



The Wicked Problem of China's Disappearing Coral Reefs

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Abstract: *We examined the development of coral reef science and the policies, institutions, and governance frameworks for management of coral reefs in China in order to highlight the wicked problem of preserving reefs while simultaneously promoting human development and nation building. China and other sovereign states in the region are experiencing unprecedented economic expansion, rapid population growth, mass migration, widespread coastal development, and loss of habitat. We analyzed a large, fragmented literature on the condition of coral reefs in China and the disputed territories of the South China Sea. We found that coral abundance has declined by at least 80% over the past 30 years on coastal fringing reefs along the Chinese mainland and adjoining Hainan Island. On offshore atolls and archipelagos claimed by 6 countries in the South China Sea, coral cover has declined from an average of >60% to around 20% within the past 10–15 years. Climate change has affected these reefs far less than coastal development, pollution, overfishing, and destructive fishing practices. Ironically, these widespread declines in the condition of reefs are unfolding as China's research and reef-management capacity are rapidly expanding. Before the loss of corals becomes irreversible, governance of China's coastal reefs could be improved by increasing public awareness of declining ecosystem services, by providing financial support for training of reef scientists and managers, by improving monitoring of coral reef dynamics and condition to better inform policy development, and by enforcing existing regulations that could protect coral reefs. In the South China Sea, changes in policy and legal frameworks, refinement of governance structures, and cooperation among neighboring countries are urgently needed to develop cooperative management of contested offshore reefs.*

Keywords: climate change, coral reef conservation, environmental governance, marine pollution, overfishing, South China Sea

El Problema Malvado de la Desaparición de los Arrecifes de Coral en China

Resumen: *Examinamos el desarrollo de la ciencia sobre arrecifes de coral y los marcos de referencia de políticas, instituciones y gobernanza para el manejo de arrecifes de coral en China para resaltar el problema malvado de la preservación de arrecifes al mismo tiempo que se promueve el desarrollo humano y nacional. China y otros estados soberanos en la región están experimentando una expansión económica, un crecimiento poblacional acelerado, migración masiva, desarrollo costero extensivo y pérdida de hábitat sin precedentes. Analizamos literatura, extensa y fragmentada, sobre la condición de los arrecifes de coral en China y en los territorios en disputa en el Mar de la China Meridional. Encontramos que la abundancia de coral ha declinado en por lo menos 80% durante los últimos 30 años en los arrecifes costeros a lo largo de la China continental y en la Isla Hainan adyacente. En los atolones y archipiélagos reclamadas por 6 países en el Mar de la China Meridional, la cobertura de coral ha declinado en un promedio de >60% a cerca de 20% en los últimos 10–15 años. El cambio climático ha afectado a estos arrecifes mucho menos que el desarrollo costero, la contaminación, la sobrepesca y las prácticas pesqueras destructivas. Irónicamente, estas declinaciones extensivas en la condición de los arrecifes se están revelando al mismo tiempo que se está expandiendo rápidamente la capacidad china de investigación y manejo de arrecifes. Antes que la pérdida de arrecifes*

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sea irreversible, la gobernanza de los arrecifes costeros debe ser mejorada mediante el incremento de la conciencia pública sobre la declinación de los servicios del ecosistema, proporcionando soporte financiero para la capacitación de científicos y manejadores de arrecifes, mejorando el monitoreo de la dinámica y condición de los arrecifes de coral para obtener información para el desarrollo de políticas y aplicando la regulación existente que puede proteger a los arrecifes de coral. En el Mar de la China Meridional, se requiere urgentemente de cambios en los marcos políticos y legales, refinamiento de las estructuras de gobernanza y cooperación entre los países vecinos para desarrollar manejo colaborativo de los arrecifes en disputa.

Palabras Clave: Cambio climático, conservación de arrecifes de coral, contaminación marina, gobernanza ambiental, Mar de la China Meridional, sobrepesca

Introduction

The concept of wicked problems originally arose in the context of social planning (Rittel & Webber 1973). More recently it has been applied to environmental challenges, such as how to improve governance for coping with anthropogenic climate change (Levin et al. 2009) and depleted fisheries (Jentoft & Chuenpagdee 2009). Here, we applied the wicked-problem paradigm to the social and ecological challenges of sustainably managing coral reefs in rapidly developing countries, exemplified by the subtropical reefs of mainland China and the disputed South China Sea, where 6 countries claim sovereignty over offshore reefs and atolls. A wicked problem by definition is complex and involves multiple sets of players (e.g., the general public, industries, governments, scientists, nongovernmental organizations, and multiple sovereign states). It has no single or optimal solution, and partial solutions invariably cause new, often unforeseen, problems and conflicts among players (Rittel & Webber 1973). For example, the coastal environments of China and elsewhere support multiple competing activities, including fishing, aquaculture, tourism, coastal development, and shipping (Cao & Wong 2007; Gu & Wong 2008). Policies that advantage one set of players often disadvantage others, creating winners and losers (Lebel et al. 2006; Jentoft & Chuenpagdee 2009). Similarly, shifts in livelihoods from fishing to aquaculture or to tourism can improve the sustainability of coastal resources or create new environmental and social problems (Cabral & Aliño 2011; Foale et al. 2012). Wicked problems are also characterized by inadequate governance, missing institutions, and a shortage of time before the problem becomes even harder to address (Rittel & Webber 1973; Levin et al. 2009; Walker et al. 2009). Our premise is that all these traits apply to the regional- and global-scale decline of coral reefs.

China's ongoing economic expansion has exacerbated many wicked environmental problems (Chen & Uitto 2003; Liu 2010), including widespread habitat loss due to coastal development, unsustainable levels of fishing, and pollution (Yu 1994; Zhang 2001a). The extent of China's mangroves decreased by 73% between the 1950s and 2002 (Zhang & Sui 2001; Cao & Wong 2007). Simi-

larly, the intensity of fishing increased rapidly after World War II because local artisanal harvesting was replaced by long-distance industrial fishing (Yu 1994). The reported number of Chinese fishing vessels increased 8-fold between the 1960s and 1990s (Zhou & Cai 2010), whereas catch per unit effort declined by two-thirds (Chen & Uitto 2003). Since 1999, China has intermittently banned fishing during seasonal closures or placed restrictions on gear types (Ding et al. 2008). At best, such steps are only a partial solution to overfishing because poor management of local fisheries has contributed to the expansion of China's ecological footprint far beyond its own territorial waters. Unable to catch enough seafood locally to meet market demand, China today imports at least 60% of the live reef fish harvested from coral reefs across the western Pacific and eastern Indian oceans (Sadovy 2005; Fabinyi 2012). Coastal and nearshore aquaculture in China has also boomed in response to rising consumer demand and depleted stocks of wild fish. For example, aquaculture production in Guangdong province increased 17-fold between 1986 and 2000 (Han et al. 2006), and the number of aquaculture pens in Daya Bay, 50 km north of Hong Kong, increased from 1000 in 1988 to more than 20,000 in 2004 (Yu et al. 2010). By 2006, approximately 30,000 km² of China's coastal seas were classified as unsafe for aquaculture or swimming due to sewage, industrial waste, aquaculture effluent, and other forms of pollution (Cao & Wong 2007).

Coral reefs on China's coastal fringing reefs and on disputed offshore atolls and islands in the South China Sea (Fig. 1) occupy about 30,000 km² (Supporting Information). They represent important natural assets of high conservation value and they support livelihoods and provide ecosystem services such as fish and areas for aquaculture and reef-based tourism (Morton & Blackmore 2001; Gu & Wong 2008). Offshore, the South China Sea has approximately 130 atolls and platform reefs (Morton & Blackmore 2001) claimed by up to 6 countries: Brunei, China, Malaysia, Taiwan, Philippines, and Vietnam.

Here, we present the first comprehensive analysis of the scattered information on coral reef condition recorded over the past 50 years from mainland China and from the highly disputed atolls and archipelagos of the South China Sea region (Fig. 1 & Supporting Information).

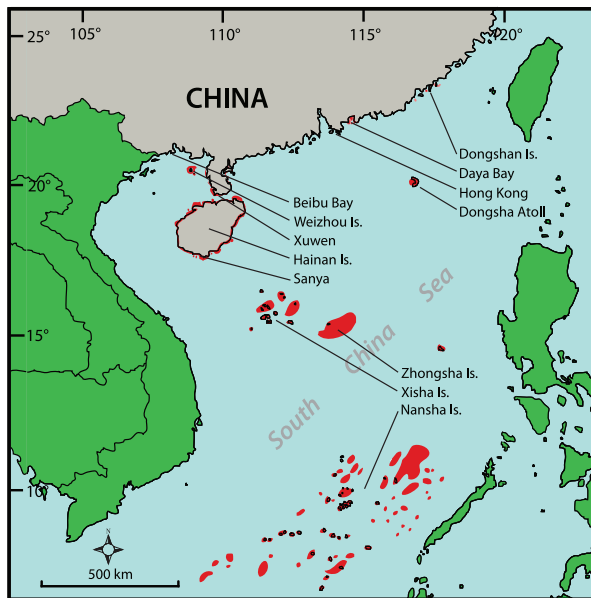


Figure 1. The subtropical coast of China, neighboring countries, and the contested coral reef archipelagos of the South China Sea. Coral reef habitat is in red (from Spalding et al. [2001] and other sources). See Supporting Information for further information on species richness and biogeographic setting of the region.

We have documented for the first time the regional extent of the losses of corals in China and the contested South China Sea over the past half century. We also mapped the development of coral reef science and monitoring in China to show that a window of opportunity exists to improve the management of these dwindling resources, but it is rapidly closing. We outline important changes in reef-related policies and governance that have occurred and provide suggestions for further improvements to prevent irretrievable loss of reefs throughout the region.

Coral Reef Science and Monitoring in China

China's recent social and economic transformation has coincided with an upsurge in coral reef research, scientific training, and monitoring programs. Publications on coral reef research have proliferated since the early 1980s, and in recent years this literature has become much more accessible and more internationalized as English has emerged as the dominant language (Fig. 2). English journal articles were uncommon before the late 1990s, but now account for approximately two-thirds of the rapidly growing number of coral reef publications by Chinese authors (Fig. 2). We identified 655 Chinese language journal articles, book chapters, and reports on coral reef research published since 1950, and 661 English

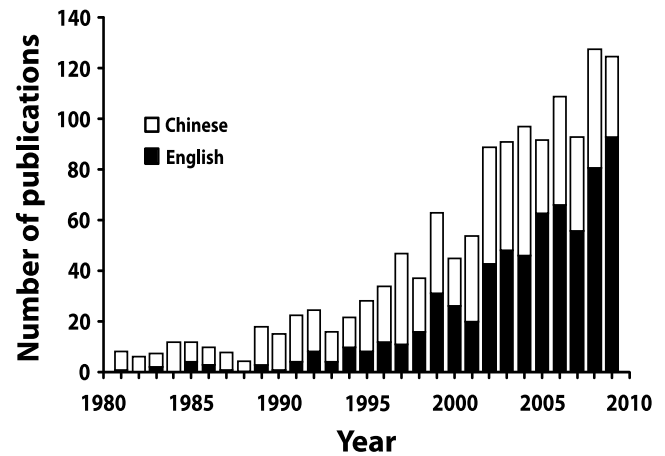


Figure 2. Number of journal publications on coral reefs in English or in Chinese by authors with addresses in China and Hong Kong since 1980.

language publications written by authors from mainland China over the same period. We methodically cross-referenced bibliographies from individual publications, working backward in time, until we found no new and relevant reports. Most of the primary data on reef condition we compiled (see below) came from Chinese peer-reviewed journals and reports that are not detectable in a standard bibliometric search conducted through, for example, Scopus or ISI Thompson Web of Science, sources that previous reviews of reef condition have heavily relied on.

China's coral reefs were closed to scientific scrutiny during the Cultural Revolution (1966–1976), and the literature on coral reefs before then is sparse. The South China Sea Institute of Oceanology (SCSIO) was founded by the Chinese Academy of Sciences in 1959. In 1979, SCSIO established the Tropical Marine Biology Research Station (TMBRS) near Sanya City on Hainan Island, adjacent to Luhuitou fringing reef (Supporting Information). Most of the coral reef research from coastal China over the past 30 years has been conducted at this location. Researchers at TMBRS launched an ongoing program of systematic monitoring in 2002 (Zhang et al. 2006), which includes semiquantitative surveys of coral cover, species richness, and reef condition at 6 locations (Xisha Islands, Sanya Bay at the southern end of Hainan Island, eastern Hainan Island, Beibu Bay and Xuwen close to the Vietnam border, Daya Bay adjacent to Hong Kong, and Dongshan Bay at the northern limits of China's coastal coral assemblages [Fig. 1 & Supporting Information]). Additional monitoring of coral reefs has been undertaken intermittently in recent years by the Guangdong Provincial Ocean Administration, scattered research groups, non-governmental organizations, and local volunteers. Reef Check, a volunteer reef-monitoring program, has been

increasingly active in China following its launch in Hong Kong in 1999 (Hodgson 1999).

Despite these local activities, monitoring of reef condition in mainland China is sparse and uncoordinated. This is a critical weakness that urgently needs to be addressed, in order to better inform regional-scale management of coral reefs. Without systematic monitoring, the status of coral reefs in China and the South China Sea will remain poorly understood and the decline in coral cover we document here will be easier to miss, ignore, or deny. Therefore, monitoring the condition of coral reefs and understanding why they are changing are critical aspects of addressing the wicked problem of loss of reef habitat and the decline in ecosystem services they provide.

We extracted information on coral cover from tables and graphs in the large body of literature we compiled (Fig. 2) to calculate trends over time. Because the quality of data was highly variable, especially for older studies, we included only quantitative measurements that used replicate sampling conducted with widely accepted techniques (i.e., quadrats, line and belt transects, and image analysis from replicated photographs or videos). We found 17 studies that reported 84 records from 10 locations (listed in Supporting Information). These estimates provide a conservative measure of trends in coral cover over time because much of the decline in these coral reefs was not recorded, and because once coral cover decreased scientists often abandoned their initial study sites in favor of new ones with greater cover (e.g., Scott & Cope 1986; Chen et al. 2009). To partially compensate for this potential bias in site selection in the literature, we calculated the trend in coral cover with a regression model fit to data from 14 inshore and offshore sites that were resampled multiple times.

Regional Changes in Coral Reef Ecosystems

Our quantitative analyses of the data we compiled from the literature revealed that nearly 80% of the coral cover on fringing reefs along the Chinese mainland and around Hainan Island has been destroyed by human activity since the 1980s (Fig. 3). Hainan Island was earmarked for rapid development by the Chinese government in 1988 when it was declared a Special Economic Zone. Its provincial jurisdiction was controversially extended far to the south in 1984 to include the disputed Zongsha and Xisha islands and the Nansha (Spratly) archipelago (Fig. 1), which is claimed in whole or partially by 6 countries in the region. Information on the ecological status of coral reefs from the major offshore atolls and archipelagos in the disputed South China Sea is patchier and mostly quite recent (Supporting Information). Nonetheless, we found that coral cover has declined from an average of >60% to around 20% within the past decade, even at these relatively remote locations (Fig. 3).

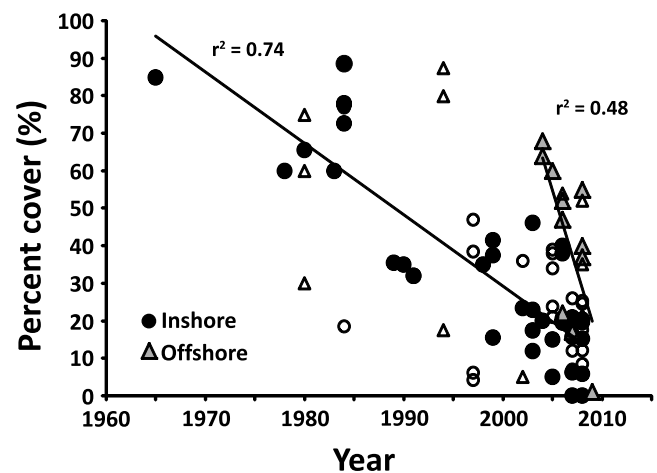


Figure 3. Percent coral cover over time on China's inshore reefs and on disputed offshore reefs in the South China Sea (linear-regression lines are fit to solid symbols, which represent data from 14 sites that were repeatedly surveyed; open symbols indicate an additional 35 records from one-time reef assessments). See Supporting Information for location details and sources.

Throughout the region, declining coral cover has frequently coincided with phase shifts to macroalgae or other weedy species (Li et al. 2000; Aliño & Quibilan 2003), outbreaks of crown-of-thorns starfish (*Acanthaster planci*) (Kimura et al. 2008), hyperabundances of sea urchins (Hutchings & Wu 1987; Fiege et al. 1994; Hodgson & Yau 1997), and more recently coral disease (Kimura et al. 2004; Liao et al. 2007). Adult brood stocks of corals have sharply declined and are physiologically stressed, whereas nearshore water quality, sedimentation, and algal blooms are all unfavorable for new coral recruitment (Shi et al. 2007). The abundance of harvested stocks (e.g., fish, mollusks, crustaceans, and sea cucumbers) have been reduced substantially, and destructive fishing practices (e.g., use of explosives and cyanide) continue to cause widespread damage to corals and other species (e.g., Dai 2006). Inshore, the combined effects of pollution, sedimentation, dredging, land reclamation, and aquaculture have been severe (e.g., Scott & Cope 1986; Shi et al. 2007). Although increases in ocean temperature and ocean acidification are often considered the primary threats to coral reefs, almost none of the sustained decline of inshore corals in coastal China is attributable to climate change. Climate change is adding to the wicked problems of sustaining the world's coral reefs (Hughes et al. 2003), but ongoing overfishing, pollution, coastal development, and other human activities that affect reefs are much more prevalent in many densely populated regions like China (Fig. 4).

The declining status of fringing coral reefs and the extent of coastal development are exemplified by Sanya



Figure 4. Coastal and military infrastructure adjoining coral reefs in the South China Sea: Sanya City and port, southern Hainan Island, in (a) 1988 and (b) 2010 (photographs by H. Huang). Note the extensive changes in just 12 years. (c) Yongxing Island, part of the disputed Xisha (Paracel) Islands east of Vietnam, showing a well-developed reef and cay and a Chinese military outpost (image reprinted in accordance with the requirements and guidelines of Google Earth and DigitalGlobe). Two dredged harbors are at the bottom of the photograph and the military airstrip is 2.6 km long.

City (Figs. 4a & 4b). From a fishing village of 2000 people in the 1950s (Zhang 2001b), Sanya grew to a city of over 600,000 people in 2010. Driven by China's booming economy and rising personal wealth, the number of domestic tourists visiting Sanya City in 2009 rose to over 6 million, 10 times the resident population. Coastal

development, including expansion of Sanya port, new hotels, an artificial island, increased pollution from sewage and industrial waste, and intensified food production from aquaculture and market gardens, have destroyed the fringing reefs closest to the city, where coral cover is now close to zero (Huang et al. 2003; Zhao et al. 2008; Figs. 4a & 4b). After more than 30 years of operation, SCSIO's TMBRS may need to relocate to a less-degraded location because of new development near the station.

Offshore, many of the scattered islets in the South China Sea are military outposts of China, Taiwan, or other countries. Some have aircraft runways and dredged naval harbors, which in itself has caused significant loss of coral habitat (Fig. 4c). Destructive fishing with poisons and explosives is rampant throughout the South China Sea. For example, in 1996, 1044 fishing boats from China, Hong Kong, and Taiwan were recorded on or near Dongsha Atoll, and approximately 50 t of cyanide and 1 t of dynamite were deployed there in that single season (Dai 2006). By 2001, the number of fishing boats visiting Dongsha Atoll had increased nearly 8-fold to 7976, and virtually everything harvestable (e.g., fish, mollusks, crustaceans, echinoderms) had been stripped from the atoll (Dai 2006). Coral bleaching and outbreaks of disease and crown-of-thorns starfish have also been reported throughout the South China Sea since the late 1990s, and these events resulted in substantial loss of coral cover (e.g., Soong et al. 2002; Huang et al. 2009; Huang et al. 2011). For example, coral cover was 68% and 51% on the Xisha Islands (Fig. 4c) in 2002 and 2006, respectively (Huang et al. 2011). By 2009, cover at these same sites was 1% following an outbreak of crown-of-thorns starfish (Huang et al. 2009). Similarly, on the Nansha (Spratly) Islands, coral cover near Taiwan's military garrison on Itu Aba Island was 60–70% in 1980 (Zhao et al. 1996). Dai and Fan (1996) also observed >50% coral cover on most reef flats in 1996. However, coral bleaching was recorded throughout the Nansha Islands in 1997 and 1998 and an outbreak of coral disease was observed in 2004 (Kimura et al. 2004). By 2007, live coral cover had declined to an average of 17% and there were extensive areas of dead corals attributed to blast fishing, bleaching, and disease (Huang et al. 2011). (Further details on social trajectories and changes in the condition of coral reefs at well-studied sites are provided in Supporting Information.)

Coral Reef Governance and Wicked Problems

The loss of coral reef habitat in China (Fig. 3), as in other nations, is caused by a failure of governance. By governance, we mean the structures and processes by which multiple actors (e.g., governments, non-governmental organizations, the private sector) share

power and make decisions. Governance includes formal laws and regulations, but also more diffuse and often unrecognized components that influence decision making, such as the media, religion, commerce, and public opinion (e.g., Lebel et al. 2006; Jentoft & Chuenpagdee 2009). These informal elements are powerful. Consequently, societal norms and attitudes in China are major aspects of the wicked problem of sustaining coral reefs. From this broader perspective, governance in China is not only top-down but also bottom-up. For example, in contemporary China, the consumption of live reef fish, *bêche de mer*, and shark fin, often during lavish banquets, builds personal status and business relationships (Yang 1994; Fabinyi 2012). Rapidly growing wealth and rising consumption of seafood, combined with poor governance and management of fisheries, has led to unsustainable harvesting of targeted species (e.g., Sadovy 2005; Berkes et al. 2006; Fabinyi 2012). In the longer term, changing public perceptions in China is at least as important as shifts in state, provincial, and municipal policies and laws for confronting the wicked problem of sustaining coral reefs.

Policy and legislative frameworks for environmental management have developed incrementally in China over the past few decades. For example, in 1993 the State Law of Marine Environment Protection and the State Management Regulation Preventing Coastal Engineering Projects from Marine Environmental Damage and Pollution were passed and adopted in an effort to protect coastal ecosystems. In 1994, sustainable development was proclaimed as a national priority (Liu 2010). In 1996, the State Ocean Administration launched the 21st century Ocean Agenda of China (Zhang 2001c) that established a system of marine zoning. In 1998, the State Ocean Administration established a priority program, Restoration of Coral Reef Ecosystems and Protection and Management of its Biodiversity in South China Sea of China. In 2001, the State Law of Ocean Use Management established a new requirement that coastal development must be compatible with the objectives of previously established marine zones (Zhang 2001c). In response to the growing costs of environmental degradation, China has steadily increased its expenditure on environmental protection (Liu 2010): From 2006 to 2010, China expended 1.5% of its annual gross domestic product (GDP) in environmental protection, double that of the previous 5 years (Zhou & Cai 2010).

However, despite these top-down legislative changes, rapid economic growth and urbanization continue to overwhelm regulatory frameworks that are hampered by a lack of public awareness or concern about environmental degradation (Huang et al. 2003; Han et al. 2006; Zhou & Cai 2010). For example, the Hainan Province Regulation of Coral Reef Protection (1998) aspires to protect against activities like coral mining and destructive fishing practices and to prevent new waste

discharge into marine parks (Zhang 2001c). Coral harvesting on Hainan Island has been illegal since 1999, when more than 90 lime kilns were closed down and demolished (Fujiwara et al. 2000). However, many tons of corals are still sold as souvenirs each year. In 2003, 14 prawn and abalone ponds that discharge untreated effluent were built beside the fringing reef in Luhuitou Bay, part of the Sanya National Coral Reef Reserve (Shi et al. 2007). Other development adjoining the reserve includes urban sprawl, a major tourist resort, a marina, and a golf course. In Sanya City and elsewhere, the performance of Chinese government officials, agencies, and local and provincial governments is typically assessed by economic metrics aimed at achieving higher GDP and tax revenues rather than environmental sustainability (Liu 2010).

To date, the establishment of coastal marine parks on the Chinese coastline has not prevented the decline of nearshore coral reefs (Zhang 2001a, 2001c; Ding et al. 2008) (Fig. 3). Seven national marine protected areas (MPAs) were established by China in 1990–1991 (Zhang 2001c), and today about 50 more are governed by provincial or local authorities (Kimura et al. 2008) (Supporting Information). However, these parks are small and do not adequately represent the diversity of China's coastal ecosystems (Han et al. 2006). Furthermore, there is no legally mandated system of environmental monitoring in most of these MPAs, so ongoing environmental change such as the rapid loss of coral cover (Fig. 3) is often unrecognized and unreported.

Long-term monitoring of coral reefs in Australia, the Caribbean, the Galapagos Islands, and elsewhere indicate that once a shift away from coral dominance has occurred, it is difficult to reverse (Hughes et al. 2010). Thus, the transition to alternate ecosystems that replace coral-dominated reefs illustrates a critical element of the wicked problem concept: a narrowing window of opportunity to prevent permanent loss of coral reefs. Consequently, maintaining marine ecosystems in good condition is a much better management approach than attempting to rebuild them after they have been severely damaged. Yet, there is an emphasis in China on attempting to restore ecosystems, a manifestation of attitudes and practices that favor rapid development now and postponement of environmental protection (e.g., Morton & Blackmore 2001; Liu 2010). For example, 20 vessels and 216 tire modules were sunk in shallow water off Hong Kong in 1998 and 131 concrete balls and 8 piles of quarry rocks were deployed in 1999 in an effort to establish so-called artificial reefs (Morton & Blackmore 2001). Given the regional scale of ongoing coral loss (Fig. 3), we recommend that a more proactive response should be implemented to directly address causes of environmental decline, such as chronic pollution and destructive fishing, rather than focusing on highly localized restoration projects.

Grappling with China's Wicked Problems

Partial solutions to wicked problems typically disadvantage some players while benefiting others and often generate new problems (Rittel & Webber 1973). For example, the rapid expansion of aquaculture in coastal China is potentially a partial solution to overfishing, but widespread pollution from sea pens has also triggered toxic red tides and unprecedented hypoxia events (Kimura et al. 2004). Similarly, although marine governance is improving in China, it has also become highly sectoral, resulting in unforeseen impediments to tackling complex and wicked problems. For example, up to 20 ministries and agencies have separate responsibilities for activities like fishing, shipping, oil exploration, water quality, and environmental protection. Each one represents a partial solution, but further governance reform is needed to reduce unnecessary institutional overlap and redundancy, to establish clear responsibilities, and to improve coordination (Han et al. 2006; Cao & Wong 2007; Gu & Wong 2008).

Partial solutions implemented now can also restrict future options (Jentoft & Chuenpagdee 2009; Levin et al. 2009). The challenge therefore is to initiate partial solutions to wicked problems that do not preclude future incremental improvements. In the context of climate change as a wicked problem, Levin et al. (2009) refer to this pathway as "progressive incrementalism." In China recent improvements in legislative frameworks, investment in education and monitoring, internationalization of science, and the establishment of a rudimentary national system of marine parks represent positive steps that can be built on. However, other decisions are more likely to incrementally worsen the wicked problem of coral reefs in China and the South China Sea. For example, building or expanding a city adjoining fringing reefs or converting a coral reef flat into an airport runway (Fig. 4) are not easily reversible and open a pathway away from environmental sustainability.

Recent incremental reforms in the governance of coastal ecosystems in Australia, Chile, and the Philippines share a number of traits. These include progressive leadership, capacity to improve laws and policies, development of a shared vision, partnerships among different players, reduction of conflict, building of strong public support for change, allocation of financial and human resources, and development of new knowledge on ecosystem trajectories for informing and testing policies (Alcala & Russ 2006; Olsson et al. 2008; Gelcich et al. 2010). Yet, many of these elements remain poorly developed in China (Han et al. 2006; Cao & Wong 2007; Gu & Wong 2008).

Governing wicked problems becomes more challenging as they increase in extent from local to regional or global scales, particularly where institutions are weak or

nonexistent (Walker et al. 2009). Specifically, the trans-boundary status of the disputed South China Sea is a major impediment to effective governance of coral reefs across the region. The Nansha or Spratly Islands are claimed in their entirety by China, Taiwan, and Vietnam and partially by the Philippines, Malaysia, and Brunei. Coral reef research on offshore archipelagos is often conducted during brief expeditions with logistic support from national defense forces, which links scientific activities to disputed claims of sovereignty and rights to offshore oil and gas resources. For example, SCSIO website lists their "comprehensive investigation on the *resources and rights and interest* of the Nansha (Spratly) Archipelagos and its vicinity" (emphasis added) as one of the institutes most noted accomplishments (South China Sea Institute of Oceanology 2012). Zhao and Wu (2008) propose that China should rapidly develop these contested territories to foster high-end tourism, fishing, aquaculture, oil and gas extraction, construction of desalination plants, and especially to establish Chinese sovereignty and strengthen national defense. Calls to establish a multinational marine park in the disputed Nansha (Spratly) Islands (McManus 1994; McManus et al. 2010) have so far been ignored.

There is no quick fix to a wicked problem as complex as securing a sustainable future for coral reefs in China and the South China Sea. We suggest that governance of China's coastal reefs can be improved by increasing public awareness, by legal and institutional reform that promotes progressive change, by providing financial support for training of reef scientists and managers, expanding monitoring of coral reef status and dynamics, and by enforcing existing regulations that protect reef ecosystems. Centralized governance in China is often criticized for being insensitive to local needs and conditions and for promoting uniform solutions that do not achieve their goals (Cao & Wong 2007). Yet, the predominantly top-down structure of China's governance could also provide an opportunity to rapidly implement a transformation in coral reef management. The key missing elements appear to be innovative leadership and a groundswell of public support for environmental protection. It is not too late to protect the remnants of China's mainland reefs, and it would take only a small commitment from the country's enormous economic and scientific resources to lead an international effort with neighboring sovereign states aimed at better management of coral reefs throughout the disputed South China Sea. An initial step is to acknowledge the extent of losses of coral habitat that have occurred so far.

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Supporting Information

Geographic setting and coral biological diversity patterns in the region (Appendix S1), data sources used to quantify declining coral cover (Appendix S2), and further details of environmental trajectories at well-studied sites (Appendix S3) are available online. The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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