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# Biodiversity and China's new Great Wall

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## Abstract

Coastal armouring and the reclamation of intertidal areas through the use of seawalls and other artificial structures has been practiced for thousands of years, but its recent expansion in China and elsewhere in Asia has been unprecedented in its rate and intensity. One result has been the recent loss of nearly two-thirds of tidal flats in the Yellow Sea, a globally unique ecosystem of high ecological value. The severe effects on biodiversity of the recent large-scale coastal land claim activities in China are well documented, yet some recent studies have emphasized the ecological opportunities provided by such artificial coastal infrastructure in China, in some cases suggesting that the ecological impacts of coastal infrastructure should be reconsidered due to benefits to some rocky shore species in a changing climate. This is cause for concern because, while studying the "new ecology" arising from coastal modification is useful, broad conclusions around the ecological role or conservation gains from seawall construction without adequate contextualization underplays the ecological consequences of large-scale coastal land claim, and could potentially undermine efforts to achieve biodiversity conservation. Here, we clarify the characteristics of seawall construction in China and summarize the environmental damage and some broadscale impacts caused by this type of infrastructure expansion on the endangered Yellow Sea tidal flats ecosystem. We also highlight the urgent need for all coastal development plans to consider how coastal wetlands and ecosystem functionality can be maximally retained within the development precinct.

**KEYWORDS**
artificial infrastructure, ecosystem function, mudflat, reclamation, wetland

## 1 | INTRODUCTION

For thousands of years, coastal armouring and conversion of intertidal areas to other land use types, through the use of seawalls and other artificial structures, have been used to facilitate the expansion of human activities along coastlines (e.g., Dugan, Airoldi, Chapman, Walker, & Schlacher, 2011; Han, 2002; Lotze et al., 2005). These processes create new arable land, prevent shoreline retreat through erosion, and defend human coastal activities and property from wave action and storm damage. The physical impacts of such infrastructure on the coastal environment and associated mitigation methods have been extensively studied and reviewed, but the ecological impacts, especially on the surrounding marine environment, remain incompletely understood (Dugan et al., 2011; Gittman, Scyphers, Smith, Neylan, & Grabowski, 2016; Perkins, Ng, Dudgeon, Bonebrake, & Leung, 2015). China is a global epicentre of coastal development and land claims, with more than half of its coastline comprising seawalls that have enclosed and converted vast areas of intertidal flats and shallow sea into new terrestrial-dominated land uses (Luo et al., 2015).

The ecological consequences of such broadscale seawall construction have resulted in some contrasting narratives about biodiversity that need to be clarified. Ma, Melville, et al. (2014) raised concerns about the large-scale loss of coastal wetlands and associated biodiversity and ecosystem services resulting from coastal land claim in China, which has been largely engineered through seawalls. In a rebuttal to this article, Huang, Wang, and Dong (2015) argued that "biodiversity on the new Great Wall is showing a tendency to increase," via settlement of rocky intertidal species. Furthermore, Dong, Huang, Wang, Li, and Wang (2016) showed empirically that seawalls in the Jiangsu coast of China provide habitat for 20 rocky shore species, allowing for greater dispersal of some marine invertebrates across former phylogeographic barriers. Consequently, Dong et al. (2016) concluded that "the biogeography of rocky shore species and other ecological impacts of this infrastructure [*concrete seawalls, riprap*] along global coastlines should be reconsidered under the coupled impacts of climate change and human activities." This call for a general reconsideration of the ecological impacts of seawalls is cause for concern because it inappropriately conveys that coastal land claim may increase biodiversity, perhaps even counterbalancing the negative impacts.

While we do not dispute the empirical findings supporting Huang et al. (2015) and Dong et al.'s (2016) claims, we do challenge any suggestion that there is a positive effect of the newly constructed seawalls and associated developments on "biodiversity" in the coastal tidal flats ecosystem (Dong et al., 2016; Huang et al., 2015). Local increases in some organisms on the seawalls themselves must be set against the full range of deleterious effects on biodiversity at a larger spatial scale. To do otherwise risks the emergence of a narrative that aims to legitimize continued destruction of coastal ecosystems, including the globally important Yellow Sea tidal flats ecosystem (Murray, Ma, & Fuller, 2015). Considering their study area in the Jiangsu coast and the wider Yellow Sea tidal flats ecosystem (Figure 1), here we survey the biodiversity impacts of seawall construction in China, and the attendant risks to the endangered Yellow Sea tidal flats ecosystem.

## 2 | CONTEXTUALIZING SEAWALL CONSTRUCTION

Globally, engineered coastal defence structures are increasingly being used to combat wave damage and sea-level rise, and to create new land for built infrastructure and agriculture. No global estimate is yet available, but in China, 58%–61% of the coastline is now lined by seawall (Guan & A, 2013; Luo et al., 2015). In the USA, only 14% of the coastline is hardened but that equates to twice the absolute length of seawalls found in China (11,560 km in China, 22,842 km in USA; Gittman et al., 2015; Luo et al., 2015). Most of the seawalls in the USA and Europe are intended to protect the existing shoreline (Charlier, Marie Claire, & Selim, 2005; Dugan et al., 2011; Moschella et al., 2005). However, in China, where the rate of seaward expansion of seawalls has doubled in the last decade (Zhang et al., 2013), the primary purpose has been for coastal land claim activities that convert natural intertidal wetlands to new land for development (Figure 2; Han, 2002; Ma, Melville, et al., 2014). This difference in purpose is reflected by the significantly lower rate of coastal wetland reduction in Europe and North America (deltaic plains: 1.5 ± 1.2% loss per year, $n$ = 5) compared to Asia (deltaic plains: 11.5 ± 12.1% loss per year, $n$ = 5) between the mid-1980s and early 2000s (Coleman, Huh, & Braud, 2008; Davidson, 2014; Lotze et al., 2006; Meng et al., 2017).

The Jiangsu coast holds some of the largest intertidal flats in China (Koh & de Jonge, 2014; Wang, Zhu, & Wu, 2002), but an enormous amount of tidal flat conversion has occurred over the last several decades. Along the central Jiangsu coast, 43% of tidal flat conversion between 1977 and 2015 was for aquaculture (Cai, van Vliet, Verburg, & Pu, 2017). Further north in Laizhou Bay in Shandong, most of the eastern coast of the bay has been converted to aquaculture ponds and residential land since the 1990s (Wang et al., 2016). A further 28% of the remaining ~5,017 km$^2$ of tidal flat in Jiangsu was proposed for conversion between 2010 and 2020 (Jiangsu Provincial People's Government Office, 2010), although the actual amount to be reclaimed by 2020 remains uncertain. The increasing scale and rate of transformation of natural tidal wetlands into aquaculture ponds and other development has led to the dominance of relatively "young" seawalls along the China coastline (Figure 1). For example, mean seawall age in the study by Dong et al. (2016) was only 8.4 ± 8.5 years. Some "young" seawalls are constructed illegally (Melville, Chen, & Ma, 2016) and can result in the seawall crumbling during storms and wave surges (Fig. S1; Han, 2002). Such a rapid turnover and seaward expansion of seawalls primarily built to create new land at a large scale in China contrasts with seawalls in Europe and America constructed primarily as static defences for existing coastlines (Asselen, Verburg, Vermaat, & Janse, 2013).

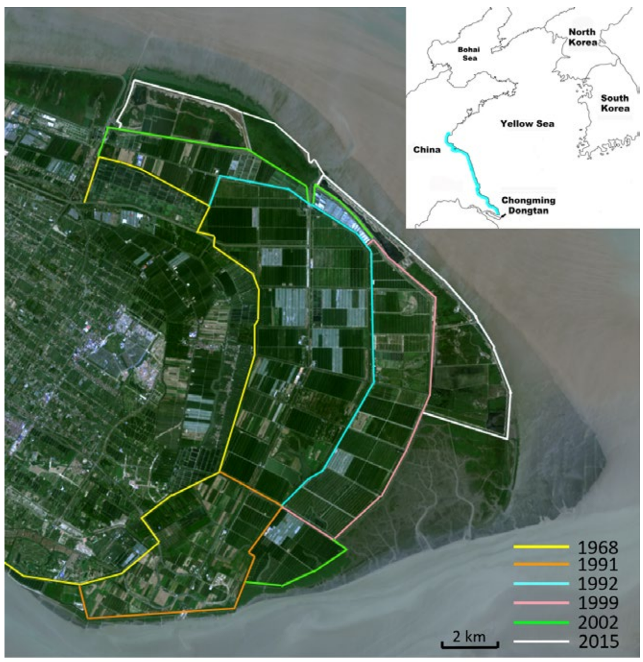


**FIGURE 1** Low-tide satellite image taken on 3 August 2015, showing the rapid advance of the seawall at Chongming Dongtan, Shanghai. This conversion of natural tidal wetlands into aquaculture ponds and arable lands is occurring at an alarming rate in coastal China and South-East Asia (Image courtesy of the U.S. Geological Survey). The inset shows the location of Chongming Dongtan and Jiangsu coast (shaded in cyan) within the Yellow Sea.

**FIGURE 2** An aerial view of the current seawall at Tiaozini of southern Jiangsu Province (upper panel) and Chongming Dongtan (lower panel) of Shanghai, China. The seawall breaks the bare (upper panel) or vegetated (lower panel) upper tidal flat away from the natural intertidal wetlands (left of the seawall) and converts the natural tidal flats into aquaculture ponds and arable land (right of the seawall) (Photographs provided by Chia-Yang Tsai and Shunqi Bo)

Given this large-scale change in the coastal landscape, it is important to consider local projects within this wider context. A number of studies on the impacts of coastal structures on community assemblage focus on communities associated with the surface of the structures themselves, by comparing biodiversity on coastal infrastructures with analogous rocky shores (Dong et al., 2016; Firth et al., 2013; Moschella et al., 2005). However, the effects of coastal infrastructure at a large scale are much broader than its effects on surface assemblages. Coastal infrastructure often causes ecosystem-level changes in the areas surrounding the infrastructure that have cascading biological effects. Thus, it is important to investigate the impact of seawall infrastructure beyond the spatial footprint of the infrastructure itself by including surrounding habitats and comparing the ecological parameters between the modified and original natural ecosystem (Dugan, Hubbard, Rodil, Revell, & Schroeter, 2008; Dugan et al., 2011; Perkins et al., 2015).

## 3 | THE ENDANGERED YELLOW SEA TIDAL FLATS ECOSYSTEM

The Yellow Sea coastal and shallow sea region in East Asia fringes more than 7,000 km of the coastlines of China, North Korea and South Korea (Luo et al., 2015; Murray et al., 2015). This ecosystem supports at least 3,461 species, including 1,069 benthic species, 339 fish species and 150 waterbird species, with many of the 464 Yellow Sea endemic species occurring only in the tidal flats ecosystem (China Coastal Waterbird Census Group, 2015; UNDP/GEF, 2007). The region includes some of the largest and widest tidal flats in the world, stretching up to 36 km offshore with a total tidal flat area of about 18,340 $km^2$ (based on data from the 1990s), almost four times the size of tidal flats in the Wadden Sea (Koh & de Jonge, 2014; Wang et al., 2002; Yang, Wang, & Zhu, 1997). The Yellow Sea tidal flat ecosystem is biologically productive, and important for a wide range of biota. The supra-littoral, upper and some middle intertidal zones are often occupied by saltmarsh plants, which support diverse saltmarsh birds. The remaining area in the middle and most of the lower intertidal zones is predominantly unvegetated (Greenberg et al., 2014; Ma & Ma, 2006; Wang et al., 2002), but full of high densities of benthic invertebrates living in the mud (Table S1). This tidal flat ecosystem provides important ecosystem services worth an estimated US$30 billion per year (MacKinnon, Verkuil, & Murray, 2012). These ecosystem services include storm protection, water purification and food production, in a region that hosts more than 60 million people in the low elevation coastal zone (<10 m above sea level, Murray, Clemens, Phinn, Possingham, & Fuller, 2014).

The influx of two million migratory shorebirds during their annual migration between arctic/subarctic breeding grounds and Asia/Oceania non-breeding areas is a key feature of the Yellow Sea tidal flats ecosystem (Barter, 2002). At least 38 migratory shorebird species occur in the Yellow Sea region in internationally important numbers (over 1% of the flyway population; Barter, 2002; Bai et al., 2015) and rely on the productive tidal flats to rest and refuel not only for the next flight, but also for breeding (Choi et al., 2009; Hua, Piersma, & Ma, 2013; Morrison & Hobson, 2004). For six of these species, almost the entire breeding population refuels by feeding on benthic invertebrates in the Yellow Sea tidal flats during migration stopovers (Barter, 2002; Choi et al., 2017). Four migratory shorebird species that depend heavily on the Yellow Sea's tidal flats are currently considered globally threatened (one critically endangered, three endangered) and 10 others are near threatened (IUCN, 2017).

The tidal flats in the Jiangsu coast, where Dong et al. (2016) conducted most of their study, comprise more than one-third of the remaining tidal flats in the Yellow Sea region and form a critical part of the Yellow Sea tidal flat ecosystem (Koh & de Jonge, 2014). This section of tidal flats supports at least 140 benthic species, 105 waterbird species, and 132 fish, shrimp, crab and cephalopoda species (China Coastal Waterbird Census Group, 2015; Liu, 2014).

Almost two-thirds (~65%) of the Yellow Sea tidal flat area has been lost over the last five decades (Murray et al., 2014), mainly due to the seawalls associated with land claim activities primarily for aquaculture and salt ponds, and also agriculture, urbanization and industrial activities (Cai et al., 2017; Suo, Lin, & Zhang, 2016; Wang et al., 2016). Seawalls introduce a new habitat type (hard substrate) into a predominantly soft-sediment system, and unsurprisingly this facilitates the dispersal of some rocky intertidal species (Dong et al., 2016). Yet a much bigger effect of the land claim process is the substantial changes to tidal flows resulting in loss of saltmarsh and tidal flats (Chen et al., 2016; Choi, 2014; Han, 2002; The State Oceanic Administration of China, 2003), with flow-on effects to the waterbirds, songbirds, fishes, insects, nematodes and benthic organisms associated with the system (Greenberg et al., 2014; Koh & Khim, 2014; Lotze et al., 2005; Ma & Ma, 2006; Wu, Fu, Lu, & Chen, 2005). The altered and disturbed tidal flat system may also promote the spread of non-native species (Ma, Gan, Choi, & Li, 2014). Further, the area of intertidal habitat lost due to seawall construction is far greater than the area of new habitat created. For example, in Saemanguem, South Korea, a 33-km-long sea wall was constructed which destroyed 400 $km^2$ of intertidal habitat and the diverse assemblages of plants and animals supported by the system (Moores, Rogers, Rogers, & Hansbro, 2016). If we assume the seawall was on average 32.5 m wide (Beemsterboer, Christophe, Scheepjens, Veldman, & van Wielen, 2012), the area of new hard-substrate habitat created by the seawall would be just around 1 $km^2$ or an area 0.3% the size of the lost intertidal habitat.

## 4 | ECOLOGICAL CONSEQUENCES OF TIDAL FLAT LOSS AND SEAWALL CONSTRUCTION

Seawall construction has led to the loss of at least 10,520 $km^2$ of tidal flat and shallow sea in the Yellow Sea since the 1960s (Koh & Khim, 2014; Lee, Kim, & Lee, 2005; Piersma et al., 2016). Assuming a mean density of 623–820 benthic organisms per $m^2$ of sediment (Table S1), this would have resulted in the loss of 6.6–8.6 trillion ($10^{12}$) individuals, or 115,720–189,360 tonnes (ash-free dry mass) of sediment-specialist organisms. This estimate refers only to standing stock and would be higher if the annual productivity of both natural and cultivated benthic organisms was considered (e.g., 1,000 $km^2$ intertidal flat could potentially yield 8,800 tonnes of cultivated Venus clams (Family: Veneridae) annually; Koh & Khim, 2014). Changes in the abundance of common species have profound ecosystem consequences (Gaston & Fuller, 2008), and the reduction in biomass and other ecosystem services caused by land claim projects in China could cost up to US$ 177 billion per year (Chen & Zhang, 2000). In addition, loss of Yellow Sea tidal flat habitat is the most likely explanation for the drastic declines of migratory shorebird populations within the East Asian–Australasian Flyway, which are most pronounced for species using the Yellow Sea as a refuelling site (Amano, Szekely, Koyama, Amano, & Sutherland, 2010; Murray et al., 2017; Piersma et al., 2016, 2017; Studds et al., 2017). This ecosystem has been classified as Endangered, using International Union for Conservation of Nature Red List of Ecosystems criteria due to widespread loss of habitat, pollution, algal and jellyfish blooms, hypoxic dead zones, and documented declines in fauna (Murray et al., 2015).

Constructing artificial structures in the intertidal zone has complex ecological consequences that may compound the ecosystem-scale impacts of tidal flat loss. Effects at the community level require scrutiny beyond simplistic measures of biodiversity, such as species richness. Seawalls and other artificial structures are often colonized by introduced species and may change the distribution of locally abundant species (Bacchiocchi & Airoldi, 2003; Bulleri & Chapman, 2010) as occurred in the Wadden Sea, where species richness did not change significantly following loss of transitional saltmarsh habitat because the loss of native species was balanced by the gain of introduced species (Lotze et al., 2005). But the abundance of threatened species declined severely and species composition shifted markedly with “large, long-lived, slow-growing and specialist species” (e.g., mammals and birds) being depleted, while “small, short-lived, fast-growing and generalist species” (e.g., polychaetes, green algae) increased or colonized (Lotze et al., 2005). This example highlights that sole use of species richness is not an appropriate measure of biodiversity within this context as it can mask other measures more important for appraising ecosystem state, such as functional or phylogenetic diversity (Cadotte, Carscadden, & Mirotchnick, 2011).

## 5 | RESTORATION AND MITIGATIONS

None of the preceding discussion negates the need to design anthropogenic infrastructure that is sensitive to the needs of biodiversity, but it is important that environmental harm is minimized in the process. Further, carefully designed anthropogenic infrastructure can play an important part in avoiding further loss of biodiversity and ecosystem function while re-establishing the components of assemblages that have been lost, rather than attracting non-native species (Chapman & Underwood, 2011; Murcia et al., 2014).

Intertidal habitat restoration could help mitigate ongoing biodiversity losses. This approach is challenging in China due to the potential market value of land adjacent to the coast and the importance of these areas for national food security. However, the aquaculture and salt ponds that dominate large parts of the coastal landscape are physically similar to natural tidal flats, potentially making intertidal flat restoration easier than on other more developed land. In areas where dismantling and realigning the seawall is feasible (Dugan et al., 2011), attempts could be made to reintroduce appropriate vegetation, aquaculture and fisheries in these newly established intertidal areas (Primavera, 2005). In areas where restoration is less feasible, such as on reclaimed areas that have been pushed towards the low-tide mark, vegetation plantings or a mix of hard engineering and plantings (Gittman, Peterson, et al., 2016) may be deployed. This approach has become increasingly popular in China (Luo et al., 2015) and, although less ideal, may still present useful opportunities for increasing ecosystem functionality, such as provision of nursery habitat by marshes, in already-reclaimed areas.

Even when well resourced, some conservation efforts have failed to restore former coastal ecosystem structure and function (Lotze et al., 2006) and thus, any decisions to convert coastal wetlands to other uses should consider the possibility that restoration may be difficult or impossible. Further, in the future baseline ecological data should be collected more regularly at proposed land claim areas to allow proper evaluation of mitigations, as it is not always clear what has been lost following reclamation. It is also important to note that mitigations seldom provide ecological benefits equivalent to natural ones and therefore cannot and should not be used to justify further destruction of intertidal flats (Ma et al., 2004; Perkins et al., 2015). A comprehensive interdisciplinary spatial planning exercise identifying the best solutions in various sites based on the socio-economic and biodiversity costs, benefits and likelihood to succeed could be useful to assist decision-makers in taking the best actions to benefit both people and nature in the Yellow Sea and the rest of Chinese coastal tidal flat ecosystems.

There have been encouraging signs that coastal wetland conservation is increasingly a priority in China. Recently, 14 tidal flats in the Bohai Sea and Yellow Sea coast were placed on the tentative list of World Heritage sites, eight of which are currently unprotected (UNESCO, 2017). Nonetheless, further land claim activities or seawall repairing and strengthening in the Chinese Yellow Sea seem inevitable, with significant further seawall construction already scheduled and approved (at least 3,387 km$^2$ of the Chinese Yellow Sea tidal flats is proposed to be converted between 2005 and 2020; Wang, Liu, Li, & Su, 2014). Therefore, there will be an increasing need to protect disappearing tidal flat ecosystems, to restore lost habitats and to mitigate irreversible losses.

## 6 | FINAL REMARKS

The role of science in biodiversity conservation is entrenched in political processes which are driven by human values; hence, science can be used not only to inform conservation policy but also to legitimize political decisions that drive biodiversity loss (Innerarity, 2013). In this context, scientific studies can inadvertently advance agendas that compete with biodiversity conservation goals, through the construction of social meaning that creates political leverage (Neff & Hueter, 2013). In the case of the Yellow Sea region, we fear that accepting and promoting seawalls and associated fauna as a novel ecosystem (degraded environments that represent a "new normal" for that ecosystem; Zhang, Dearing, Tong, & Hughes, 2016) could lead to just such outcomes and contribute to acceptance of further intertidal land claim projects. We do not contest the need to study novel ecosystems emerging with the widespread modification of the Yellow Sea coastline, they are fascinating and important. However, we caution against an uncritical narrative focused on these localized ecosystems, as efforts to achieve effective biodiversity conservation could be hampered when local increases in a few species are not discussed in the context of the collapse of an entire ecosystem.

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## REFERENCES

Amano, T., Szekely, T., Koyama, K., Amano, H., & Sutherland, W. J. (2010). A framework for monitoring the status of populations: An example from wader populations in the East Asian-Australasian flyway. *Biological Conservation*, *143*, 2238–2247. https://doi.org/10.1016/j.biocon.2010.06.010

Asselen, S. V., Verburg, P. H., Vermaat, J. E., & Janse, J. H. (2013). Drivers of wetland conversion: a global meta-analysis. *PLoS ONE*, *8*, e81292. https://doi.org/10.1371/journal.pone.0081292

Bacchiocchi, F., & Airoldi, L. (2003). Distribution and dynamics of epibiota on hard structures for coastal protection. *Estuarine, Coastal and Shelf Science*, *56*, 1157–1166. https://doi.org/10.1016/S0272-7714(02)00322-0

Bai, Q., Chen, J., Chen, Z., Dong, G., Dong, J., Dong, W., … Zeng, X. (2015). Identification of coastal wetlands of international importance for waterbirds: A review of China Coastal Waterbird Surveys 2005–2013. *Avian Research*, *6*, 1–16.

Barter, M. (2002) *Shorebirds of the Yellow Sea: Importance, threats and conservation status*. Canberra, Australia: Wetlands International. Global Series 9, International Wader Studies 12.

Beemsterboer, D., Christophe, J., Scheepjens, R., Veldman, M., & dervan Wielen, V. (2012). *Tiaozini land reclamation: Preliminary port area design*. Delft: University of Technology, p. 188.

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology*, *47*, 26–35. https://doi.org/10.1111/jpe.2010.47.issue-1

Cadotte, M. W., Carscadden, K., & Mirotchnick, N. (2011). Beyond species: Functional diversity and the maintenance of ecological processes and services. *Journal of Applied Ecology*, *48*, 1079–1087. https://doi.org/10.1111/jpe.2011.48.issue-5

Cai, F., van Vliet, J., Verburg, P. H., & Pu, L. (2017). Land use change and farmer behavior in reclaimed land in the middle Jiangsu coast, China. *Ocean & Coastal Management*, *137*, 107–117. https://doi.org/10.1016/j.ocecoaman.2016.12.015

Chapman, M. G., & Underwood, A. J. (2011). Evaluation of ecological engineering of "armoured" shorelines to improve their value as habitat. *Journal of Experimental Marine Biology and Ecology*, *400*, 302–313. https://doi.org/10.1016/j.jembe.2011.02.025

Charlier, R. H., Marie Claire, P. C., & Selim, M. (2005). Panorama of the history of coastal protection. *Journal of Coastal Research*, *21*, 79–111. https://doi.org/10.2112/03561.1

Chen, Y., Dong, J., Xiao, X., Zhang, M., Tian, B., Zhou, Y., … Ma, Z. (2016). Land claim and loss of tidal flats in the Yangtze Estuary. *Scientific Reports*, *6*, 24018. https://doi.org/10.1038/srep24018

Chen, Z., & Zhang, X. (2000). Value of ecosystem services in China. *Chinese Science Bulletin*, *45*, 870–876. https://doi.org/10.1007/BF02886190

China Coastal Waterbird Census Group (2015) China coastal waterbird census report (Jan. 2010–Dec. 2011). Hong Kong: Hong Kong Birdwatching Society Limited.

Choi, K. (2014). Morphology, sedimentology and stratigraphy of Korean tidal flats – Implications for future coastal managements. *Ocean & Coastal Management*, *102*, 437–448. https://doi.org/10.1016/j.ocecoaman.2014.07.009

Choi, C.-Y., Battley, P. F., Potter, M. A., Ma, Z., Melville, D. S., & Sukkaewmanee, P. (2017). How migratory shorebirds selectively exploit prey at a staging site dominated by a single prey species. *The Auk*, *134*, 76–91. https://doi.org/10.1642/AUK-16-58.1

Choi, C. Y., Gan, X. J., Ma, Q., Zhang, K. J., Chen, J. K., & Ma, Z. J. (2009). Body condition and fuel deposition patterns of calidrid sandpipers during migratory stopover. *Ardea*, *97*, 61–70. https://doi.org/10.5253/078.097.0108

Coleman, J. M., Huh, O. K., & Braud, D. (2008). Wetland loss in world deltas. *Journal Of Coastal Research*, *24*, 1–14. https://doi.org/10.2112/05-0607.1

Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, *65*, 934–941. https://doi.org/10.1071/MF14173

Dong, Y.-W., Huang, X.-W., Wang, W., Li, Y., & Wang, J. (2016). The marine 'great wall' of China: local- and broad-scale ecological impacts of coastal infrastructure on intertidal macrobenthic communities. *Diversity and Distributions*, *22*, 731–744. https://doi.org/10.1111/ddi.2016.22.issue-7

Dugan, J. E., Airoldi, L., Chapman, M. G., Walker, S. J., & Schlacher, T. (2011). Estuarine and Coastal Structures: Environmental Effects, A Focus on Shore and Nearshore Structures. Treatise on Estuarine and Coastal Science, Vol 8: Human-Induced Problems (Uses and Abuses), 17–41.

Dugan, J. E., Hubbard, D. M., Rodil, I. F., Revell, D. L., & Schroeter, S. (2008). Ecological effects of coastal armoring on sandy beaches. *Marine Ecology-an Evolutionary Perspective*, *29*, 160–170. https://doi.org/10.1111/j.1439-0485.2008.00231.x

Firth, L. B., Thompson, R. C., White, F. J., Schofield, M., Skov, M. W., Hoggart, S. P. G., … Hawkins, S. J. (2013). The importance of water-retaining features for biodiversity on artificial intertidal coastal defence structures. *Diversity and Distributions*, *19*, 1275–1283. https://doi.org/10.1111/ddi.2013.19.issue-10

Gaston, K. J., & Fuller, R. A. (2008). Commonness, population depletion and conservation biology. *Trends in Ecology & Evolution*, *23*, 14–19. https://doi.org/10.1016/j.tree.2007.11.001

Gittman, R. K., Fodrie, F. J., Popowich, A. M., Keller, D. A., Bruno, J. F., Currin, C. A., … Piehler, M. F. (2015). Engineering away our natural defenses: An analysis of shoreline hardening in the US. *Frontiers in Ecology and the Environment*, *13*, 301–307. https://doi.org/10.1890/150065

Gittman, R. K., Peterson, C. H., Currin, C. A., Fodrie, F. J., Piehler, M. F., & Bruno, J. F. (2016). Living shorelines can enhance the nursery role of threatened estuarine habitats. *Ecological Applications*, *26*, 249–263. https://doi.org/10.1890/14-0716

Gittman, R. K., Scyphers, S. B., Smith, C. S., Neylan, I. P., & Grabowski, J. H. (2016). Ecological Consequences of Shoreline Hardening: A Meta-Analysis. *BioScience*, *66*, 763–773. https://doi.org/10.1093/biosci/biw091

Greenberg, R., Cardoni, A., Ens, B. J., Gan, X., Isacch, J. P., Koffijberg, K., & Loyn, R. (2014). The distribution and conservation of birds of coastal salt marshes. In B. Maslo & J. L. Lockwood (Eds.), *Coastal conservation* (pp. 180–242). Cambridge: Cambridge University Press.

Guan, D. M., & A, D. (2013) *Study on the national marine functional zoning: general report on the national marine functional zoning research (2011-2020)*. Beijing: Ocean Press.

Han, M. (2002). Human influences on muddy coasts. In T. Healy, Y. Wang & J.-A. Healy (Eds.), *Muddy coasts of the world: Processes, deposits and function* (pp. 293–318). Elsevier Science B.Y., Amsterdam. https://doi.org/10.1016/S1568-2692(02)80086-9

Hua, N., Piersma, T., & Ma, Z. (2013). Three-phase fuel deposition in a long-distance migrant, the Red Knot (*Calidris canutus piersmai*), before the flight to high arctic breeding grounds. *PLoS ONE*, *8*, e62551. https://doi.org/10.1371/journal.pone.0062551

Huang, X. W., Wang, W., & Dong, Y. W. (2015). Complex ecology of China's seawall. *Science*, *347*, 1079. https://doi.org/10.1126/science.347.6226.1079-b

Innerarity, D. (2013). Power and knowledge: The politics of the knowledge society. *European Journal of Social Theory*, *16*, 3–16. https://doi.org/10.1177/1368431012468801

IUCN (2017) *The IUCN Red List of Threatened Species. Version 2017-1*. Retrieved from: www.iucnredlist.org (accessed 5-April 2017).

Jiangsu Provincial People's Government Office (2010) Notification of coastal reclamation and development plan. Provincial Development and Reform Commission Office of Jiangsu Province), Jiangsu, China.

Koh, C.-H., & de Jonge, V. N. (2014). Stopping the disastrous embankments of coastal wetlands by implementing effective management principles: Yellow Sea and Korea compared to the European Wadden Sea. *Ocean & Coastal Management*, *102*, 604–621. https://doi.org/10.1016/j.ocecoaman.2014.11.001

Koh, C.-H., & Khim, J. S. (2014). The Korean tidal flat of the Yellow Sea: Physical setting, ecosystem and management. *Ocean & Coastal Management*, *102*, 398–414. https://doi.org/10.1016/j.ocecoaman.2014.07.008

Lee, M. B., Kim, N.-S., & Lee, G.-R. (2005). Reclamations and coastal changes with case study on Yeonmju and Cheolsan in the west coast of North Korea. *Journal of the Korean Geomorphological Association*, *12*, 99–110.

Liu, P. (2014). The ecology and biological resources of the radial sand ridges. In Y. Wang (Ed.), *South Yellow Sea radial sand ridges environment and resources* (pp. 380–416). Beijing: Ocean Press.

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., … Jackson, J. B. C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, *312*, 1806–1809. https://doi.org/10.1126/science.1128035

Lotze, H. K., Reise, K., Worm, B., van Beusekom, J., Busch, M., Ehlers, A., … Wolff, W. J. (2005). Human transformations of the Wadden Sea ecosystem through time: A synthesis. *Helgoland Marine Research*, *59*, 84–95. https://doi.org/10.1007/s10152-004-0209-z

Luo, S. L., Cai, F., Liu, H. J., Lei, G., Qi, H. S., & Su, X. Z. (2015). Adaptive measures adopted for risk reduction of coastal erosion in the People's Republic of China. *Ocean & Coastal Management*, *103*, 134–145. https://doi.org/10.1016/j.ocecoaman.2014.08.008

Ma, Z. J., Gan, X. J., Choi, C. Y., & Li, B. (2014). Effects of invasive Cordgrass on presence of marsh grassbird in an area where it is not native. *Conservation Biology*, *28*, 150–158. https://doi.org/10.1111/cobi.12172

Ma, Z. J., Li, B., Zhao, B., Jing, K., Tang, S. M., & Chen, J. K. (2004). Are artificial wetlands good alternatives to natural wetlands for waterbirds? A case study on Chongming Island, China. *Biodiversity and Conservation*, *13*, 333–350. https://doi.org/10.1023/B:BIOC.0000006502.96131.59

Ma, Z. J., & Ma, Y. A. (2006). *Chongming Dongtan: A Wetland of International Importance*. Beijing: Chinese Forestry Publishing House.

Ma, Z., Melville, D. S., Liu, J., Chen, Y., Yang, H., Ren, W., … Li, B. (2014). Rethinking China's new great wall. *Science*, *346*, 912–914. https://doi.org/10.1126/science.1257258

MacKinnon, J., Verkuil, Y. I., & Murray, N. (2012). *IUCN situation analysis on East and Southeast Asian intertidal habitats, with particular reference to the Yellow Sea (including the Bohai Sea). Occasional Paper of the IUCN Species Survival Commission No. 47*. IUCN, Gland, Switzerland and Cambridge, UK.

Melville, D. S., Chen, Y., & Ma, Z. (2016). Shorebirds along the Yellow Sea coast of China face an uncertain future – a review of threats. *Emu*, *116*, 100–110. https://doi.org/10.1071/MU15045

Meng, W., Hu, B., He, M., Liu, B., Mo, X., Li, H., … Zhang, Y. (2017). Temporal-spatial variations and driving factors analysis of coastal reclamation in China. *Estuarine, Coastal and Shelf Science*, *191*, 39–49. https://doi.org/10.1016/j.ecss.2017.04.008

Moores, N., Rogers, D. I., Rogers, K., & Hansbro, P. M. (2016). Reclamation of tidal flats and shorebird declines in Saemangeum and elsewhere in the Republic of Korea. *Emu*, *116*, 136–146. https://doi.org/10.1071/MU16006

Morrison, R. I. G., & Hobson, K. A. (2004). Use of body stores in shorebirds after arrival on High-Arctic breeding grounds. *The Auk*, *121*, 333–344. https://doi.org/10.2307/4090397

Moschella, P. S., Abbiati, M., Aberg, P., Airoldi, L., Anderson, J. M., Bacchiocchi, F., ... Hawkins, S. J. (2005). Low-crested coastal defence structures as artificial habitats for marine life: Using ecological criteria in design. *Coastal Engineering*, *52*, 1053–1071. https://doi.org/10.1016/j.coastaleng.2005.09.014

Murcia, C., Aronson, J., Kattan, G. H., Moreno-Mateos, D., Dixon, K., & Simberloff, D. (2014). A critique of the 'novel ecosystem' concept. *Trends in Ecology & Evolution*, *29*, 548–553. https://doi.org/10.1016/j.tree.2014.07.006

Murray, N. J., Clemens, R. S., Phinn, S. R., Possingham, H. P., & Fuller, R. A. (2014). Tracking the rapid loss of tidal wetlands in the Yellow Sea. *Frontiers in ecology and the environment*, *12*, 267–272. https://doi.org/10.1890/130260

Murray, N. J., Ma, Z., & Fuller, R. A. (2015). Tidal flats of the Yellow Sea: A review of ecosystem status and anthropogenic threats. *Austral Ecology*, *40*, 472–481. https://doi.org/10.1111/aec.2015.40.issue-4

Murray, N. J., Marra, P. P., Fuller, R. A., Clemens, R. S., Dhanjal-Adams, K., Gosbell, K. B., ... Studds, C. E. (2017). The large-scale drivers of population declines in a long-distance migratory shorebird. Ecography, https://doi.org/10.1111/ecog.02957.

Neff, C., & Hueter, R. (2013). Science, policy, and the public discourse of shark "attack": A proposal for reclassifying human–shark interactions. *Journal of Environmental Studies and Sciences*, *3*, 65–73. https://doi.org/10.1007/s13412-013-0107-2

Perkins, M. J., Ng, T. P. T., Dudgeon, D., Bonebrake, T. C., & Leung, K. M. Y. (2015). Conserving intertidal habitats: What is the potential of ecological engineering to mitigate impacts of coastal structures? *Estuarine Coastal and Shelf Science*, *167*, 504–515. https://doi.org/10.1016/j.ecss.2015.10.033

Piersma, T., Chan, Y.-C., Mu, T., Hassell, C. J., Melville, D. S., Peng, H.-B., ... Wilcove, D. S. (2017). Loss of habitat leads to loss of birds: Reflections on the Jiangsu, China, coastal development plans. *Wader Study*, *124*, 93–98.

Piersma, T., Lok, T., Chen, Y., Hassell, C. J., Yang, H.-Y., Boyle, A., ... Ma, Z. (2016). Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. *Journal of Applied Ecology*, *53*, 479–490. https://doi.org/10.1111/1365-2664.12582

Primavera, J. H. (2005). Mangroves and Aquaculture in Southeast Asia. In V. T. Sulit, M. E. T. Aldon, I. T. Tendencia, S. B. Alayon & A. S. Ledesma (Eds.), *Report of the Regional Technical Consultation for the Development of Code of Practice for Responsible Aquaculture in Mangrove Ecosystems*, (pp. 25–37). Iloilo: SEAFDEC Aquaculture Department.

Studds, C. E., Kendall, B. E., Murray, N. J., Wilson, H. B., Rogers, D. I., Clemens, R. S., ... Fuller, R. A. (2017). Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nature Communications*, *8*, 14895. https://doi.org/10.1038/ncomms14895

Suo, A., Lin, Y., & Zhang, M. (2016). Regional difference of coastal land use around the Bohai sea based on remote sensing images. *Multimedia Tools and Applications*, *75*, 12061–12075. https://doi.org/10.1007/s11042-016-3334-1

The State Oceanic Administration of China (2003) Bulletin of Marine Environmental Status of China for the year of 2002. In, Beijing China.

UNDP/GEF (2007). The Yellow Sea: Analysis of environmental status and trends, volume 1, part I: National reports - China. In, p. 316, Ansan: UNDP/GEF Yellow Sea Project.

UNESCO (2017) *The Coast of the Bohai Gulf and the Yellow Sea of China*. Retrieved from: http://whc.unesco.org/en/tentativelists/6189/ (accessed 5-Apr 2017).

Wang, W., Liu, H., Li, Y., & Su, J. (2014) Development and management of land reclamation in China. *Ocean & Coastal Management*, *102*, Part B, 415–425. https://doi.org/10.1016/j.ocecoaman.2014.03.009

Wang, Q., Zhong, S., Li, X., Zhan, C., Wang, X., & Liu, P. (2016). Supratidal Land Use Change and Its Morphodynamic Effects along the Eastern Coast of Laizhou Bay during the Recent 50 Years. *Journal of Coastal Research*, *74*, 83–94. https://doi.org/10.2112/SI74-008.1

Wang, Y., Zhu, D., & Wu, X. (2002). Tidal flats and associated muddy coast of China. In T. Healy, Y. Wang & J.-A. Healy (Eds.), *Muddy coasts of the world: Processes, deposits and function* (pp. 319–346). Amsterdam: Elsevier Science B.Y. https://doi.org/10.1016/S1568-2692(02)80087-0

Wu, J., Fu, C., Lu, F., & Chen, J. (2005). Changes in free-living nematode community structure in relation to progressive land reclamation at an intertidal marsh. *Applied Soil Ecology*, *29*, 47–58. https://doi.org/10.1016/j.apsoil.2004.09.003

Yang, B., Wang, Y., & Zhu, D. (1997). The tidal flat resource of China. *Journal of natural resources*, *12*, 307–316.

Zhang, K., Dearing, J. A., Tong, S. L., & Hughes, T. P. (2016). China's degraded environment enters a new normal. *Trends in Ecology & Evolution*, *31*, 175–177. https://doi.org/10.1016/j.tree.2015.12.002

Zhang, X., Yan, C., Xu, P., Dai, Y., Yan, W., Ding, X., ... Mei, D. (2013). Historical evolution of tidal flat reclamation in the Jiangsu coastal areas. *Acta Geographica Sinica*, *68*, 1549–1558.

**BIOSKETCH**

This article was the result of collaboration between current and former members of the Fuller lab, led by **Richard A. Fuller**. We are a group of researchers interested in how people have affected nature and how some of their destructive effects can best be reversed. Much of our current work focuses on the distribution and conservation of tidal flat ecosystems globally, utilizing methods such as remote sensing to map tidal flats on multiple spatial and temporal scales.

Author Contributions: R.A.F. conceived the idea; C-Y.C. collated the data; C-Y.C., M.V.J. and E.G.-C. drafted the manuscript; X.G. prepared the figures; all authors commented and contributed to the final manuscript.

## SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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