping Artifact "Tianjing Hao", a Great Meritorious Machine in China's Land Reclamation in Nansha", YouTube Video (10 Apr. 2015), available at https://www.youtube.com/ watch?v=wsnd56-5HiI (accessed 5 Nov. 2015)
Annex 800	Transcript of Guangdong TV, "The Magic Dredge Pumping Artifact "Tianjing Hao", a Great Meritorious Machine in China's Land Reclamation in Nansha", YouTube Video (10 Apr. 2015), available at https://www.youtube.com/watch?v=wsnd56-5HiI (accessed 5 Nov. 2015)
Annex 858	"Tian Jing Hao", Dredgepoint.org, available at https://www.dredgepoint.org/dredging-database/equipment/tian-jing-hao (accessed 24 Nov. 2015)

C. <u>Scientific Material from the Record (cited by Author in Alphabetic Order)</u>

V. Christensen, et. al., "Fisheries Impact on the South China Sea Large Marine Ecosystem: A Preliminary Analysis Using Spatially-Explicit Methodology", in Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries, WorldFish Center Conference Proceedings, No. 67 (G. Silvestre, et al., eds. 2003)	Annex 844
C.F. Dai and T.Y. Fan, "Coral Fauna of Taiping Island (Itu Aba Island) in the Spratlys of the South China Sea", Atoll Research Bulletin, No. 436 (1996)	Annex 258
Edward J. Goodwin, International Environmental Law and the Conservation of Coral Reefs (2011)	Annex 718

ANNEX B: List of Cited Documents Provided by the PCA

D. Huang, et al., "Extraordinary Diversity of Reef Corals in the South China Sea", Marine Biodiversity, Vol. 45, No. 2 (2015)	Annex 848
P.L.A. Erftemeijer, et al., "Environmental Impacts of Dredging and Other Sediment Disturbances on Corals: A Review", Marine Pollution Bulletin, Vol. 64, No. 9 (2012)	Annex 847
S. Jennings and N. Polunin, "Impacts of Fishing on Tropical Reef Ecosystems", Ambio: A Journal of the Human Environment, Vol. 25, No. 1 (Feb. 1996)	Annex 708
R.J. Jones & O. Hoegh-Guldberg, "Effects of Cyanide on Coral Photosynthesis: Implications for Identifying the Cause of Coral Bleaching and for Assessing the Environmental Effects of Cyanide Fishing", Marine Ecology Progress Series, Vol. 177 (1999)	Annex 842
Pakjuta Khemakorn, Sustainable Management of Pelagic Fisheries in the South China Sea Region (2006)	Annex 279
John W. McManus, "Toward Establishing a Spratly Islands International Marine Peace Park: Ecological Importance and Supportive Collaborative Activities with an Emphasis on the Role of Taiwan", Ocean Development & International Law, Vol. 41 (2010)	Annex 289
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 (*Revised Version, 21 April 2016*)	Annex 850
M. Spalding et al., World Atlas of Coral Reefs (2001)	Annex 713
K. Warren-Rhodes, et al., "Marine Ecosystem Appropriation in the Indo-Pacific: A Case Study of the Live Reef Fish Food Trade", Ambio: A Journal of the Human Environment, Vol. 32, No. 7 (Nov. 2003)	Annex 845

ANNEX C: List of Additional References

Adjeroud, M., Michonneau, F., Edmunds, P. J., Chancerelle, Y., Loma, T. L., Penin, L., et al. (2009) "Recurrent disturbances, recovery trajectories, and resilience of coral assemblages on a South Central Pacific reef," *Coral Reefs,* 28: 775-780.

Albert, S., Grinham, A., Dunbabin, M., Bird, B., Moore, B., Jimuru, M., et al. (2011) "Preliminary assessment of a large fish kill in Marovo Lagoon, Solomon Islands," In. Brisbane, Australia: University of Queensland.

Almany, Glenn R., Hamilton, Richard J., Bode, M., Matawai, M., Potuku, T., Saenz-Agudelo, P., et al. (2013) "Dispersal of Grouper Larvae Drives Local Resource Sharing in a Coral Reef Fishery," *Current Biology,* 23: 626-630.

Alongi, D. M., Pfitzner, J., & Trott, L. A. (2006) "Deposition and cycling of carbon and nitrogen in carbonate mud of the lagoons of Arlington and Sudbury Reefs, Great Barrier Reef," *Coral Reefs,* 25: 123-143.

Appeldoorn, R., Ballantine, D., Bejarano, I., Carlo, M., Nemeth, M., Otero, E., et al. (2015) "Mesophotic coral ecosystems under anthropogenic stress: a case study at Ponce, Puerto Rico," *Coral Reefs,* 35: 63-75.

Arnold, S. N., Steneck, R. S., & Mumby, P. J. (2010) "Running the gauntlet: inhibitory effects of algal turfs on the processes of coral recruitment," *Marine Ecology Progress Series,* 414: 91-105.

Ashworth, J. S., Bruce, O. E., & Hellw, M. E. (2006) "Fish assemblages of Red Sea backreef biotopes," *Aquatic Conservation: Marine and Freshwater Ecosystems,* 16: 593-609.

Babcock, R., & Davies, P. (1991) "Effects of sedimentation on settlement of *Acropora millepora*," *Coral Reefs,* 9: 205-208.

Babcock, R., & Smith, L. (2000) "Effects of sedimentation on coral settlement and survivorship," In *Proceedings of the 9th International Coral Reef Symposium*. Bali, Indonesia.

Barnes, B. B., Hu, C., Kovach, C., & Silverstein, R. N. (2015) "Sediment plumes induced by the Port of Miami dredging: Analysis and interpretation using Landsat and MODIS data," *Remote Sensing of Environment,* 170: 328-339.

Beger, M., Selkoe, K. A., Treml, E., Barber, P. H., von der Heyden, S., Crandall, E. D., et al. (2014) "Evolving coral reef conservation with genetic information," *Bulletin of Marine Science,* 90: 159-185.

Bejarano, S., Golbuu, Y., Sapolu, T., & Mumby, P. J. (2013) "Ecological risk and the exploitation of herbivorous reef fish across Micronesia," *Marine Ecology Progress Series,* 482: 197-215.

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

Bellwood, D. R., & Fulton, C. J. (2008) "Sediment-mediated suppression of herbivory on coral reefs: Decreasing resilience to rising sea-levels and climate change?," *Limnology and Oceanography,* 53: 2695-2701.

Bertram, D. F., & Leggett, W. C. (1994) "Predation risk during the early life history periods of fishes: separating the effects of size and age," *Marine Ecology Progress Series,* 109: 105-114.

Birrell, C. L., McCook, L. J., & Willis, B. L. (2005) "Effects of algal turfs and sediment on coral settlement," *Marine Pollution Bulletin,* 51: 408-414.

Birtles, B. (2016) "South China Sea coral reef destruction 'recoverable', Chinese think-tank chief says," *ABC News* 25. January 2016.

Blueweiss, L., Fox, H., Kudzma, V., Nakashima, D., Peters, R., & Sams, S. (1978) "Relationships between body size and some life history parameters," *Oecologia,* 37: 257-272.

Bozec, Y.-M., O'Farrell, S., Bruggemann, J. H., Luckhurst, B. E., & Mumby, P. J. (2016) "Tradeoffs between fisheries harvest and the resilience of coral reefs," *Proceedings of the National Academy of Sciences*: in press.

ANNEX C: List of Additional References

Browne, N. K., Tay, J., & Todd, P. A. (2015) "Recreating pulsed turbidity events to determine coral–sediment thresholds for active management," *Journal of Experimental Marine Biology and Ecology,* 466: 98-109.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011) *Reefs at Risk Revisited*. Washington, DC, USA: World Resources Institute (WRI).

Cesar, H. S. J. (2000) "Coral reefs: their functions, threats and economic value," In *Collected Essays on the Economics of Coral Reefs,* edited by H. S. J. Cesar. Kalmar, Sweden: CORDIO, Kalmar University.

Challenger, G. E. (2006) "International trends in injury assessment and restoration," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press.

Cheal, A. J., Emslie, M., MacNeil, M. A., Miller, I., & Sweatman, H. (2013) "Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs," *Ecological Applications,* 23: 174-188.

Chen, C. A., Ablan, M. C. A., McManus, J. W., Bell, J., Tuan, V. S., Cabanban, A. S., et al. (2004) "Population Structure and Genetic Variability of Six Bar Wrasse (*Thallasoma hardwicki*) in Northern South China Sea Revealed by Mitochondrial Control Region Sequences," *Marine Biotechnology,* 6: 312-326.

Chen, G.-B., & Li, Y.-Z. (2005) "Composition and distribution of Serranidae in main coral reef waters of South China Sea," *South China Fisheries Science,* 1: 18-25 [in Chinese; Tables in English].

Chen, G., Li, Y., & Chen, X. (2007) "Species diversity of fishes in the coral reefs of South China Sea," *Biodiversity Science,* 15: 373-381 [in Chinese; Tables in English].

Chew, C. A., Hepburn, C. D., & Stephenson, W. (2013) "Low-level sedimentation modifies behaviour in juvenile *Haliotis iris* and may affect their vulnerability to predation," *Marine Biology,* 160: 1213-1221.

Cinner, J. E., Marnane, M. J., McClanahan, T. R., Clark, T. H., & Ben, J. (2005) "Trade, Tenure, and Tradition: Influence of Sociocultural Factors on Resource Use in Melanesia," *Conservation Biology,* 19: 1469-1477.

Coker, D. J., Wilson, S. K., & Pratchett, M. S. (2014) "Importance of live coral habitat for reef fishes," *Reviews in Fish Biology and Fisheries,* 24: 89-126.

Connell, H. J. (1997) "Disturbance and recovery of coral assemblages," *Coral Reefs,* 16: S101-S113.

Cooper, T. F., & Fabricius, K. E. (2012) "Pigmentation of massive corals as a simple bioindicator for marine water quality," *Marine Pollution Bulletin,* 65: 333-341.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., et al. (2014) "Changes in the global value of ecosystem services," *Global Environmental Change,* 26: 152-158.

Crabbe, M., & Smith, D. (2005) "Sediment impacts on growth rates of *Acropora* and *Porites* corals from fringing reefs of Sulawesi, Indonesia," *Coral Reefs,* 24: 437-441.

Dalzell, P. (1996) "Catch rates, selectivity and yields of reef fishing," In *Reef Fisheries,* edited by N. V. C. Polunin & C. M. Roberts. London, UK: Chapman and Hall.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., et al. (2012) "Global estimates of the value of ecosystems and their services in monetary units," *Ecosystem Services,* 1: 50-61.

Dodge, R. E., Aller, R. C., & Thomson, J. (1974) "Coral Growth Related to Resuspension of Bottom Sediments," *Nature,* 247: 574-577.

Done, T. J. (1988) "Simulation of recovery of pre-disturbance size structure in populations of *Porites* spp. damaged by the crown of thorns starfish *Acanthaster planci*," *Marine Biology,* 100: 51-61.

Dorman, J. G., Castruccio, F. S., Curchitser, E. N., Kleypas, J. A., & Powell, T. M. (2016) "Modeled connectivity of *Acropora millepora* populations from reefs of the Spratly Islands and the greater South China Sea," *Coral Reefs,* 35: 169-179.

ANNEX C: List of Additional References

Doropoulos, C., Ward, S., Roff, G., González-Rivero, M., & Mumby, P. J. (2015) "Linking Demographic Processes of Juvenile Corals to Benthic Recovery Trajectories in Two Common Reef Habitats," *PLoS ONE,* 10: e0128535.

Doropoulos, C., Roff, G., Bozec, Y.-M., Zupan, M., Werminghausen, J., & Mumby, P. J. (2016) "Characterizing the ecological trade-offs throughout the early ontogeny of coral recruitment," *Ecological Monographs,* 86: 20-44.

Dudgeon, S. R., Aronson, R. B., Bruno, J. F., & Precht, W. F. (2010) "Phase shifts and stable states on coral reefs," *Marine Ecology Progress Series,* 413: 201-216.

Dullo, W.-C. (2005) "Coral growth and reef growth: a brief review," *Facies,* 51: 33-48.

Edwards, A. J., & Clark, S. (1999) "Coral Transplantation: A Useful Management Tool or Misguided Meddling?" *Marine Pollution Bulletin,* 37: 474-487.

Edwards, A. J., & Gomez, E. D. (2007) *Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty*. St. Lucia, Australia: Coral Reef Targeted Research & Capacity Building for Management Programme.

Edwards, A. J. (2010) "Reef Rehabilitation Manual.," St Lucia, Australia: Coral Reef Targeted Research & Capacity Building for Management Program: p. 3.

Endean, R. (1976) "Destruction and recovery of coral reef communities," In *Biology and Geology of Coral Reefs,* edited by O. A. Jones & R. Endean. New York, NY, USA; San Francisco, CA, USA; London, UK: Academic Press.

Erftemeijer, P. L. A., & Robin Lewis III, R. R. (2006) "Environmental impacts of dredging on seagrasses: A review," *Marine Pollution Bulletin,* 52: 1553-1572.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., et al. (2011) "Trophic Downgrading of Planet Earth," *Science,* 333: 301-306.

Fabricius, K. E. (2005) "Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis," *Marine Pollution Bulletin,* 50: 125-146.

Fagerstrom, J. A. (1987) *The evolution of reef communities*. New York, NY, USA: John Wiley and Sons Inc.

Feng, X.-j., Yang, Q., Li, Y.-q., & Ao, L. (2011) "Survey and protection countermeasure on ecosystem of coral reef in Nansha coral reef," *Journal of Logistical Engineering University,* 27: 68-71 [in Chinese; unofficial translation provided by PCA].

Fisher, R., Stark, C., Ridd, P., & Jones, R. (2015) "Spatial Patterns in Water Quality Changes during Dredging in Tropical Environments," *PLoS ONE,* 10: e0143309.

Fisher, R., O'Leary, Rebecca A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, Russell E., et al. (2015) "Species Richness on Coral Reefs and the Pursuit of Convergent Global Estimates," *Current Biology,* 25: 500-505.

Flores, F., Hoogenboom, M. O., Smith, L. D., Cooper, T. F., Abrego, D., & Negri, A. P. (2012) "Chronic Exposure of Corals to Fine Sediments: Lethal and Sub-Lethal Impacts," *PLoS ONE,* 7: e37795.

Fortes, M. D. (2004) "National Report on Seagrass in the South China Sea - Philippines," In. Bangkok, Thailand: UNEP/GEF South China Sea Project.

Foster, N. L., Paris, C. B., Kool, J. T., Baums, I. B., Stevens, J. R., Sanchez, J. A., et al. (2012) "Connectivity of Caribbean coral populations: complementary insights from empirical and modelled gene flow," *Molecular Ecology,* 21: 1143-1157.

Fox, H. E., & Caldwell, R. L. (2006) "Recovery from blast fishing on coral reefs: a tale of two scales," *Ecological Applications,* 16: 1631-1635.

Gilmour, J. (1999) "Experimental investigation into the effects of suspended sediment on fertilisation, larval survival and settlement in a scleractinian coral," *Marine Biology,* 135: 451-462.

ANNEX C: List of Additional References

Gilmour, J. P., Smith, L. D., Heyward, A. J., Baird, A. H., & Pratchett, M. S. (2013) "Recovery of an Isolated Coral Reef System Following Severe Disturbance," *Science,* 340: 69-71.

Glynn, P. W. (1984) "Widespread Coral Mortality and the 1982–83 El Niño Warming Event," *Environmental Conservation,* 11: 133-146.

Gordon, S. E., Goatley, C. H. R., & Bellwood, D. R. (2016) "Low-quality sediments deter grazing by the parrotfish *Scarus rivulatus* on inner-shelf reefs," *Coral Reefs,* 35: 285-291.

Graham, N. A. J., Wilson, S. K., Jennings, S., Polunin, N. V. C., Bijoux, J. P., & Robinson, J. (2006) "Dynamic fragility of oceanic coral reef ecosystems," *Proceedings of the National Academy of Sciences of the USA,* 103: 8425-8429.

Graham, N. A. J., Jennings, S., MacNeil, M. A., Mouillot, D., & Wilson, S. K. (2015) "Predicting climate-driven regime shifts versus rebound potential in coral reefs," *Nature,* 518: 94-97.

Graus, R. R., & Macintyre, I. G. (1989) "The zonation patterns of Caribbean coral reefs as controlled by wave and light energy input, bathymetric setting and reef morphology: computer simulation experiments," *Coral Reefs,* 8: 9-18.

Halford, A., Cheal, A. J., Ryan, D., & Williams, D. M. (2004) "Resilience to large-scale disturbance in coral and fish assemblages on the Great Barrier Reef," *Ecology,* 85: 1892-1905.

Hamner, W. M., & Wolanski, E. (1988) "Hydrodynamic forcing functions and biological processes on coral reefs: A status review," In *6th International Coral Reef Symposium,* edited by J. H. Choat, D. Barnes, M. A. Borowitzka, J. C. Coll, P. J. Davies, P. Flood, B. G. Hatcher, D. Hopley, P. A. Hutchings, D. Kinsey, G. R. Orme, M. Pichon, P. F. Sale, P. Sammarco, C. C. Wallace, C. Wilkinson, E. Wolanski & O. Bellwood. Townsville, Australia.

Harborne, A. R. (2013) "The ecology, behaviour and physiology of fishes on coral reef flats, and the potential impacts of climate change," *Journal of Fish Biology,* 83: 417-447.

Harrison, P. L., & Wallace, C. C. (1990) "Reproduction, dispersal and recruitment of scleractinian corals," In *Ecoystems of the World,* edited by Z. Dubinsky. New York and Amsterdam: Elsevier Science.

Heileman, S. (2009) "South China Sea LME," In *The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas,* edited by K. Sherman & G. Hempel. Nairobi, Kenya: United Nations Environment Programme.

Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008) "Predicting ecological consequences of marine top predator declines," *Trends in Ecology & Evolution,* 23: 202-210.

Hernández-Delgado, E. A., Montañez-Acuña, A., Otaño-Cruz, A., & Suleimán-Ramos, S. E. (2014) "Bomb-cratered coral reefs in Puerto Rico, the untold story about a novel habitat: from reef destruction to community-based ecological rehabilitation," *Revista de Biologia Tropical,* 62: 350-367.

Hess, S., Wenger, A. S., Ainsworth, T. D., & Rummer, J. L. (2015) "Exposure of clownfish larvae to suspended sediment levels found on the Great Barrier Reef: Impacts on gill structure and microbiome," *Scientific Reports,* 5: 10561.

Hixon, M. A., & Beets, J. P. (1993) "Predation, Prey Refuges, and the Structure of Coral-Reef Fish Assemblages," *Ecological Monographs,* 63: 77-101.

Hock, K., Wolff, N. H., Condie, S. A., Anthony, K. R. N., & Mumby, P. J. (2014) "Connectivity networks reveal the risks of crown-of-thorns starfish outbreaks on the Great Barrier Reef," *Journal of Applied Ecology,* 51: 1188-1196.

Hodgson, G. (1990) "Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*," *Coral Reefs,* 9: 41-43.

Hoegh-Guldberg, O. (1999) "Climate change, coral bleaching and the future of the world's coral reefs," *Marine and Freshwater Research,* 50: 839-866.

Hooper, J. N. A., Kennedy, J. A., & van Soest, R. W. M. (2000) "Annotated checklist of sponges (Porifera) of the South China Sea region," *The Raffles Bulletin of Zoology,* Supplement 8: 125-207.

ANNEX C: List of Additional References

Huang, H., Zhang, C.-L., Yang, J.-H., You, F., Lian, J.-S., & Tan, Y.-H. (2012) "Scleractinian coral community characteristics in Zhubi reef sea area of Nansha Islands," *Journal of Oceanography in Taiwan Strait,* 31: 79-84 [in Chinese, unofficial translation provided by PCA].

Hughes, T. P., Rodrigues, M. J., Bellwood, D. R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., et al. (2007) "Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change," *Current Biology,* 17: 360-365.

Hughes, T. P., Huang, H. U. I., & Young, M. A. L. (2013) "The Wicked Problem of China's Disappearing Coral Reefs," *Conservation Biology,* 27: 261-269.

Humphrey, C., Weber, M., Lott, C., Cooper, T., & Fabricius, K. (2008) "Effects of suspended sediments, dissolved inorganic nutrients and salinity on fertilisation and embryo development in the coral *Acropora millepora* (Ehrenberg, 1834)," *Coral Reefs,* 27: 837-850.

Johannes, R. E., & Riepen, M. (1995) "Environmental, Economic, and Social Implications of the Live Reef Fish Trade in Asia and the Western Pacific," Arlington, VA, USA: The Nature Conservancy.

Jones, G. P., McCormick, M. I., Srinivasan, M., & Eagle, J. V. (2004) "Coral decline threatens fish biodiversity in marine reserves," *Proceedings of the National Academy of Sciences of the United States of America,* 101: 8251-8253.

Jones, G. P., Almany, G., Russ, G., Sale, P., Steneck, R., van Oppen, M., et al. (2009) "Larval retention and connectivity among populations of corals and reef fishes: history, advances and challenges," *Coral Reefs,* 28: 307-325.

Jones, R., Ricardo, G. F., & Negri, A. P. (2015) "Effects of sediments on the reproductive cycle of corals," *Marine Pollution Bulletin,* 100: 13-33.

Jones, R., Bessell-Browne, P., Fisher, R., Klonowski, W., & Slivkoff, M. (2016) "Assessing the impacts of sediments from dredging on corals," *Marine Pollution Bulletin,* 102: 9-29.

Junjie, R. K., Browne, N. K., Erftemeijer, P. L. A., & Todd, P. A. (2014) "Impacts of Sediments on Coral Energetics: Partitioning the Effects of Turbidity and Settling Particles," *PLoS ONE,* 9: e107195.

Kennedy, E. V., Holderied, M. W., Mair, J. M., Guzman, H. M., & Simpson, S. D. (2010) "Spatial patterns in reef-generated noise relate to habitats and communities: Evidence from a Panamanian case study," *Journal of Experimental Marine Biology and Ecology,* 395: 85-92.

Kojis, B. L., & Quinn, N. J. (1984) "Seasonal and depth variation in fecundity of *Acropora palifera* at two reefs in Papua New Guinea," *Coral Reefs,* 3: 165-172.

Kool, J. T., Paris, C. B., Barber, P. H., & Cowen, R. K. (2011) "Connectivity and the development of population genetic structure in Indo-West Pacific coral reef communities," *Global Ecology and Biogeography,* 20: 695-706.

Knop, D. (1996) *Giant Clams. A comprehensive Guide to the Identification and Care of Tridacnid Clams.* Ettlingen, Germany: Dähne Verlag GmbH.

Lachmuddin, S. (1987) "The exploration of giant clam fossils on the fringing reef areas of Karimun Jawa Islands," *Biotrop Special Publication,* 29: 59-64.

Lane, D. J. W., Marsh, L. M., VandenSpiegel, D., & Rowe, F. W. E. (2000) "Echinoderm fauna of the South China Sea: an inventory and analysis of distribution patterns," *The Raffles Bulletin of Zoology,* Supplement 8: 459-493.

Lee, V. R. (2016) "Satellite Imagery Shows Ecocide in the South China Sea," *The Diplomat* January 15, 2016.

Letourneur, Y., Chabanet, P., Vigliola, L., & Harmelin-Vivien, M. (1998) "Mass Settlement and Post-Settlement Mortality of *Epinephelus merra* (Pisces: Serranidae) On Réunion Coral Reefs," *Journal of the Marine Biological Association of the United Kingdom,* 78: 307-319.

ANNEX C: List of Additional References

Li, S., Yu, K., Chen, T., Shi, Q., & Zhang, H. (2011) "Assessment of coral bleaching using symbiotic zooxanthellae density and satellite remote sensing data in the Nansha Islands, South China Sea," *Chinese Science Bulletin,* 56: 1031-1037.

Li, X.-Z., Li, B.-Q., Wang, H.-F., Wang, S.-Q., Wang, J.-B., & Zhang, B.-L. (2007) "Macrobenthic community characters of Zhubi Reef, Nansha Islands, South China Sea," *Acta Zoologica Sinica,* 53: 83-94 [in Chinese; English abstract].

Li, X.-b., Huang, H., Lian, J.-s., Liu, S., Huang, L.-m., & Yang, J.-h. (2013) "Spatial and temporal variations in sediment accumulation and their impacts on coral communities in the Sanya Coral Reef Reserve, Hainan, China," *Deep Sea Research Part II: Topical Studies in Oceanography,* 96: 88-96.

Li, Y.-Z., Lin, Z.-J., Chen, P.-M., Sun, D.-R., Chen, Y., Chen, G.-B., et al. (2003) "Survey for coral reef fish resources in the center & north waters of the Nansha Islands," *Journal of Fisheries of China,* 27: 315-321 [in Chinese; English abstract].

Li, Y.-Z., & Chen, P.-M. (2004) "Quantitative distribution of fish resources in main coral reef waters of Nansha Islands," *Journal of Fisheries of China,* 28: 651-656 [in Chinese; English abstract].

Liu, Z., Huang, W., Li, J., Wang, P., Wang, R., Yu, K., et al. (2009) "Sedimentology," In *The South China Sea: Paleoceanography and Sedimentology,* edited by P. Wang & Q. Li. Dordrecht, The Netherlands: Springer Netherlands.

Lokrantz, J., Nyström, M., Thyresson, M., & Johansson, C. (2008) "The non-linear relationship between body size and function in parrotfishes," *Coral Reefs,* 27: 967-974.

Lough, J. M., & Barnes, D. J. (2000) "Environmental controls on growth of the massive coral Porites," *Journal of Experimental Marine Biology and Ecology,* 245: 225-243.

Loya, Y., Lubinevsky, H., Rosenfeld, M., & Kramarsky-Winter, E. (2004) "Nutrient enrichment caused by in situ fish farms at Eilat, Red Sea is detrimental to coral reproduction," *Marine Pollution Bulletin,* 49: 344-353.

Mallela, J., Roberts, C., Harrod, C., & Goldspink, C. R. (2007) "Distributional patterns and community structure of Caribbean coral reef fishes within a river-impacted bay," *Journal of Fish Biology,* 70: 523-537.

McAllister, D. E. (1988) "Environmental, economic and social costs of coral reef destruction in the Philippines," *Galaxea, Journal of Coral Reef Studies,* 7: 161-178.

McAllister, D. E. (1995) "Status of the World Ocean and its biodiversity," *Sea Wind,* 9: 14.

McClanahan, T. R., Polunin, N. V. C., & Done, T. J. (2002) "Ecological states and the resilience of coral reefs," *Conservation Ecology,* 6: 18.

McClanahan, T. R., Graham, N. A. J., MacNeil, M. A., Muthiga, N. A., Cinner, J. E., Bruggemann, J. H., et al. (2011) "Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries," *Proceedings of the National Academy of Sciences,* 108: 17230-17233.

McClanahan, T. R., Graham, N. A. J., MacNeil, M. A., & Cinner, J. E. (2014) "Biomass-based targets and the management of multispecies coral reef fisheries," *Conservation Biology,* 29: 409-417.

McCook, L. J., Schaffelke, B., Apte, S. C., Brinkman, R., Brodie, J., Erftemeijer, P., et al. (2015) "Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef: Report of an Independent Panel of Experts" Townsville, Australia.

McCormick, M. I., & Makey, L. J. (1997) "Post-settlement transition in coral reef fishes: overlooked complexity in niche shifts," *Marine Ecology Progress Series,* 153: 247-257.

McManus, J. W. (1994) "The Spratly Islands: A Marine Park?," *AMBIO,* 23: 181-186.

McManus, J. W. (1997) "Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia," *Coral Reefs,* 16: S121-S127.

McManus, J. W., Reyes Jr, R. B., & Nañola Jr, C. L. (1997) "Effects of Some Destructive Fishing Methods on Coral Cover and Potential Rates of Recovery," *Environmental Management,* 21: 69-78.

ANNEX C: List of Additional References

McManus, J. (2016) "Update on Spratly Islands," http://coral.aoml.noaa.gov/pipermail/coral-list/2016-April/016891.html. Accessed 27 April 2016.

Meesters, E. H., Bos, A., & Gast, G. J. (1992) "Effects of sedimentation and lesion position on coral tissue regeneration," In *7th International Coral Reef Symposium,* edited by R. H. Richmond. Guam, Micronesia: University of Guam Press, UOG Station, Guam.

Mellin, C., Aaron MacNeil, M., Cheal, A. J., Emslie, M. J., & Julian Caley, M. (2016) "Marine protected areas increase resilience among coral reef communities," *Ecology Letters*: in press.

Mora, C., Caldwell, I. R., Birkeland, C., & McManus, J. W. (2016) "Dredging in the Spratly Islands: Gaining Land but Losing Reefs," *PLoS Biology,* 14: e1002422.

Morton, B., & Blackmore, G. (2001) "South China Sea," *Marine Pollution Bulletin,* 42: 1236-1263.

Mumby, P. J., Edwards, A. J., Arias-Gonzalez, E. J., Lindeman, K. C., Blackwell, P. G., Gall, A., et al. (2004) "Mangroves enhance the biomass of coral reef fish communities in the Caribbean," *Nature,* 427: 533-536.

Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V., Micheli, F., Brumbaugh, D. R., et al. (2006) "Fishing, Trophic Cascades, and the Process of Grazing on Coral Reefs," *Science,* 311: 98-101.

Mumby, P. J., Hastings, A., & Edwards, H. J. (2007) "Thresholds and the resilience of Caribbean coral reefs," *Nature,* 450: 98-101.

Mumby, P. J., & Steneck, R. S. (2008) "Coral reef management and conservation in light of rapidly evolving ecological paradigms," *Trends in Ecology & Evolution,* 23: 555-563.

Mumby, P. J., Broad, K., Brumbaugh, D. R., Dahlgren, C. P., Harborne, A. R., Hastings, A., et al. (2008) "Coral Reef Habitats as Surrogates of Species, Ecological Functions, and Ecosystem Services," *Conservation Biology,* 22: 941-951.

Mumby, P. J., Steneck, R. S., Edwards, A. J., Ferrari, R., Coleman, R., Harborne, A. R., et al. (2012) "Fishing down a Caribbean food web relaxes trophic cascades," *Marine Ecology Progress Series,* 445: 13-24.

Mumby, P. J., Steneck, R. S., Adjeroud, M., & Arnold, S. N. (2015) "High resilience masks underlying sensitivity to algal phase shifts of Pacific coral reefs," *Oikos*: in press.

Myers, R. A., & Worm, B. (2003) "Rapid worldwide depletion of predatory fish communities," *Nature,* 423: 280-283.

Newton, K., Côté, I. M., Pilling, G. M., Jennings, S., & Dulvy, N. K. (2007) "Current and Future Sustainability of Island Coral Reef Fisheries," *Current Biology,* 17: 655-658.

Nyström, M., Folke, C., & Moberg, F. (2000) "Coral reef disturbance and resilience in a human-dominated environment," *Trends in Ecology & Evolution,* 15: 413-417.

Nyström, M., Graham, N., Lokrantz, J., & Norström, A. (2008) "Capturing the cornerstones of coral reef resilience: linking theory to practice," *Coral Reefs,* 27: 795-809.

Nyström, M., Norström, A., Blenckner, T., de la Torre-Castro, M., Eklöf, J., Folke, C., et al. (2012) "Confronting Feedbacks of Degraded Marine Ecosystems," *Ecosystems,* 15: 695-710.

Padilla-Gamiño, J. L., Hédouin, L., Waller, R. G., Smith, D., Truong, W., & Gates, R. D. (2014) "Sedimentation and the Reproductive Biology of the Hawaiian Reef-Building Coral *Montipora capitata*," *Biological Bulletin,* 226: 8-18.

Pal, A. (2007) "Spratlys Fish Stocks Dwindling, Say Scientists," *Philippine Daily Inquirer* 03. May 2007.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F. (1998) "Fishing Down Marine Food Webs," *Science,* 279: 860-863.

Pearson, R. G. (1981) "Recovery and recolonization of coral reefs," *Marine Ecology Progress Series,* 4: 105-122.

ANNEX C: List of Additional References

Perry, C. T., Spencer, T., & Kench, P. S. (2008) "Carbonate budgets and reef production states: a geomorphic perspective on the ecological phase-shift concept," *Coral Reefs,* 27: 853-866.

Perry, C. T., Kench, P. S., Smithers, S. G., Riegl, B., Yamano, H., & O'Leary, M. J. (2011) "Implications of reef ecosystem change for the stability and maintenance of coral reef islands," *Global Change Biology,* 17: 3679-3696.

Perry, C. T., Murphy, G. N., Kench, P. S., Smithers, S. G., Edinger, E. N., Steneck, R. S., et al. (2013) "Caribbean-wide decline in carbonate production threatens coral reef growth," *Nature Communications,* 4: 1402.

PIANC. (2010) "Dredging and port construction around coral reefs," Brussels, Belgium: UNEP, The World Association for Waterborne Transport Infrastructure (PIANC).

Pineda, M. C., Duckworth, A., & Webster, N. (2016) "Appearance matters: sedimentation effects on different sponge morphologies," *Journal of the Marine Biological Association of the United Kingdom,* 96: 481-492.

Pratchett, M. S., Munday, P. L., Wilson, S. K., Graham, N. A. J., Cinner, J. E., Bellwood, D. R., et al. (2008) "Effects of climate-induced coral bleaching on coral-reef fishes - ecological and economic consequences," *Oceanography and Marine Biology: an Annual Review,* 46: 251-296.

Pratchett, M. S., Hoey, A. S., Wilson, S. K., Messmer, V., & Graham, N. A. J. (2011) "Changes in biodiversity and functioning of reef fish assemblages following coral bleaching and coral loss," *Diversity,* 3: 424-452.

Randall, J. E., Lim, K. K. P., & (eds.). (2000) "A checklist of the fishes of the South China Sea," *The Raffles Bulletin of Zoology,* Supplement 8: 569-667.

Renken, H., Mumby, P. J., Matsikis, I., & Edwards, H. J. (2010) "Effects of physical environmental conditions on the patch dynamics of *Dictyota pulchella* and *Lobophora variegata* on Caribbean coral reefs," *Marine Ecology Progress Series,* 403: 63-74.

Ricardo, G. F., Jones, R. J., Clode, P. L., Humanes, A., & Negri, A. P. (2015) "Suspended sediments limit coral sperm availability," *Scientific Reports,* 5: 18084.

Ricardo, G. F., Jones, R. J., Negri, A. P., & Stocker, R. (2016) "That sinking feeling: Suspended sediments can prevent the ascent of coral egg bundles," *Scientific Reports,* 6: 21567.

Roff, G., Bejarano, S., Bozec, Y.-M., Nugues, M., Steneck, R. S., & Mumby, P. J. (2014) "Porites and the Phoenix effect: unprecedented recovery after a mass coral bleaching event at Rangiroa Atoll, French Polynesia," *Marine Biology,* 161: 1385-1393.

Roff, G., Doropoulos, C., Zupan, M., Rogers, A., Steneck, R. S., Golbuu, Y., et al. (2015) "Phase shift facilitation following cyclone disturbance on coral reefs," *Oecologia,* 178: 1193-1203.

Rogers, A., Blanchard, Julia L., & Mumby, Peter J. (2014) "Vulnerability of Coral Reef Fisheries to a Loss of Structural Complexity," *Current Biology,* 24: 1000-1005.

Rogers, C. S. (1990) "Responses of coral reefs and reef organisms to sedimentation," *Marine Ecology Progress Series,* 62: 185-202.

Rollon, R. N., Cayabyab, N. M., & Fortes, M. D. (2001) "Vegetative dynamics and sexual reproduction of monospecific *Thalassia hemprichii* meadows in the Kalayaan Island Group," *Aquatic Botany*, 71: 239-246.

Rosenberg, D. (2009) "Fisheries Management in the South China Sea," In *Security and International Politics in the South China Sea: Towards a Co-operative Management Regime,* edited by S. Bateman & R. Emmers. Oxon, UK: Routledge, Taylor & Francis.

Salinas-de-León, P., Costales-Carrera, A., Zeljkovic, S., Smith, D. J., & Bell, J. J. (2011) "Scleractinian settlement patterns to natural cleared reef substrata and artificial settlement panels on an Indonesian coral reef," *Estuarine, Coastal and Shelf Science,* 93: 80-85.

ANNEX C: List of Additional References

Saunders, M. I., Leon, J. X., Callaghan, D. P., Roelfsema, C. M., Hamylton, S., Brown, C. J., et al. (2014) "Interdependency of tropical marine ecosystems in response to climate change," *Nature Climate Change,* 4: 724-729.

Shen, J., & Wang, Y. (2008) "Modern microbialites and their environmental significance, Meiji reef atoll, Nansha (Spratly) Islands, South China Sea," *Science in China Series D: Earth Sciences,* 51: 608-617.

Sherman, K., & Alexander, L. (1986) "Variability and management of large marine ecosystems," *AAAS Selected Symposium 99*. Boulder, CO, USA: Westview Press, Inc.

Sherman, K., & Hempel, G. (2009) "The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas," *UNEP Regional Seas Report and Studies 182*. Nairobi, Kenya: United Nations Environment Programme.

Stafford-Smith, M. G., & Ormond, R. F. G. (1992) "Sediment-rejection mechanisms of 42 species of Australian scleractinian corals," *Marine and Freshwater Research,* 43: 683-705.

Steneck, R. S. (1988) "Herbivory on coral reefs: a synthesis," In *6th International Coral Reef Symposium,* edited by J. H. Choat, D. Barnes, M. A. Borowitzka, J. C. Coll, P. J. Davies, P. Flood, B. G. Hatcher, D. Hopley, P. A. Hutchings, D. Kinsey, G. R. Orme, M. Pichon, P. F. Sale, P. Sammarco, C. C. Wallace, C. Wilkinson, E. Wolanski & O. Bellwood. Townsville, Australia.

Steneck, R. S., Arnold, S. N., & Mumby, P. J. (2014) "Experiment mimics fishing on parrotfish: insights on coral reef recovery and alternative attractors," *Marine Ecology Progress Series,* 506: 115-127.

Sun, Z. (2000) "Nansha Islands coral sand engineering properties," *Tropic Oceanology,* 19: 1-8.

Szostek, C. L., Davies, A. J., & Hinz, H. (2013) "Effects of elevated levels of suspended particulate matter and burial on juvenile king scallops *Pecten maximus*," *Marine Ecology Progress Series,* 474: 155-165.

Tomascik, T., & Sander, F. (1987) "Effects of eutrophication on reef-building corals," *Marine Biology,* 94: 77-94.

Uthicke, S. (1999) "Sediment bioturbation and impact of feeding activity of *Holothuria (Halodeima) atra* and *Stichopus chloronotus*, two sediment feeding holothurians, at Lizard Island, Great Barrier Reef," *Bulletin of Marine Science,* 64: 129-141.

Valencia, M. J. (1991) "Coastal area management in ASEAN: the transnational issues," In *Towards an Integrated Management of Tropical Coastal Resources,* edited by L. M. Chou, T.-E. Chua, H. W. Khoo, P. E. Lim, J. N. Paw, G. T. Silvestre, M. J. Valencia, A. T. White & P. K. Wong. Singapore: National University of Singapore; National Science and Technology Board, Singapore; ICLARM, Philippines.

Van Oppen, M. J. H., Bongaerts, P. I. M., Underwood, J. N., Peplow, L. M., & Cooper, T. F. (2011) "The role of deep reefs in shallow reef recovery: an assessment of vertical connectivity in a brooding coral from west and east Australia," *Molecular Ecology,* 20: 1647-1660.

Vidra, R. L. (2006) "Ethical dilemmas in coral reef restoration," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press.

Wang, Z. (2008) "Engineering geological characteristics of the construction of Nansha Islands coral reefs and large-scale project feasibility study," *Institute of Rock and Soil Mechanics*. Wuhan, China: Chinese Academy of Sciences.

Webb, A. P., & Kench, P. S. (2010) "The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific," *Global and Planetary Change,* 72: 234-246.

Wen, C. K. C., Pratchett, M. S., Almany, G. R., & Jones, G. P. (2013) "Patterns of recruitment and microhabitat associations for three predatory coral reef fishes on the southern Great Barrier Reef, Australia," *Coral Reefs,* 32: 389-398.

Wenger, A. S., Johansen, J. L., & Jones, G. P. (2012) "Increasing suspended sediment reduces foraging, growth and condition of a planktivorous damselfish," *Journal of Experimental Marine Biology and Ecology,* 428: 43-48.

ANNEX C: List of Additional References

Wenger, A. S., McCormick, M. I., McLeod, I. M., & Jones, G. P. (2013) "Suspended sediment alters predator–prey interactions between two coral reef fishes," *Coral Reefs,* 32: 369-374.

Wenger, A. S., McCormick, M. I., Endo, G. G. K., McLeod, I. M., Kroon, F. J., & Jones, G. P. (2014) "Suspended sediment prolongs larval development in a coral reef fish," *Journal of Experimental Biology,* 217: 1122-1128.

Wiedenmann, J., D'Angelo, C., Smith, E. G., Hunt, A. N., Legiret, F.-E., Postle, A. D., et al. (2013) "Nutrient enrichment can increase the susceptibility of reef corals to bleaching," *Nature Climate Change,* 3: 160-164.

Wilkinson, C. (1998) *Status of Coral Reefs of the World: 1998*. Townsville, Australia: Global Coral Reef Monitoring Network, Australian Institute of Marine Science.

Wilkinson, C., ed. (2008) *Status of Coral Reefs of the World*. Townsville, Australia: Global Coral Reef Monitoring Network (GCRMN) and Reef and Rainforest Research Centre.

Wilson, S. K., Graham, N. A. J., Pratchett, M. S., Jones, G. P., & Polunin, N. V. C. (2006) "Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient?," *Global Change Biology,* 12: 2220-2234.

Wolkenhauer, S.-M., Uthicke, S., Burridge, C., Skewes, T., & Pitcher, C. R. (2010) "The ecological role of *Holothuria scabra* (Echinodermata: Holothuroidea) within subtropical seagrass beds," *Journal of the Marine Biological Association of the United Kingdom,* 90: 215-223.

Wooldridge, S. A. (2009) "Water quality and coral bleaching thresholds: Formalising the linkage for the inshore reefs of the Great Barrier Reef, Australia," *Marine Pollution Bulletin,* 58: 745-751.

Yadav, S., Rathod, P., Alcoverro, T., & Arthur, R. (2016) "“Choice” and destiny: the substrate composition and mechanical stability of settlement structures can mediate coral recruit fate in post-bleached reefs," *Coral Reefs,* 35: 211-222.

Yonge, C. M., & Nicholls, A. G. (1931) "Studies on the physiology of corals. V. The effect of starvation in light and in darkness on the relationship between corals and zooxanthellae," *Scientific Reports of the Great Barrier Reef Expedition 1928-1929,* 1: 177-211.

Yu, K.-F., Zhao, J.-X., Collerson, K. D., Shi, Q., Chen, T.-G., Wang, P.-X., et al. (2004) "Storm cycles in the last millennium recorded in Yongshu Reef, southern South China Sea," *Palaeogeography, Palaeoclimatology, Palaeoecology,* 210: 89-100.

Yu, K.-F., Zhao, J.-X., Shi, Q., Chen, T.-G., Wang, P.-X., Collerson, K. D., et al. (2006) "U-series dating of dead Porites corals in the South China sea: Evidence for episodic coral mortality over the past two centuries," *Quaternary Geochronology,* 1: 129-141.

Zimmer, B. (2006) "Coral reef restoration: an overview," In *Coral Reef Restoration Handbook,* edited by W. F. Precht. Boca Raton, FL, USA: CRC Press/Taylor and Francis.

Zhao, H., Weng, X., Sun, Z., Zheng, D., & Yuan, J. (1996) "Nansha Islands coral reef natural features," *Acta Oceanologica Sinica,* 18: 61-70 [in Chinese; unofficial translation using GoogleTranslate].

Zhao, H.-T., & Wu, T.-Q. (2008) "Some ideas about further development of the Xisha, Nansha and Zhongsha Islands," *Tropical Geography,* 28: 369-375 [in Chinese; unofficial translation using GoogleTranslate].

Zhao, M. X., Yu, K. F., Shi, Q., Chen, T. R., Zhang, H. L., & Chen, T. G. (2013) "Coral communities of the remote atoll reefs in the Nansha Islands, southern South China Sea," *Environmental Monitoring and Assessment,* 185: 7381-7392.

Zheng, F., Qiu, G., Fan, H., & Zhang, W. (2013) "Diversity, distribution and conservation of Chinese seagrass species," *Biodiversity Science,* 21: 517-526 [in Chinese; unofficial translation using GoogleTranslate].