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Review

Shorebirds along the Yellow Sea coast of China face an uncertain future – a review of threats

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Abstract. Wetlands along the Yellow Sea coast of China, which are a major staging area for shorebirds in the East Asian–Australasian Flyway, are in a state of crisis that threatens the future of this migration system. Populations of many shorebirds in the Flyway have declined in recent decades at a time when there has been widespread loss of habitat and degradation of coastal wetlands around the Yellow Sea. Here we examine current threats to coastal wetlands along China's Yellow Sea coast based on field surveys in 2013 and 2014 and a review of the literature. Intertidal habitats have been lost to land claim or degraded through aquaculture and harvesting, as well as gross pollution and invasion of exotic *Spartina*, all of which have negatively affected shorebird foraging, roosting and breeding sites. Planned further development, if unchecked, will result in the loss of most of the remaining intertidal area, which is likely to result in calamitous declines in populations of many shorebirds. There is a need for immediate action to curb future land claim and to develop an integrated coastal management strategy. Further research on applied aspects of shorebird ecology is urgently needed to inform future policy development and decision making.

Additional keywords: aquaculture, conservation, land claim, migration, waders, wetlands.

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Without policy change it is likely that most coastal wetlands will disappear within the next 10 to 20 years, especially in East China. (World Bank 1992)

Introduction[1]

Wetlands provide high-value ecological services and support abundant biodiversity but are under serious threat worldwide. Coastal wetlands along China's Yellow Sea coast are in crisis (MacKinnon *et al*. 2012; Ma *et al*. 2014) and the tidal flats have been identified as an endangered ecosystem under IUCN criteria (Murray *et al*. 2015). Murray *et al*. (2014) estimate the area of China's tidal flats were ~5398 km^2 in the 1950s, ~2677 km^2 in the 1980s and, by the 2000s, had decreased to 1611 km^2, with the average annual rate of loss since the 1980s being 1.8% per annum (p.a.) Piersma *et al.* (2016), however, report an annual loss of 4% between 1990 and 2013. Nevertheless, the rate of loss is increasing; rates of land claim, which were ~400 km^2 p.a. in the period 2006–10, are expected to be ~600 km^2 p.a. in the period 2011–20 (CCICED 2010); Jiangsu Province alone has plans to reclaim 1800 km^2 between 2009 and 2020 (Zou 2009). The World Bank's 1992 prediction (above) has nearly been realised, albeit a few years later than forecast.

Many shorebirds use coastal wetlands – and some species depend on them exclusively – during the non-breeding season and for stopovers during migration. Early accounts of China's coasts recorded the presence of shorebirds (Swinhoe 1871; David and Oustalet 1877; Styan 1891; La Touche 1931–34; Shaw 1936) and Cheng (1976, 1987) summarised the distribution of all species. However, it was not until Mark Barter and colleagues undertook their pioneering surveys, which covered much of the coast, during the 1990s that the truly international importance of China's Yellow Sea coast for shorebirds was recognised, it being the major stopover site for most species of shorebird using the East Asian–Australasian Flyway (Barter 2002). Barter (2002) estimated that at least 2 million shorebirds used the Yellow Sea coast on northward migration, and identified 27 sites that met Ramsar criteria for designation as wetlands of international importance, including 10 in China.

Despite major changes to many coastal areas surveyed by Mark Barter (Yang *et al*. 2011), and reported declines in many shorebird populations within the East Asian–Australasian Flyway (Amano *et al*. 2010; Rogers *et al*. 2011; Wilson *et al.* 2011; MacKinnon *et al*. 2012; Australian Government 2015*a*, 2015*b*; Choi *et al*. 2015; Hansen *et al*. 2015), current surveys by Fudan

[1]Extensive supplementary material is available at http://www.publish.csiro.au/paper/MU15045.htm; not all of this is referenced in this text.

University (Y. Chen, unpublished data) and the China Coastal Waterbird Census team (Bai *et al*. 2015; Hua *et al*. 2015) show that almost the entire soft shore of China's Yellow Sea coast meets Ramsar listing criteria as either staging sites, wintering grounds or breeding grounds, this being reflected in current proposals for designating 'red lines' (L. Zhang *et al*., unpubl. data). Red lining is a planning mechanism to demarcate areas for 'the implementation of strict protection with regard to natural ecosystem services, environmental quality and security, and natural resource utilization' (Li 2014).

Shorebirds on China's Yellow Sea coast are suffering not only from direct habitat loss as a result of land claim but also degradation of the remaining intertidal habitat from a wide variety of human activities that are affecting foraging, roosting and breeding sites over large areas. In this paper we examine developments along China's Yellow Sea coast and the potential effects on shorebirds, based on field surveys in 2013 and 2014 and a review of the literature, and identify priority actions to safeguard remaining habitat.

The Yellow Sea coast

China's Yellow Sea coast extends ~7000 km from the estuary of the Yalu River (39°48′N, 124°09′E) on the border with North Korea, south to the estuary of the Yangtze (Changjiang) River (31°24′N, 121°56′E; Fig. 1). The mouth of the Bohai Sea is formed by the rocky Shandong and Liaodong Peninsulas; most of the remaining coast comprises soft shores formed by discharge from rivers, the two most important being the Yellow (Huanghe) and Yangtze Rivers, which historically, together, carried ~11.5% of all sediment discharged to the world's oceans (Milliman and Meade 1983) (Fig. S1 in Supplementary material, available online only).

The extensive alluvial coast of Jiangsu Province and the Dongsha Shoals are derived from sediment from both the Yangtze and the Yellow Rivers. However, both rivers have changed. The Yangtze's flow is now directed southwards so its sediment load is carried to Hangzhou Bay, whereas the Yellow River made a spectacular 90° course change in 1855 so that it now discharges into the Bohai Sea. The coast of Jiangsu Province now has very little sediment discharge and is largely relying on historical deposits; since the Yellow River stopped discharging off Jiangsu the northern coast of the province has eroded some 17 km inland (Wang and Aubrey 1987). However, the central coastal area is protected by the extensive Dongsha Shoals, and reworking of existing sediments results in an annual growth to the Jiangsu coast of ~13.3 km^2 (Wang and Wall 2010).

All rivers flowing to the Yellow Sea have been heavily modified through damming, and extensive water abstraction such that flows are now severely reduced, as is transport of sediment to the coast. The Yellow River now carries only ~10.7% of the suspended solid load it did in the 1950s and, overall, sediment supply is insufficient to counter erosion in the old abandoned delta lobes (Yu *et al*. 2013). There are ~50 000 dams on the Yangtze River and its tributaries (Yang *et al*. 2005), and there was a 50% reduction in sediment load reaching the sea between 1965 and 2002. Sediment discharge has dropped a further 70% since 2003 when the Three Gorges Dam was completed (Dai *et al*. 2014).

Historically, the soft coast would have been backed by saltmarsh, with the reed *Phragmites australis* further inland. Storm surges would have brought floods of sea water resulting in hypersaline flats at the top of the beach, as still found in a few areas in Laizhou Bay, Shandong Province (Fig. S2 in Supplementary material). The Yellow Sea coast has been so modified by human activity for so long that probably no natural saltmarsh communities remain (Yang and Chen 1995) (Fig. S3 in Supplementary material). Saltmarshes would previously have provided ample roosting sites for shorebirds, as well as breeding habitats for species such as Common Redshank (*Tringa totanus*), Far Eastern Oystercatcher (*Haematopus* [*ostralegus*] *osculans*) and Saunders' Gull (*Larus saundersi*) (Fig. S4 in Supplementary material).

Common Cordgrass (*Spartina anglica*) was first introduced to Jiangsu Province in 1963; the larger, more aggressive, Smooth Cordgrass (*S. alterniflora*) was introduced to Jiangsu in 1979 and has spread along more than 400 km of the coast and, by the early 2000s, occurred in bands up to 4 km wide (Zhang *et al*. 2004). Smooth Cordgrass has also been planted at several sites around the Bohai Sea and, although winter sea-ice seems to be slowing its spread, it is encroaching quite rapidly in some areas, such as at Tianjin Municipality, and at Nanpu, Hebei Province, which is the main staging area for Red Knots (*Calidris canutus*) (Rogers *et al*. 2010). The spread of *Spartina* has negatively affected shorebirds by removing roosting sites and smothering foraging grounds, as well as potentially changing sediment conditions in adjacent intertidal areas (Gan *et al*. 2009; Ge *et al*. 2009); shellfishers also are becoming increasingly concerned about the loss of fishing grounds.

Coastal development policies

China began reform and 'opening-up' in 1978, at which time it moved from an even policy for economic development across the country to one favouring development in coastal regions, initially through the development of special economic zones (SEZs), then more generally. In 1988 the 'economic development strategy of the coastal region' was formally named (Tian 2001). The coastal provinces have prospered dramatically (He *et al*. 2014); for example, Jiangsu Province accounts for 1% of the total land area of China, 6% of the population and 10% of the gross domestic product (GDP) of the nation (Anon. 2013), but this has been achieved at a very considerable environmental cost, in particular the dramatic loss of intertidal areas.

Responding to significant loss of agricultural land to urbanisation, predictions of the effects of climate change on future harvests, and the need to feed a growing population, China implemented a 'no net loss' policy in 1997 to safeguard cultivated land. Thus, if agricultural land were to be taken for urbanisation or industrial use an equivalent area of new agricultural land must be made available – this has resulted in coastal land claim becoming an increasingly attractive proposition as no compensation is required. Additionally the cost per m^2 of tidal land claim is much less than converting agricultural land (Anon. 2009). Simultaneously, China embarked on a change in land ownership laws, whereby local government is now able to sell land-use rights and retain 60–70% of the revenue for development of infrastructure and other purposes.

Officially, provincial reclamation plans have to be approved by the State Council (Wang *et al*. 2014). The area currently

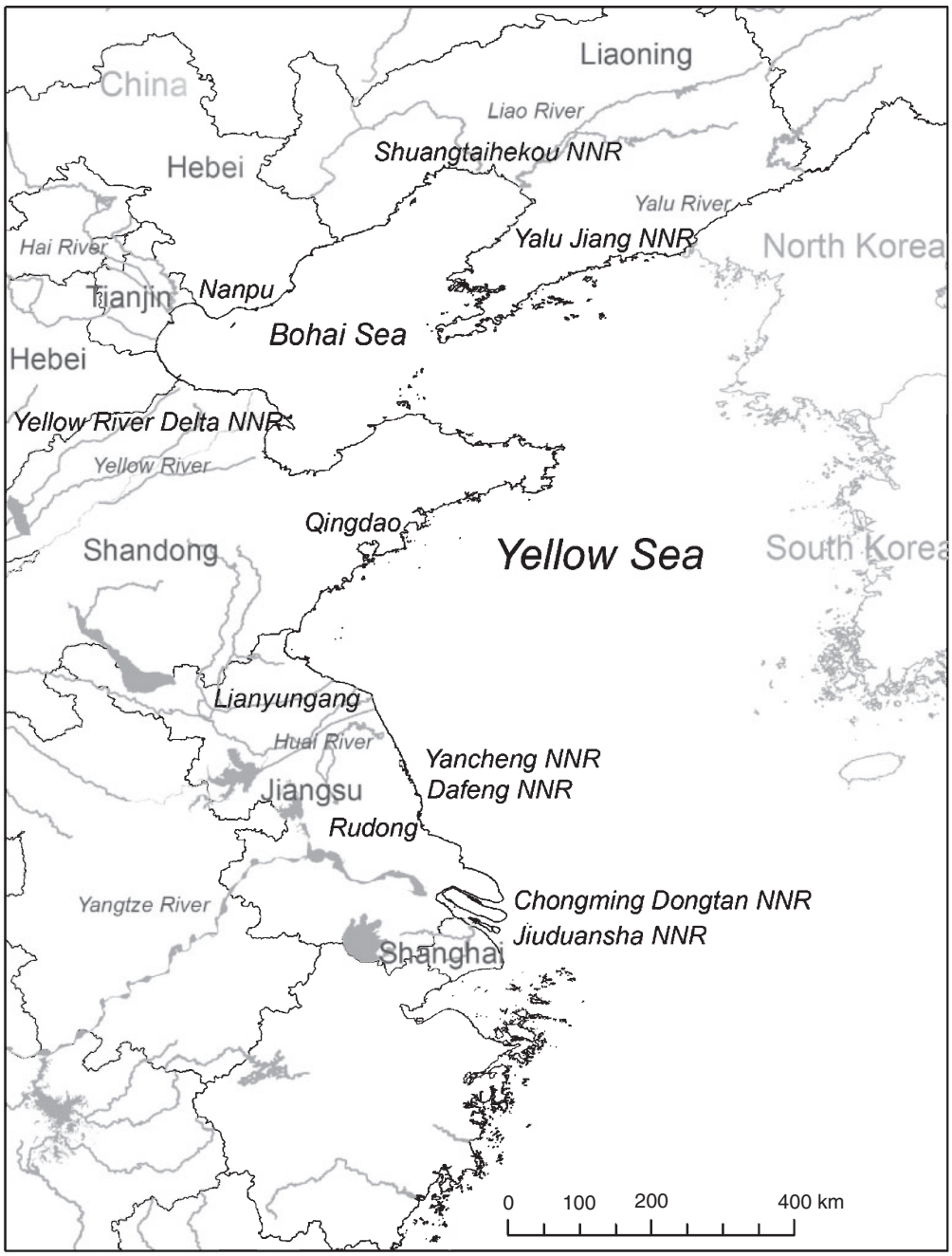

Fig. 1. China's Yellow Sea coast.

approved by the State Council for reclamation up to 2020 is only ~25% of that proposed by coastal provinces (Table S1 in Supplementary material). However it has to be recognised that illegal reclamation is widespread – between 2006 and 2007 some 189 km^2 was claimed illegally, mostly by state-owned companies and government bodies (Anon. 2009). Thus, in one year illegal land claim was equivalent to ~16.8% of the total approved by the State Council for the whole period to 2020 (Fig. S5 in Supplementary material). Furthermore, many projects are broken into units smaller than 50 ha, thereby avoiding the need for State Council approval. Additionally, although the Marine Environmental Protection Law requires environmental impact assessments for coastal reclamation projects, these usually are undertaken on a case by case basis and do not address cumulative effects and thus are more likely to receive approval (Feng *et al.* 2015).

Land claim

Land claim has a long history in eastern China. It is likely that the first land claims took place around 7700 before present (Zong *et al*. 2007). During the 1950s and 1960s the first wave

of large-scale land claims resulted in large salt farms along the Jiangsu Province and Bohai Sea coasts (Wang *et al*. 2014). Such development was in the upper beach zone and continued discharge of sediment from rivers meant that the coast was still prograding. Early land claim was done by simply digging sediment and constructing bunds – ponds for salt or aquaculture having simple sluice gates. As the outer boundary of reclamations has moved progressively offshore there has been a need to strengthen seawalls with rock armour or concrete. Most of the Yellow Sea coast is now backed by seawalls (Table S2, Figs S6, S7, S8 in Supplementary material).

Zuo *et al*. (2013) modelled the effects on China's eastern coast of a rise in sea level resulting from climate change, taking into account natural tectonic ground movement, as well as land subsidence which may be exacerbated by ground water and oil extraction, and construction of large buildings (Table S3 in Supplementary material). They predict that with a 100-year return water level there could be massive inundation, including inundation of 5000 km^2 around Bohai Bay and of 64 100 km^2 in the Yangtze River Delta–Jiangsu area in 2080. This highlights the need for improved coastal defences, which in many areas may be achieved through construction of new seawalls, rather than modification of existing structures. With major investment in new structures it seems likely that these will be pushed towards the low-tide mark, as is currently happening at several sites in Liaoning Province (Fig. S9 in Supplementary material) and Hebei Province, as this will be seen as the last opportunity for land claim.

Today the area of intertidal flats along China's Yellow Sea coast is being rapidly reduced. Even if all further land claim was to stop today the reduced sediment discharges and reworking of the remaining coastal sediments, in part owing to increased energy impacts from narrower tidal margins resulting from reclamation, mean that the area of intertidal flats is likely to continue to be reduced (Murray *et al*. 2014).

Seawalls are now being constructed so far offshore that, in places where there still remain tidal flats beyond the wall (which in places still are several kilometres wide), they do not become exposed until at least 3 h after high tide. This raises a question as to whether birds will be able to meet their energy requirements in the exposure time available. There is insufficient information about the distribution and availability of stocks of benthic prey for shorebirds – an exception being at Yalu Jiang in Liaoning Province (Choi *et al*. 2014*b*) – to assess properly the potential effects on shorebirds at this time.

Development of ports

The massive port developments at Tianjin and Caofeidian, Hebei (the latter with an area of 31 000 ha being one of the largest land claim projects in the world) have received much international attention (Yang *et al*. 2011), but what is not generally recognised is that probably every county-level administration along the Yellow Sea coast is also actively developing port facilities, or at least has plans to do so. Such development, which in many cases is happening very rapidly (Fig. S10 in Supplementary material), is part of a massive urbanisation of the Yellow Sea coast, which is expected to form a 1800-km long urban corridor extending from Hangzhou Bay to the northern Bohai Sea (Seto *et al*. 2012), equivalent to the distance from Canberra to Alice Springs. Liaoning Province's 'Five Points, One Line' coastal development plan (Fig. S11 in Supplementary material) adds another 600 km of coastal infrastructure and the development of five major ports.

Where deep-water access is close to shore, port development is fairly easy, but where wide intertidal and subtidal flats occur, access is achieved by dredging channels, or construction of lengthy bridges (as with the 12.4-km long bridge at the Rudong liquefied natural gas terminal, Jiangsu Province) or causeways (as with the 15-km long causeway at Binzhou Port, Shandong Province) (Fig. S12 in Supplementary material) or a combination of these. The construction of port facilities may also affect adjacent areas. The construction of a port at Donggang, Liaoning Province, extending 10 km (Fig. S10 in Supplementary material) seems likely to affect the adjacent Yalujiang National Nature Reserve (NNR) by changing patterns of sediment dispersal from the Yalu River (Gao *et al*. 2003), whereas the construction of Dafeng Port, Jiangsu Province, has already resulted in erosion of the western edge of the Dongsha Shoals (Chen and Zhang 2011). Such effects beyond the boundaries of construction sites are cause for concern, especially in the case of the proposed port and windfarm developments on Dongsha Shoals (Fig. S13 in Supplementary material) and the potential for changes to the intertidal flats at Rudong, where most of the world population of the critically endangered Spoon-billed Sandpiper (*Calidris pygmaea*) stages on migration. It has been suggested that the sediment characteristics of this site make it particularly attractive to the species (N. Clark, pers. comm.).

Port capacity is ever growing, to support both export trade and the import of raw materials, especially coal for power generation (see below) and iron ore for steel production. Eight ports currently have the capacity to berth, or are planning to build for, the world's largest vessels (400 000 deadweight tonnage), including Qingdao, Tianjin, Caofeidian and Lianyungan, Jiangsu Province (Zhong 2015).

Salt production

China is the largest producer of salt in the world. There are extensive saltpan complexes along the coast of the Bohai Sea (Table S4, Fig. S14 in Supplementary material), with smaller areas in Jiangsu Province; the city of Yancheng ('Salt City') has a history of salt production extending back to 119 BC (Anon. 2013). Initially, salt production would have been for food storage and culinary purposes, but now most coastal salt production is for industrial use. In some areas saltpans have been lost, for example to fish ponds (at Yancheng, Jiangsu), and urban and industrial use (at Lianyungang, Jiangsu; at Tianjin) (Fig. S15 in Supplementary material), but new saltponds are being constructed in other areas (Laizhou Bay, Shandong Province).

The saltponds at Tianjin Municipality and Nanpu in Hebei Province are of international importance for shorebirds (Barter 2002; Conklin *et al*. 2014); concentrations of brine shrimps (*Artemia* spp.) and brine flies (Ephydridae) provide important prey resources for some shorebirds. Saltponds can also provide valuable high-tide roosting sites, which are likely to be of growing importance in future as roosting sites become increasingly restricted owing to loss of upper tidal areas to land claim. The continuing economic importance of the salt industry means that saltponds should remain along parts of the Yellow Sea coast for

the foreseeable future, thus providing foraging and roosting habitat for some, but not all, shorebirds.

Energy

China is the fastest growing consumer of energy in the world, and the massive industrial expansion taking place along much of the Yellow Sea coast is energy hungry. Jiangsu Province accounts for 10% of China's total energy consumption, and demand is expected to grow from 331 terawatt hours (TWh) in 2009 to 800 TWh by 2030 (Lu *et al*. 2014). There is growing investment in power generation and although much of this relies on new generation capacity in the coastal zone, steps are also being undertaken to develop high and ultra-high voltage transmission lines from inland areas, where coal is plentiful, to the coast.

Oil

The Bohai Sea overlies three oil fields: Liaohe, in Liaoning Province; Shengli, in Tianjin Municipality and Hebei and Shandong Provinces; and Penglai, offshore in the central Bohai Sea. Shengli is China's second largest oil-field, and produced ~557 000 barrels day^{-1} in 2014 (Anon. 2015*a*). Oil extraction occurs on land, in the intertidal and offshore. Oil-wells in the intertidal are accessed by causeways that may affect tidal flows, and the delta of the Yellow River was engineered and the course of the river changed to protect oil-field infrastructure. China is the largest importer of oil in the world, and large new refineries are being developed in Bohai Bay at Caofeidian, in Hebei Province, and at Tangshan in Tianjin Municipality (Anon. 2015*a*). There are very few reports of oiled birds in China (Fig. S16 in Supplementary material), and none of shorebirds. With an increase in both offshore production in the Bohai Sea and increased imports to refining facilities onshore, the risk of serious spills is increasing. Liu *et al*. (2015*a*) identified seven high-risk zones for oil-spills in the Bohai Sea, including the sea south of Nanpu, Hebei Province, which is the main staging site for Red Knots in the Yellow Sea. Although the potential risk of a serious spill affecting this coast remains low, the impact if one was to occur during northward migration could be catastrophic.

Wind

Wind power is seen as a major expansion area for China's green-power generation capacity. There are already very large windfarms along parts of the Jiangsu and Liaoning coasts and the world's first intertidal windfarm, with 58 turbines and a generating capacity of 150 MW (Anon. 2015*b*), has been developed at Rudong, Jiangsu Province, in the area that supports much of the global population of Spoon-billed Sandpiper during both northward and southward migration, as well as internationally important populations of another 14 species of wader (Bai *et al*. 2015; Fig. S17 in Supplementary material). Two more intertidal windfarms are planned for Dafeng and Dongtai, both in Jiangsu Province (Zhang *et al*. 2011). There is another development planned for the Dongsha Shoals, which is considered offshore facility, although at least some of the area is likely to be exposed at low tide (Y. Chen and D. S. Melville, unpublished data). Zhang *et al*. (2011) indicate that as much as 18.5 GW of offshore capacity is planned for Jiangsu Province.

The potential impact of intertidal windfarms on shorebirds is not known, although Dirksen *et al*. (1998) reported that the height of daily movements of waders in tidal areas in the Netherlands were usually <100 m above the ground, which would place them in the height-band of the Rudong turbines; the diameters of the turbine rotors range from 90 to 101 m (Anon. 2015*b*), and are set 70 m above sea-surface level (Y. Y. Chen, pers. comm.). Shorebirds at Rudong could be particularly vulnerable to collisions with turbines at night and in foggy weather. There is an abrupt start to the foggy season in the Yellow Sea, in April (Zhang *et al*. 2009*b*; Ding *et al*. 2011), at the peak of northward migration for many shorebirds, and the frequency of foggy days is reported to be increasing (Du *et al*. 2011).

Desalination

A shortage of freshwater in much of northern China, including for Beijing and the Yellow Sea coastal region, is driving an increase in the number of desalination plants for both domestic and industrial supply, with plants now operating in Liaoning, Hebei, Tianjin, Shandong and Jiangsu. Although adverse environmental effects of dumped waste brine can occur (Roberts *et al*. 2010), at one plant in Tianjin the brine is being sold as a product (Watts 2011). The costs of desalination currently are checking demand but as water shortages are expected to worsen, increasing interest in desalination can be expected (Zhou and Tol 2004). Winter sea-ice in the Bohai Sea that could be used for desalination is estimated at 4.0×10^{11} m^3 (Xie *et al*. 2009), but the potential environmental effects that might arise from harvesting sea-ice have yet to be assessed.

Aquaculture

China is the world's leader in aquaculture production; production (both marine and freshwater) in 2013 was 45.4×10^6 t (Anon. 2014). Around the Yellow Sea coast, aquaculture is practised both in ponds and on intertidal and subtidal zones.

Ponds

During the 1970s and 1980s there was massive development of prawn (*Penaeus* spp.) farming with an average increase in production of 75% p.a. in the period 1980 to 1988, at which time ponds covered 162 960 ha (Xie and Yu 2007). This resulted in a gold rush for intertidal areas as ponds were excavated, mostly around the upper to middle intertidal level. White-spot syndrome virus first appeared in China in 1992 (Flegel *et al*. 2008) and production crashed from 220 000 t in 1991 to 50 000 t in 1994 (Xie and Yu 2007). This resulted in the virtual collapse of the industry in some areas and aquaculture ponds were abandoned. However, aquaculture practices have improved, new species and disease-resistant strains have been introduced, and aquaculture has developed dramatically in the past two decades.

Currently, aquaculture ponds may be used to culture single species, for example there were at least 8000 ha of ponds for jellyfish *Rhopilema* in Liaoning Province in 2003 (You *et al*. 2007), but are often used for polyculture systems that include jellyfish, prawns, bivalves such as razorshell (*Sinonovacula constricta*) and fish (Guo *et al*. 2014). There has been a dramatic increase in farming of sea cucumber (*Apostichopus japonicus*) since the early 2000s, with total production ~30000 t in 2003,

increasing to 102 200 t by 2009, and 170 830 t in 2012 (Liu *et al*. 2015*b*; Zhang *et al*. 2015).

In some areas, channels have been excavated to bring water inland to ponds created in former coastal rice paddies, because successful aquaculture can be far more profitable than rice farming, potentially a 20-fold increase in earnings (Xie and Yu 2007). However, in most instances new ponds are created in intertidal areas. The development of aquaculture ponds results in loss of intertidal habitats but the drained prawn ponds formerly provided some roosting habitat for shorebirds, at least on northward migration when awaiting seasonal flooding (Fig. S18 in Supplementary material). Sea-cucumber ponds are permanently flooded and roosting birds are confined to vegetation-free bunds between the ponds (Choi *et al*. 2014*a*; Fig. S19 in Supplementary material) where they are often subject to disturbance.

In addition to direct loss of habitat, aquaculture also has indirect effects, including discharge of waste to the coastal environment (Table S5 in Supplementary material), and the harvesting of wild species as feed, such as first-year clams (*Potamocorbula laevis*) for prawns (Fig. S22 in Supplementary material).

Intertidal–subtidal aquaculture and wild harvesting

Harvesting of polychaetes, bivalves, gastropods and crustaceans is a universal activity around the coast of the Yellow Sea, usually with no attempt at management, although artificial seeding of some species is undertaken. Harvesting of many species is by hand, digging or raking, but clams may also be collected using suction pumps, which range in size from small devices supported on large floating rafts of inner-tubes to large shipboard machines (Fig. S23 in Supplementary material). Overharvesting has resulted in major declines of some species (MacKinnon *et al*. 2012). Harvesting of organisms from the intertidal occurs throughout the coastal area, including from areas within designated nature reserves. It is not known whether the harvesting of intertidal benthos is significantly affecting shorebirds. However, the amount harvested is, in many cases, substantial and collateral damage to non-target species may be severe, especially when suction pumps are used.

Biofilm is also harvested in some areas, including at Panjin in Liaoning Province (Fig. S29 in Supplementary material) for use in the production of 'fish' feeds (Y. Chen and D. S. Melville, unpublished data), which are part of a growing market for probiotics in aquaculture (Qi *et al*. 2009). The extent of such harvesting and the potential implications for coastal ecology are not known but are potentially significant (Kuwae *et al*. 2012).

Pollution

The whole of the Yellow Sea coast suffers from contamination from domestic, agricultural and industrial sources. The Bohai Sea is the most contaminated area on China's coast (Zhang *et al*. 2009*a*), and efforts to improve water quality have been unsuccessful to date (Tong *et al*. 2014).

A wide range of contaminants are present, including alarmingly high concentrations of metals (Gao *et al*. 2014), antibiotics (Li *et al*. 2012), and persistent organic pollutants, such as dichlorodiphenyltrichloroethane (DDT) (Hu *et al*. 2010). China was still manufacturing DDT in 2007, with factories in Tianjin and Jiangsu, for use in antifouling paint for wooden hulled fishing vessels (DDT 250 t p.a.; Fig. S30 in Supplementary material), and for the production of dicofol (Anon. 2007). Pesticides, such as trichlophos and triazophos, are also widely used in aquaculture in ponds and directly on tidal flats (Fig. S25 in Supplementary material). New industrial zones in coastal cities frequently include chemical plants that may discharge (illegally) to the marine environment, as indicated, for example, by high concentrations of halogenated organophosphate flame retardants in coastal waters at Lianyungang, Jiangsu Province (Hu *et al*. 2014), and of perfluoroalkylacids in Laizhou Bay (Zhao *et al*. 2013). The risks associated with chemical facilities in coastal regions were highlighted by explosions in Tianjin and Shandong in 2015 (Melville 2015).

Harmful algal blooms, including those associated with paralytic shellfish poisoning, have become more common along China's coasts in recent years, including on the coast of the Bohai Sea (Yan and Zhou 2004). Potential impacts on bivalve-eating shorebirds, such as knots and Far Eastern Oystercatcher, are not known.

Disease

Little is known of the occurrence of disease in shorebirds in China. However, as intertidal areas become smaller as a result of land claim and birds become more concentrated in the remaining areas (Yang *et al*. 2011) there is a growing potential for transmission of disease (Krauss *et al*. 2010; Honkavuori *et al*. 2014).

Tourism

China's domestic tourist market is growing rapidly (some 10% p.a.), there being 3.26 billion domestic trips in 2012–13. Tianjin Municipality alone attracted 2.27 million tourists during the 3-day Labour Day holiday in 2015 (Anon. 2015*c*), and is developing a range of tourist attractions to meet growing demands, some of which are resulting in significant loss of intertidal area (Fig. S31 in Supplementary material).

Tourism has potential to benefit conservation if, as at Panjin, Liaoning Province, natural habitats are seen as commercially valuable (Fig. S34 in Supplementary material). Increasing public access to nature reserves may also assist in reducing illegal activities, such as the installation of oil-wells in the core area of the Yellow River Delta NNR (Kuenzer *et al*. 2014).

Hunting

Mist-netting of waders does not appear to be widely practised along the Yellow Sea coast, and very few mist-nets were recorded in use during surveys of the coast between Shanghai and the China–North Korean border in March–May 2013 and 2014 (Y. Chen and D. S. Melville, unpublished data), although some nets have been seen at Rudong, Jiangsu Province (Clark *et al*. 2015). This is very different to the situation in southern China (Guangdong and Guangxi Provinces) where Martinez and Lewthwaite (2013) recorded 11.5-km of nets in December 2012, and species caught included Spoon-billed Sandpiper. Harvesting birds using poison has been widely practiced in China for many years; Ma *et al*. (2012) estimated that at least 200 000 waterfowl were taken between 2009 and 2012, including 18 000 waders (Fig. S36 in Supplementary material).

The overall impact of hunting in the Yellow Sea on shorebird populations remains uncertain and it is apparent that harvesting practices are subject to change. There is clearly a risk to the critically endangered Spoon-billed Sandpiper from both poisoning and mist-netting. Additional mortality occurs as a result of incidental by-catch in fish nets and traps, probably accounting for tens of thousands of birds per year (Fig. S38 in Supplementary material).

Nature reserves

There are seven national nature reserves along China's Yellow Sea coast with significant shorebird populations, five of which are designated Ramsar sites. Two internationally important sites awaiting formal protection are Nanpu in Hebei Province, and Rudong in Jiangsu Province, with initial steps of reservation having been taken for Nanpu (Anon. 2015*d*).

The designation of reserves, however, usually results in only limited control over land-use activities and economic activities are widespread and even occur in the core zones of some reserves, for example commercial fishing and aquaculture at Yalujiang NNR, Liaoning Province. The boundaries of reserves also are modified to accommodate development, as at Yancheng NNR, Jiangsu Province (to accommodate a power station and port) and Yalujiang NNR (for a port) (Table S6, Fig. S39 in Supplementary material). Murray and Fuller (2015) found that the rate of loss of tidal land within nature reserves in China (–0.55% p.a.) was significantly less than outside reserves (–0.97% p.a.), but the fact that it occurred suggests that there is a need for improved management.

Pollution of coastal reserves remains a matter of concern. Sediments in the Yalu River contain levels of arsenic and DDT that are sufficiently high that impacts to benthos may be expected (Hu *et al*. 2010; Luo *et al*. 2010). The river discharges adjacent to the Yalujiang NNR, Liaoning, where in 2014 and 2015 there was a dramatic reduction in abundance of benthic prey for shorebirds, the cause or causes of which remain obscure, but which could also be associated with aquaculture activities within the reserve (Peng *et al*. 2014). Such events highlight the fact that with more birds relying on fewer sites, stochastic events are increasingly likely, even within nature reserves, with potential impacts at the population level.

Restoration of wetlands

China is placing increasing emphasis on wetland 'restoration', although in coastal regions this almost invariably means the establishment of brackish or freshwater areas. A large freshwater system has been created within the Yellow River Delta NNR that has definite conservation values, including the establishment of a breeding population of the endangered Oriental Stork (*Ciconia boyciana*), but it provides little habitat for most shorebirds (Li *et al*. 2011). In Tianjin, an environmental restoration project is working in waters 7-m deep adjacent to a port development that destroyed tidal flats (Zheng and You 2014).

Efforts are being made to create new intertidal habitats through managed retreat in some countries (Esteves 2013) but it seems highly unlikely that such an approach is realistic in China, especially bearing in mind the value of land adjacent to the coast.

A future for shorebirds on China's Yellow Sea coast?

The current loss of intertidal habitats has resulted in increasing concentrations of birds at the remaining sites (Yang *et al*. 2011) and is thought to be already adversely affecting shorebird populations (Conklin *et al.* 2016; Piersma *et al.* 2016). Significant further loss of habitat are already included in provincial development plans, but not all have yet been approved by the State Council (see above). It seems likely that most of the coast of the Bohai Sea will be lost, with the exception of parts of the Yellow River Delta, and most of the remaining Jiangsu Province intertidal area is proposed for land claim, with the exception of the area within the Yancheng NNR, an area heavily infested by *Spartina* and which now supports far fewer shorebirds than formerly (H. Wang, personal communication). Even in areas where intertidal flats remain there is uncertainty as to the availability and extent of benthic prey stocks, especially in the face of pesticide use in aquaculture activities and likely growing competition for prey with humans, a potential reduction in foraging time owing to reduced exposure of tidal flats, worsening water quality and a lack of roosting sites. The threats considered by Melville (1997) have worsened over the following 18 years.

Currently the Bohai Sea and north-eastern Liaoning coast provide the final staging areas for many shorebirds on their northward migration, including Red Knots at Nanpu, Hebei Province (Rogers *et al*. 2010; Hua *et al*. 2013), and Bar-tailed Godwits (*Limosa lapponica*) and Great Knots (*Calidris tenuirostris*) at Yalujiang, Liaoning Province (Battley *et al*. 2012; Riegen *et al*. 2014; Choi *et al*. 2015). In the event that these sites are no longer available and birds have to stage along whatever remains of the Jiangsu coast this would potentially add some 500–650 km (great-circle distance) to their flight to the breeding grounds, although it is known that Bar-tailed Godwits do not follow a great-circle route but a longer one across the Bering Strait (Gill *et al*. 2014). This would equate to an increase in flight distance of ~12.5% for Bar-tailed Godwits (race *baueri*) and 11.7% for Red Knots (race *piersmai*). It is known that both species can potentially fly for more than 10 000 km (Battley *et al*. 2012; Tomkovich *et al*. 2013), but the additional distance is likely to result in the birds arriving at the breeding grounds with reduced energy stores, which could adversely impact survival or reproductive output or both (Vézina *et al*. 2012).

Alternatively birds may be able to stage on the western coast of North Korea where land claim is progressing but, currently, at a much slower pace than in either China or South Korea (Riegen *et al.* in press). North Korea has previously expressed ambitions to reclaim large areas. In 1980, Kim Il Sung pronounced, 'Let's cultivate 300 000-jeongbo [Korean unit of measurement equivalent to 2975 km^2] of tideland'. The 8800 ha Taegyedo Tideland project was completed in June 2010 (Anon. 2010), and another project for 1600 ha of farmland is progressing at South Hwanghae, and another in North Phyongan Province (Cha 2015).

In light of the foregoing, we find the statement by Sun *et al.* (2015) that 'the future of China's coastal wetlands looks promising since the Chinese government understands that the sustainable development in China's coastal zone requires new attitudes, sound policies and concerted efforts at all levels', to be unduly optimistic. We believe that the future of the East Asian–

Australasian Shorebird Flyway is seriously threatened by loss and degradation of habitat in China.

There is an urgent need for political engagement to enable a review of current land claim projects along China's Yellow Sea coast – much of what has happened in the past decade has been driven by a desire to boost growth of GDP at any cost. The Third Plenum of the 18th Communist Party of China (CPC) Central Committee in November 2013 reaffirmed the importance of 'ecological civilisation' and highlighted the need to protect ecology and the environment, including drawing 'red lines for ecological protection', and the need to 'reform ecological and environmental protection and management systems'. There is no doubt that there is a growing awareness of the issues but it is going to take some very determined action to turn the situation round. It is thus encouraging that on 25 April 2015 the CPC Central Committee and the State Council announced a strategy to promote ecological civilisation that included the intention to retain not less than 35% of China's natural shoreline (Anon. 2015*e*). However, it should be recognised that this could be achieved through hard, rocky coasts alone. In September 2015, the Central Committee of the CPC and the State Council published a reform plan for 'promoting ecological progress' that includes provision for the introduction of a system 'to control total sea reclamation, imposing binding limits on the total area of ocean over which reclamation may take place. A system will be established for maintaining natural coastlines' (Anon. 2015*f*).

Recognising that shorebirds are but part of the biodiversity of China's Yellow Sea coast, and that the coast provides an array of ecosystem services valued at more than $US 2 billion annually (Ma *et al*. 2014), there is an urgent need for action to prevent further losses.

Among the priorities for safeguarding shorebird populations we suggest the following:

- a moratorium on further land claim beyond that already approved by the State Council to 2020, and strict enforcement of such a moratorium
- scientifically rigorous drafting of eco-environmental 'red lines' to protect coastal areas, biodiversity and ecosystem services (CCICED 2014; Li 2014)
- a thorough review of provincial and municipal plans for land claim against the eco-environmental red line
- strengthening protection and management of key sites for shorebirds, especially at Nanpu, Hebei and Rudong, in Jiangsu Province, which are currently unprotected
- development of a *Spartina* action plan, starting with eradication of the invasive exotic plant in the Bohai Sea
- assessment of the impacts of aquaculture on coastal wetlands and implementation of measures to counter negative impacts
- development of oil-spill contingency plans for coastal areas, especially in the Bohai Sea.

Additionally, Ma *et al*. (2014) noted the need to:

- adopt legislation to safeguard coastal wetlands, their biodiversity and ecosystem services
- appoint an effective agency directly under the State Council to coordinate and supervise all of the government agencies involved in coastal management
- establish a mechanism for government agencies to be accountable for ecological losses.

In the meantime there is an urgent need for increased research into shorebird use of the Yellow Sea coast to help inform future resource management decisions (Hua *et al*. 2015).

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