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Supplementary material

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

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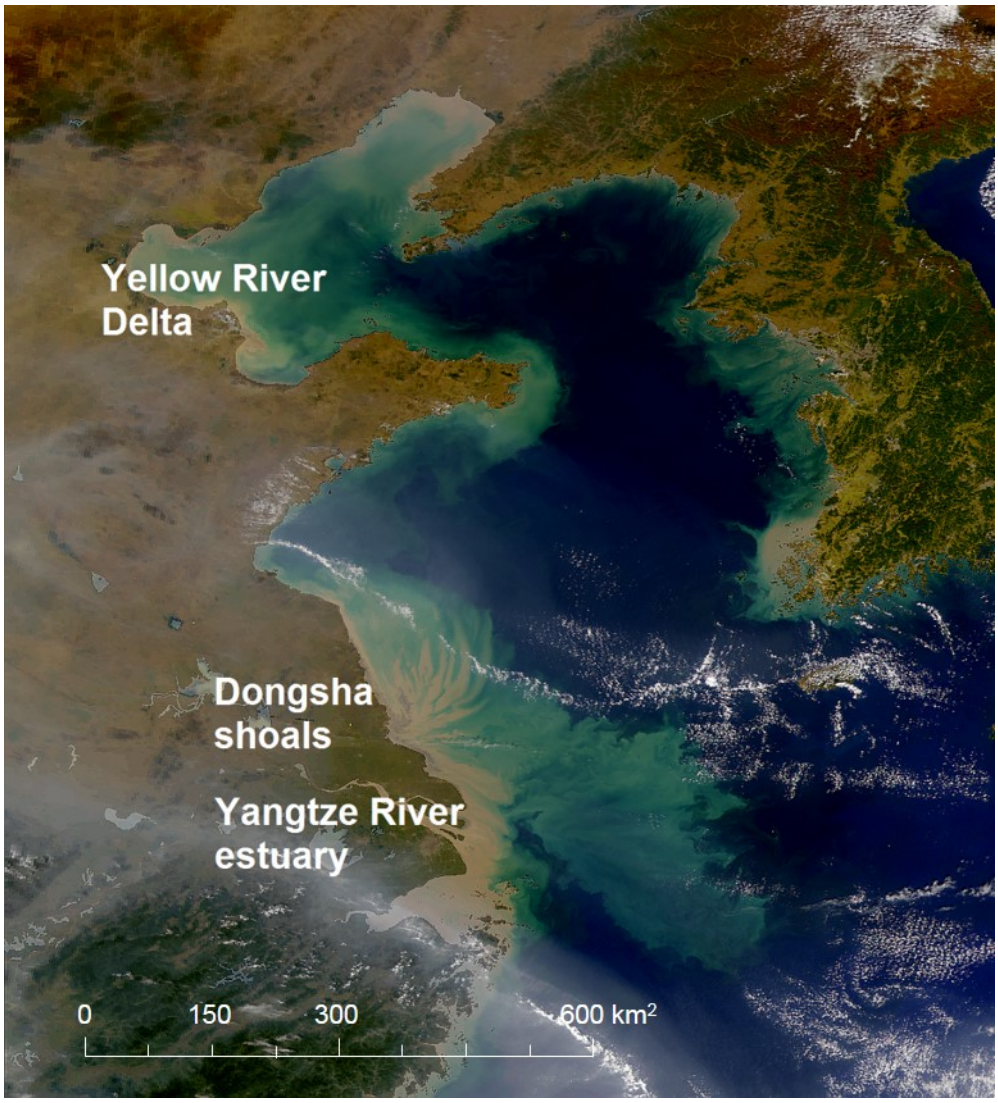
The Yellow Sea coast

Fig. S1. The Yellow Sea. This image, taken on 8 October 1997, shows the influence of sediment discharge from the Yellow and Yangtze Rivers on China's Yellow Sea coast. The radiating banks of the Dongsha Shoals, central coast of Jiangsu Province, mark where the Yellow River discharged before it changed course in 1855. (Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE, http://eoimages.gsfc.nasa.gov/images/imagerecords/52000/52494/S1997281035430.png, accessed 5 January 2016.)

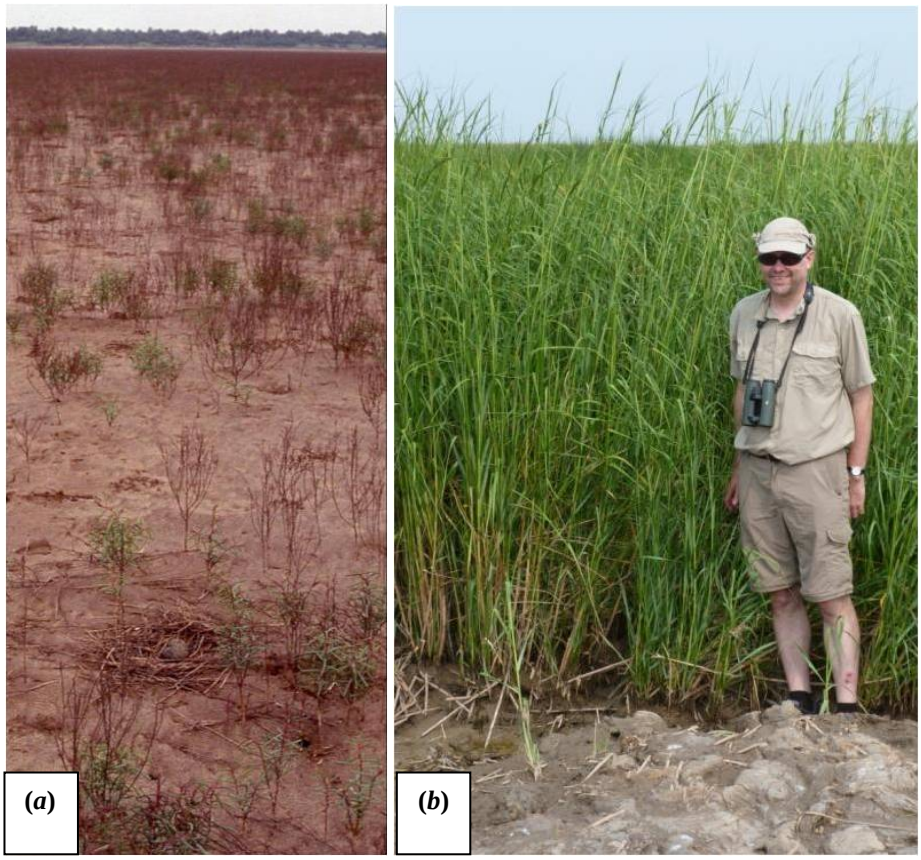


Vegetation of the Yellow Sea coast

Fig. S2. Hypersaline flats vegetated with *Suaeda* sp., Laizhou Bay, Shandong Province, 2013. It is likely that much of the Yellow Sea coast was like this before major land claim projects started. (Photo: D. S. Melville.)

Fig. S3. Fishermen drying their nets on saltmarsh, Yancheng National Nature Reserve, Jiangsu Province, 1993. Note the low height of the vegetation right to the edge of the saltmarsh, which included some small areas of low-growing Common Cordgrass (*Spartina anglica*). (Photo: D. S. Melville.)

Fig. S4. (*a*) A high-zoned flat vegetated with *Suaeda salsa*, Yancheng National Nature Reserve, Jiangsu Province, 1993. Note the open nature of the habitat and the Saunders' Gull (*Larus saundersi*) nest in the foreground. (*b*) Smooth Cordgrass (*Spartina alterniflora*) growing at Chongming Dongtan National Nature Reserve, Shanghai, 2013. The person stands 1.83 m tall. (Photos: D. S. Melville.)



The original saltmarsh vegetation around China's Yellow Sea coast was probably largely *Suaeda* spp. but would also have included *Artemisia*, *Limonium*, *Salicornia* and *Nitraria* and, around river mouths, *Scirpus*, as well as grasses such as *Zoysia macrostachya*, *Aeluropus sinensis* and *Imperata cylindrica*. Wang (1983) noted that the zone of *Suaeda* flats on the northern Jiangsu coast was 4–5 km wide. In 1993 outside the seawall at Yancheng there was still at least 1 km of *Suaeda* flat that extended to the barren tidal flats (D. S. Melville, personal observation). Some *Suaeda* flats remain, but they are now separated from the tidal flats by several kilometres of exotic Smooth Cordgrass (*Spartina alterniflora*) (Li *et al*. 2010; Zhang *et al*. 2011). *Spartina alterniflora* now covers hundreds of square kilometres of the coast of Jiangsu Province, and is spreading around the Bohai. Growing >2-m tall it makes intertidal areas totally unsuitable for shorebirds.

A large eradication project at Chongming Dongtan National Nature Reserve, Shanghai has impounded ~25 km^2 of Smooth Cordgrass marsh with a seawall and the plants are being killed by cutting and flooding. However, it will not be possible to re-establish tidal flats as the sediment elevation is now too high, so the area will be managed as a non-tidal brackish wetland. Limited trials using herbicides (broad-spectrum glyphosate and the grass-selective haloxyfop) have been started at

several sites, including Chongming Dongtan, by both shellfishers and the management of the nature reserve; initial results are very encouraging, with good killing rates, but recolonisation is a continuing problem (D. S. Melville, unpubl. data).

Spartina appears not yet to be present on the Korean Peninsula and it is important that it does not become established if the remaining tidal flats, especially in North Korea, are to remain accessible to shorebirds. Eradication in the Bohai is probably achievable by ground spraying, whereas in Jiangsu Province, aerial spraying may be required owing to the very large areas. However, current land claim in Jiangsu Province means that on some areas of coast *Spartina* is now absent, seawalls having extended beyond the immersion depth that the plant will tolerate.

Zostera spp. occurs on some open tidal flats in Liaoning Province and around the Bohai (Guo *et al.* 2010) but seagrasses have been little studied in China (Shi *et al.* 2010*a*), and their potential significance to shorebirds is not known. Seagrass beds are threatened as a result of developments in the coastal zone and *Zostera* apparently has disappeared from Yalujiang National Nature Reserve, Liaoning Province (D. S. Melville, unpubl. obs.) and at least parts of the Yellow River Delta, Shandong Province (Soissons 2013).

Coastal development policies

In 1988, Chinese leader Deng Xiaoping stated:

> The coastal areas, which comprise a vast region with a population of 200 millions, should accelerate opening-up to the outside world and develop rapidly first so as to bring along the development of the interior areas afterwards. The development of the coastal areas is of overriding importance, and the interior areas should subordinate themselves to it. When the coastal areas have developed to a certain extent, they will be required to give more help to the interior areas. (Tian 2001)

This statement laid the foundation for the dramatic coastal development that has occurred over the past 25 years. Li (2006) notes that:

> since there was no standard and effective management system for sea-use activities at the time these developments arose, there was a rise in the disorderly, excessive and free use of the sea and intense use conflicts (later referred to as the ‘three no’s’ namely ‘no order’ in marine development, ‘no control’ on the extent of marine development and ‘no fee’ paid for any sea-use activity). As a result of this, the marine resource base was seriously abused, marine environmental quality deteriorated, and the property rights of the State and the legitimate rights of investors were not properly protected.

The *Law on the Management of Sea Use* entered into effect on 1 January 2002. Under this legislation, land-use applications are to be approved by either provincial or central government.

> Chapter III Application for, and Examination and Approval of, the Use of Sea Areas
>
> Article 18. Use of sea areas for the following projects shall be subject to examination and approval by the State Council:
>
> 1. a project that involves filling more than 50 ha of sea area;

2. a project that involves enclosure of more than 100 ha of sea area;

3. a project that involves the use of more than 700 ha of sea area without altering the natural attributes of the area;

4. major national construction projects; and

5. other projects specified by the State Council.

The authority for examination and approval of the use of sea areas for projects other than those specified in the preceding paragraph shall, with the authorization of the State Council, be defined by the people's governments of provinces, autonomous regions and municipalities directly under the Central Government.

Changes to laws governing land tenure and use have allowed local governments to sell land-use rights and retain 60–70% of the revenue, providing a major source of income for local government, but these changes have also resulted in an oversupply of land, with only ~2% of land in development districts fully developed (Ding 2003). These factors have further contributed to the growth in extensive land claim in tidal areas. Meanwhile, the issue of ownership of intertidal areas remains complex. The Chinese constitution states (Article 9) that beaches are 'owned by the State, that is, by the whole people, with the exception of … beaches owned by collectives in accordance with the law' (Anon. 2015*a*), and provisions for land-use for aquaculture give little security to promote sustainable management (Liu 2007). Furthermore, administrative oversight of activities in the intertidal is highly fragmented among many different agencies, often with competing interest (Ma *et al*. 2014) and national and provincial regulations are often contradictory and promote reclamation (Hua 2014).

Table S1. Areas proposed for land claim and those approved by the Chinese State Council to 2020 (after Wang *et al*. 2014)

Region	**Period in which claim planned**	**Area planned for claim (km^2)**	**Area claimed and planned for claim (2011–20) and approved by State Council (km^2)**
Liaoning Province	–	–	253
Hebei Province	2005–20	452	149.5
Tianjin Municipality	2006–20	215	92
Shandong Province	2009–20	520	345
Jiangsu Province	2009–20	1800	264.5
Shanghai Municipality	2011–20	400	23

Fig. S5. This sign, erected by the Forest Bureau of Yingkou City, Liaoning Province, states 'Protect wetland, Protect birds'; ~200 m along the seawall a new pond is being constructed on the tidal flats, almost certainly illegally. (Photo: D. S. Melville.)

Land claim

Currently many land claims are done using a core of geo-textile tubes that are pumped full of slurry, allowed to consolidate on site, and then are covered by rock or concrete (Beemsterboer *et al*. 2012). This is a very rapid method of reclamation (e.g. ~20 km of geotextile tube seawall was constructed at Chongming Dongtan, Shanghai, in *c*. 2.5 months in 2013).

The *Code for Design of Sea Dike Project* was issued by the Central Government in 2008, before which local governments were largely responsible for setting standards (Xie *et al*. 2010). Along some parts of the coast, seawalls are in a poor state of repair and will require strengthening, increases in height or replacing, especially in response to land subsidence or rises in sea level. The risk is that rather than simply remediating the existing walls it will be decided to build new walls further offshore, thus complying with the design standard but at the cost of further loss of intertidal habitat.

Tidal energy budgets are affected by tidal flats, which both store and dissipate tidal energy. The narrowing of the intertidal and shallow subtidal zones through land claim reduces hydraulic drag and thereby increases the energy reaching the coast, with potential for damage to seawalls and other infrastructure. Furthermore, although land claim may affect tidal range locally, modelling suggests that land claim along the Jiangsu coast may affect the western coast of the Korean Peninsula and vice versa (Song *et al*. 2013). As there is large-scale land claim taking place on the Chinese and South Korean coasts of the Yellow Sea, increased tidal energy can be expected, with potential effects on

patterns of sediment deposition and erosion. Already there is evidence that land claim has resulted in an increase in sea level, especially in the Bohai (Bi *et al*. 2013).

Land subsidence is also a major problem around much of the Yellow Sea coast (Table S3). One study of part of the Yellow River Delta reports land levels dropping by 250 mm per annum (p.a.) (Higgins *et al.* 2013).

Fig. S6. (*a*–*b*) Bar-tailed Godwits (*Limosa lapponica*) roosting on an active dredge-dumping site. The material was being excavated from a channel to improve access to the Donggang Fishing Port, Liaoning Province. (*c*–*d*) The infilled area is planned to be part of an industrial park to be built on an area of intertidal mudflat that was excised from the Yalujiang National Nature Reserve by a boundary adjustment in 2012 (see Fig. S39). (Photos: D. S. Melville.)

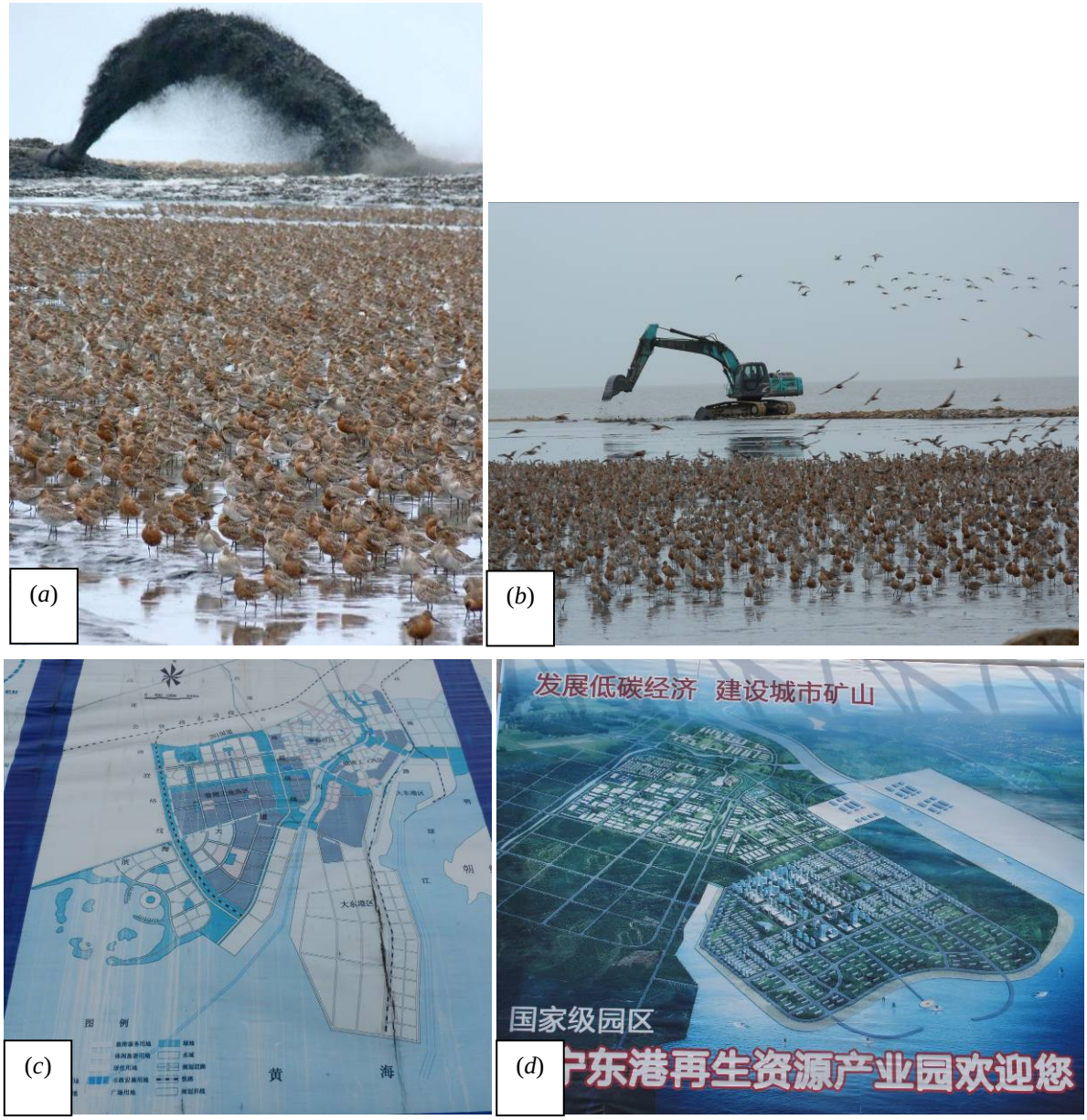


Fig. S7. Geotextile tube seawall, Rudong, Jiangsu Province, 2013. (Photos: D. S. Melville.)

Fig. S8. Seawall construction techniques vary greatly along the Yellow Sea coast. (*a*) Geotextile tube, Yancheng, Jiangsu Province, 2013. The tube has not been covered and the fabric is decaying. There is an area of *Spartina* at the top of the beach, which may reduce wave action. Note the power station in the background; this area was formerly within the Yancheng National Nature Reserve but was excised. (*b*) Rock-faced earthen seawall, Liaoning Province. An additional wall of rock has been placed on top of the dyke to increase the height. Coastal land subsidence is widespread, especially around the Bohai coast, and together with sea-level rise and increased storm surges there is a growing need to raise the height of seawalls on many parts of the coast. (*c*, *d*) Structures for dissipating wave energy. (Photos: D. S. Melville.)

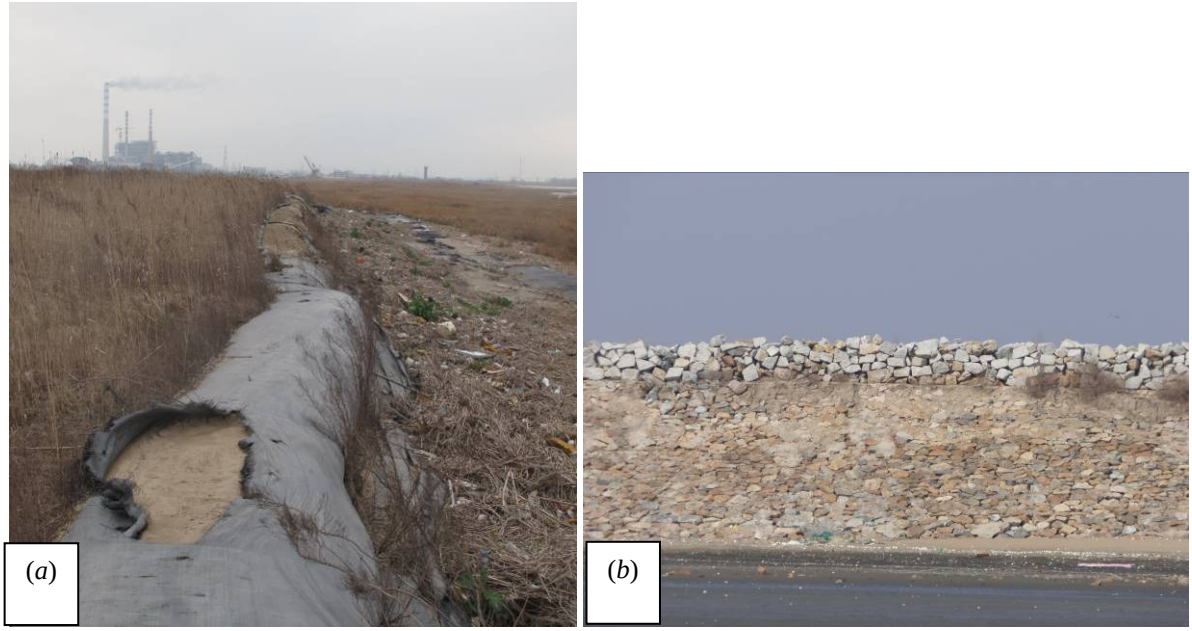


Table S2. Length of seawall in Yellow Sea provinces and municipalities (after Luo *et al*. 2015)

	Liaoning Province	Hebei Province	Tianjin Municipality	Shandong Province	Jiangsu Province	Shanghai Municipality
Length of coastline (km)	2178	487	155	3124	1039	167
Length of seawall (km)	1300	400	140	400	780	110
Proportion of coastline that is seawall (%)	59.7	82.1	90.3	12.8	75.1	65.9

Table S3. Predicted rises in sea level and areas inundated for Yellow Sea coastal plains in 2050 (after Cai *et al*. 2009)

Region	Rate of increase in sea level 1980s/90s (mm per year)	Predicted rate of increase in sea level by 2050 (mm per year)	Predicted rise in sea level by 2050 (cm)	Area potentially subject to inundation by 2050 (ha)
Yellow River Delta	4.8	6.4–6.9	35–40	39 000
Western coastal plain of Bohai	2.1	11.0–11.5	65–70	21 000
Northern Jiangsu coastal plain	2.2	6.8–7.3	40–45	38 000–89 000
Yangtze River Delta	6.6	7.9–8.4	45–50	7000–11 000

Fig. S9. Aquaculture ponds (principally for production of sea cucumbers) at Jinzhou, Liaoning Province, 20 May 2015. On image: 1 – development of ponds has extended beyond the low-tide line; 2 – land claim for Jinzhou Port; 3 – ponds have been developed on tidal flats adjacent to the Shaungatizihekou National Nature Reserve. (Landsat image: US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 19 July 2015).

Port development

Port development is taking place along much of the Yellow Sea and Bohai coasts, often with extensive reclamation far offshore.

Two major ports are being rapidly developed in southern Bohai Bay, ~20 km apart but, importantly, in different provinces (Hebei and Shandong). They are being aggressively marketed by their respective local governments, for example 'Cangzhou's great resource advantage is land, there are … 307 sq.km. tidal flat and 1051 sq.km. shallow sea' (Anon. 2015*b*). The Cangzhou port development extends ~22 km from shore, that at Binzhou only ~15 km.

An indication of the scale of infrastructure development and other construction work across China is demonstrated by the fact that China used more cement in the 3 years 2011–13 than the United States did in the entire 20th Century (BBC 2015).

Fig. S10. Port development can be rapid. Dandong Port (one of the points of Liaoning Province's 'Five Points, One Line' coastal development strategy), at the mouth of the Yalu River, on the border with North Korea, extends ~10 km out to sea: (*a*) 21 November 2009; (*b*) 17 November 2013; (*c*) 31 May 2015. (Landsat images: US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 16 July 2015).

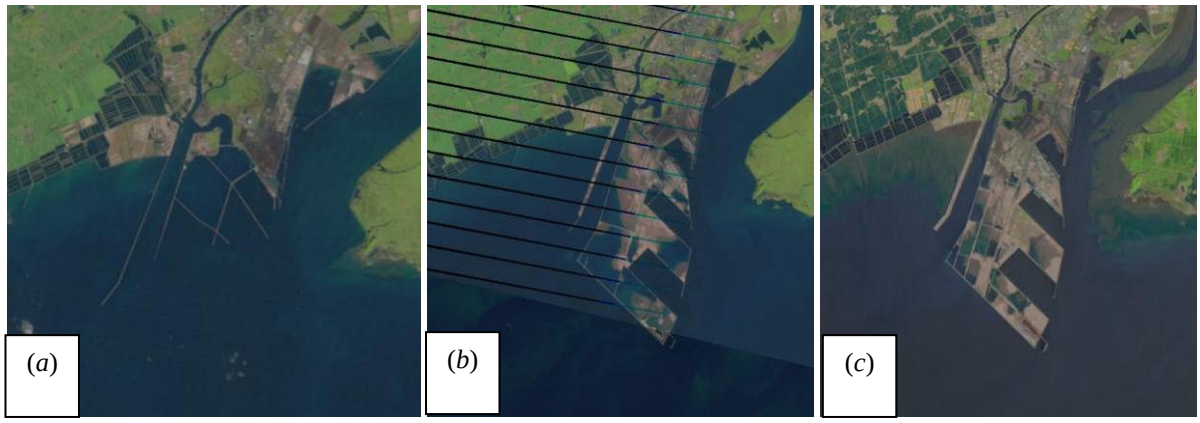


Fig. S11. Billboard depicting Liaoning Province's 'Five Points, One Line' coastal development strategy, launched in 2007. This strategy will add ~600 km to the ~1800-km urban corridor linking Hangzhou Bay, in Zhejiang Province, to Shenyang, in Liaoning Province, and promote large-scale port and industrial development covering nearly 500 km^2 (Song 2007). (Photo: D. S. Melville.)

Fig. S12. Location of Cangzhou and Binzhou Ports in southern Bohai Bay. The white line shows the Zhangwei Xin River, which is the boundary between Hebei (to the west) and Shandong (to the east) Provinces. (Landsat image: US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 17 June 2015).

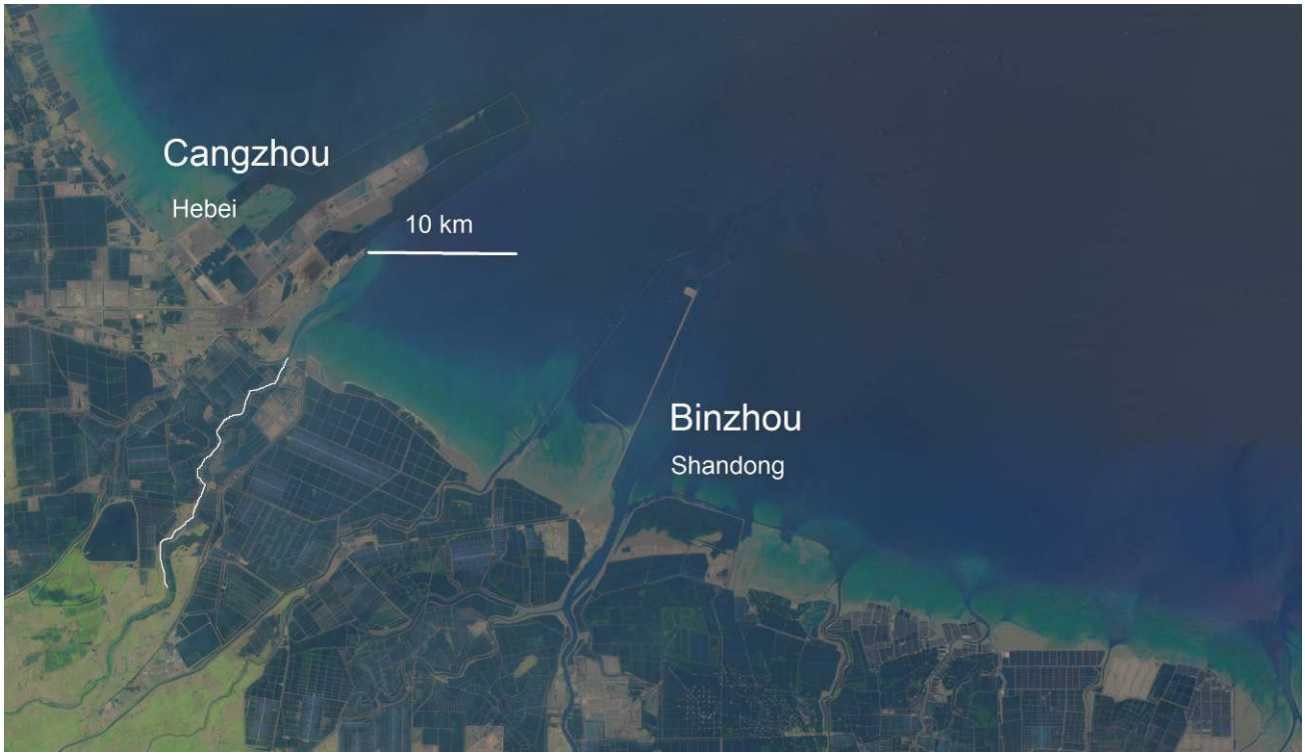
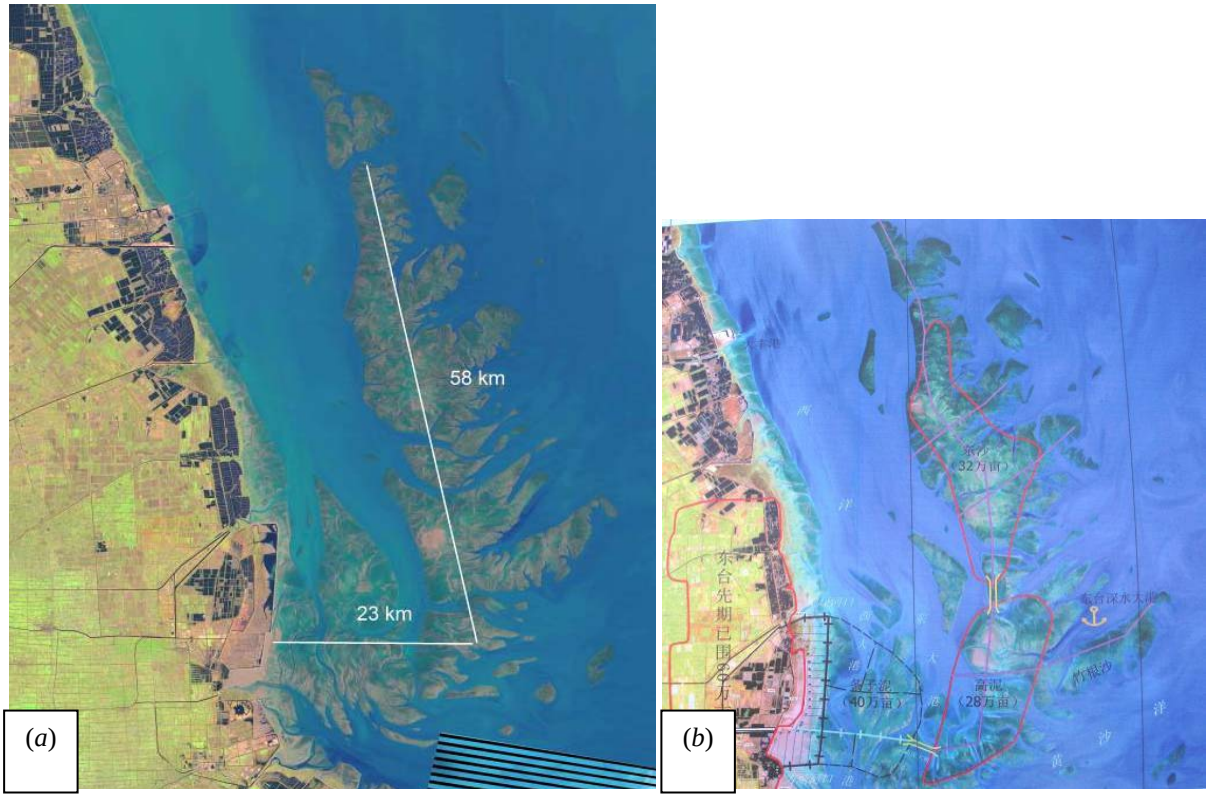


Fig. S13. The ambitious reclamation plan for Jiangsu Province includes the development of the Dongsha Shoals, in the former delta of the Yellow River. (*a*) Landsat image of Dongsha Shaols. (Image from US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 25 June 2015). (*b*) Billboard on Jiangsu coast (March 2013) showing outline of proposed development of Dongsha Shoals. (Photo: D.S. Melville.)



Salt industry

China is the largest producer of salt in the world, yet is a net importer. Demand for brine, especially for use in the chlor-alkali industry, which produces sodium hydroxide (caustic soda), chlorine and hydrogen and which are in turn used in a wide variety of industries, such as manufacture of polyvinyl chloride (PVC). Demand for salt is expected to grow at nearly 5% p.a. until 2018 (Roskill 2014). The largest areas of salt production are around the Bohai (Table S4).

The chlor-alkali process formerly used a mercury cell for electrolysis, which resulted in emission of mercury to the environment via air, water, other wastes and in the products themselves (Jiang *et al.* 2006), but other methods that do not require mercury are increasingly being adopted (Streets *et al.* 2005).

The Weifang Binhai Economic Development Zone, in Shandong Province, produces 2.5×10^6 t of crude salt, 850 000 t of soda ash, 25 000 t of bromine, 20 000 t of potassium sulphate, and 60 000 t of sodium chloride annually (Shandong Business 2015), whereas Jiangsu produces 2.34×10^6 t of crude salt (Wang and Wall 2010).

Commercial harvesting of brine shrimp and rotifers occurs in saltfarms in some areas (Dhert *et al*. 1997), the cysts in particular being an important resource for aquaculture, and there was a proposal to introduce a new variety of *Artemia* to the Tanggu Saltworks, Hebei Province, to increase production (Tackart and Sorgeloos 1991). The impact, if any, of such management activities on shorebirds is not known.

The numbers of Curlew Sandpipers (*Calidris ferruginea*) at the Tangshan saltponds have increased at a time when saltponds elsewhere in Tianjin and in Hebei Province have been lost to development. Saltponds also support internationally important breeding populations of Kentish Plover (*Charadrius alexandrinus*) (Que *et al*. 2015).

Table S4. Salt production (area under production and annual output) around the Yellow Sea coast in 1999 (after Yuan *et al.* 2001)

Note that the areas under production and output will have changed since 1999; in particular, Tianjin now has less area under production than given below (see Fig. S15) because the Tianjin Economic-Technological Development Area was developed on former saltponds (Shi *et al.* 2010*b*)

Region	Total area of salt pan (×10 000 ha)	Area of salt pan under production (×10 000 ha)	Annual output (×10 000 t)
Liaoning Province	5.78	5.31	284.7
Hebei Province	8.17	7.86	395.7
Tianjin Municipality	3.89	3.75	242.7
Shandong Province	11.81	9.22	763.6
Jiangsu Province	8.75	5.71	216.6

Fig. S14. Saltponds at Nanpu, Hebei Province. (Image from US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 19 July 2015).

Fig. S15. Loss of saltpans at Tianjin and Tanggu, Hebei Province. More than 100 km^2 of saltponds have been lost since Barter *et al.* (2000) identified the international importance of this area for shorebirds. (*a*) Landsat image 23 April 2000; the red line indicates saltpond areas subsequently lost to infilling; (*b*) Landsat image 19 May 2015. (Landsat images from US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 19 July 2015).

Energy

Oil

Fig. S16. Oiled White-winged Scoter (*Melanitta deglandi*), Liaoning Province. (Photo: D. S. Melville.)

Oil and gas extraction facilities in the Bohai discharged 2.46×10^6 t of oily water and 540 000 t of oil in 2000 (Li and Daler 2004). Small-scale leaks and spills of oil are not uncommon (CCICED 2010) and there have been occasional blow-outs and pipeline breaks that have resulted in extensive oil-spills. A pipeline break in Dalian, Liaoning Province, in 2010 affected a sea area of 366 km^2 (Anon. 2010), whereas a blow-out at the Pengli oilfield in 2011 affected a sea area of 5500 km^2 and seriously contaminated 870 km^2 (Watts 2010; Anon. 2011). An explosion at Qingdao, Shandong Province, in 2013 resulted in 55 human fatalities but apparently little oil entered the sea (Anon. 2013*a*). There are very few reports of oiled birds in China, and none of shorebirds (see Fig. S16).

The Chinese Maritime Safety Administration has the mandate to investigate and respond to marine pollution incidents in Chinese waters, but clean-up is generally undertaken by an approved ship pollution response organisation (ITOPF 2013). Administrative responsibility for handling spills is fragmented, and although oil-spill response equipment is stockpiled at six sites on the coast of the Yellow Sea (Dalian, Qinhuangdao, Yantai, Qingdao, Lianyungang, and Shanghai), this is only suitable for small-scale spills (Xiong *et al.* 2015). There appear to be no national or provincial plans for responding to oiled wildlife incidents (Sea Alarm 2009; Shangao Xiong, in litt; Qingquan Bai, in litt.).

There is little information on the immediate impacts of oil-spills on shorebirds, with most studies being conducted some time after the actual spill (Larsen and Richardson 1990). Evans *et al*. (1993) suggested that waders that were not killed outright probably responded to spills during the1991 Gulf

War by moving from contaminated areas because foraging would have been compromised in the area affected by the spills. In the region of the Gulf War, birds with >10% of their body plumage contaminated with oil had lower body mass than unoiled birds such that they were considered unlikely to be able to migrate successfully (Evans and Keijl 1993). Although the potential risk of a serious spill affecting the Nanpu coast, in Hebei Province, remains low, the impact if one were to occur during northward migration could be catastrophic, especially for Red Knots (*Calidris canutus*).

Natural gas

China is the third largest importer of natural gas in the world, and growing imports are being facilitated through large terminal developments. Liquefied natural gas (LNG) is used both domestically and for the petrochemical industry. Currently there are seven terminals on the coast of the Yellow Sea (Dalian, in Liaoning Province; Caofeidian, Hebei Province; in Tianjin Municipality; Qingdao, Shandong Province; Rudong and Nantong, in Jiangsu Province; and in Shanghai) and others are planned in the Bohai and along the Jiangsu coast (Anon. 2012*a*). LNG terminals form part of large onshore port developments, for example at Caofeidian (see above), a floating terminal at Tianjin, and a 12.4-km long bridge at Rudong, Jiangsu Province.

Wind

Although the direct impact of intertidal windfarms is confined to the turbine footprint, in some areas (e.g. Xingianhu in Shandong Province) windfarms are being developed in conjunction with land claim for aquaculture resulting in the total loss of intertidal areas. On 13 September 2015, more than 400 wind turbines (both intertidal and terrestrial) could be seen from one site on a seawall at Tiaozini, at Rudong in Jiangsu Province (D. S. Melville, unpubl. data). Such sites could, however, be dwarfed by potential development of the 'Offshore Three Gorges' on the Dongsha Shaols, which Fung *et al*. (2009) suggest could accommodate 40 000 wind turbines, more than six times the total number of operational turbines in the United Kingdom (UKWED 2015).

There is little information on the effects of wind turbines on waders away from their breeding grounds. Disturbance effects on foraging and roosting Eurasian Oystercatchers (*Haematopus ostralegus*) and European Golden Plovers (*Pluvialis apricaria*) have been reported, and disturbance of Eurasian Curlews (*Numenius arquata*) extended up to 500 m from turbines (Langston and Pullan 2003). The spacing of the intertidal turbines at Rudong could be such as to effectively make the whole site unattractive to Eurasian Curlews and possibly other species.

Because most wind turbines are located in coastal areas around the Yellow Sea, waders flying inland to roost as a result of claim of the upper intertidal zone means that they may have to cross one or more lines of turbines four times a day. At Rudong, the turbines along the seawall are ~500 m apart, compared with ~700–1000 m in the intertidal, so the risk of collision would appear to be increased for flights to and from roosts.

Coal

There is an increasing number of coal-fired power stations along the Yellow Sea coast. Additional coal-handling ports are also being developed, ranging in size from modest (3.6×10^6 t p.a. at Dafeng, Jiangsu Province) (Anon. 2011) to massive (200×10^6 tp.a. at Caofeidian, Hebei Province) (Anon. 2014*a*).

Nuclear

There are presently two nuclear power plants along the Yellow Sea coast, at Lianyungang, Jiangsu Province, and Donggangzhen, at Dalian in Liaoning Province. However, nuclear power plants are also under construction or planned for Shandong. In December 2014 the National Development and Reform Commission announced a resumption of construction of an unspecified number of plants along the eastern seaboard (Anon. 2014*b*). Development of power plants in low-lying coastal areas has raised concerns regarding safety, especially following the damage to the Fukushima plant in Japan caused by a tsunami in 2011 (Lu *et al*. 2014).

Tidal energy

Tidal power generation is little developed in China at present, with only three operational power stations, one of which, commissioned in 1978, is in the Bai Sha estuary, Ru Shan, Shandong Province (Wang *et al.* 2011). Parts of the Yellow Sea coast have potential for development of tidal power (Liu *et al*. 2011), in particular north-eastern Liaoning Province where, in 2004, Tidal Electric announced plans to develop a 300 MW offshore, tidal lagoon power-generation facility near the mouth of the Yalu River (tidal range ~7 m) (Anon. 2004). If constructed it would be the largest tidal power plant in the world but there has been no further action to date. The development of tidal lagoons could result in loss of intertidal areas, but also might provide high-tide roosting sites, depending on the location of the facility.

Solar

Solar farms are being developed on reclaimed land in some areas along the Jiangsu coast. There is a 100 MW plant at Xiangshui, Jiangsu Province, developed with aquaculture facilities (Anon. 2014*c*).

Biofuels

It has been suggested that halophytes could provide a source of biofuels (alcohol, biodiesel) (Liu *et al.* 2012), but the current rate of land claim would suggest that such developments are highly unlikely unless associated with harvesting of *Spartina*.

Fig. S17. (*a*) There are very large windfarm developments on much of the Yellow Sea coast, including in areas where shorebirds are utilising aquaculture production and saltfarms. (Photo: D. S. Melville.) (*b*) The world's first intertidal windfarm has been developed at Rudong, Jiangsu Province, in the area that supports much of the global population of the critically endangered Spoon-billed Sandpiper (*Calidris pygmaea*) during both its northward and southward migration. (Photo: D. S. Melville.) (*c*) Spacing between wind turbines is ~500 m along the seawall, whereas in the intertidal turbines are spaced ~700–1000 m apart. (Image: Google Earth, accessed 12 May 2014.)

Aquaculture

Initially pond aquaculture of sea cucumbers was largely restricted to Shandong and Liaoning Provinces, where the area of ponds was 62 673 ha and 105 903 ha, respectively, in 2012 (Zhang *et al*. 2015). Since 2008, the industry has expanded southwards as far as Guangdong and Guangxi (Liu *et al*. 2015*a*). The industry is currently valued at about $US 5.65 billion dollars, and although only accounting for ~1.04% of China's total aquaculture output, it accounts for 16.09% of the total value (Zhang *et al*. 2015). In view of this profitability it is not surprising that there has been rapid and extensive development of new ponds, which, in some areas, such as the northern Bohai, are now extending to the low-tide mark and are thus destroying the entire intertidal area (Y. Chen and D. S. Melville, unpubl. data) (also see Fig. S9).

Sea cucumbers are causing a new gold rush for intertidal areas. The intertidal area adjacent to Shuangtaizihekou National Nature Reserve, Liaoning Province, has lost >50 km^2 to development of aquaculture ponds in the 12 years to 2015, and current land claim to the west of the reserve, towards Jinzhou, is expected to result in >200 km^2 of ponds, mostly for production of sea cucumbers. Whereas earlier aquaculture development for prawns was driven by exports, the current sea cucumber industry is driven by domestic demand, highlighting how the overall economy of China has changed over the past 30 years. Sea cucumbers are a high-risk business. High infrastructure costs mean a high initial investment, whereas changes in salinity (e.g. from heavy rainfall), potentially cause mortality or adversely affect growth rates, and hence profitability. Reductions in market prices are already being reported owing to increased supply, yet new ponds continued to be developed.

Sea cucumbers require clear, not turbid, water and so the banks of pond are usually covered in concrete (sometimes just geotextile sheet). The bottom of the ponds are also modified with the construction of artificial reefs, such as piles of rocks or bricks, cloth supported by bamboo, and so on, which provide shelter for the sea cucumbers and also promote growth of benthic diatoms upon which they feed. The result is that sea cucumber aquaculture ponds are unsuitable for use by shorebirds, apart from the embankments on which birds may roost.

The clam *Potamocorbula laevis* is the main prey for both Red and Great (*Calidris tenuirostris*) Knots, as well as being important prey for Bar-tailed Godwits (*Limosa lapponica*) and Far Eastern Oystercatchers (Choi 2014). There is little information on the breeding biology of this species, and what there is is potentially contradictory (Wei 1984; Wei and Guan 1985*a*, 1985*b*; Liu and She 2003). The effects of commercial harvesting on populations and stocks available for shorebirds are not known. There is a need for research to better understand these relationships and potential effects on shorebirds

Fig. S18. Aquaculture ponds in the Yalujiang National Nature Reserve, Liaoning Province. (*a*) When ponds were used mainly for production of prawns (*Penaeus* spp.) they were drained in the spring, providing roosting sites for shorebirds (image 24 April 1990). (*b*) When used mainly for production of sea cucumbers (*Apostichopus japonicus*), the ponds remain flooded through winter and spring (image 6 May 2015). In such situations shorebirds can only roost on the banks of ponds (Fig. S19). (Landsat images: US Geological Survey, http://landsatlook.usgs.gov/viewer.html, accessed 17 June 2015).

Fig. S19. (*a*) Bar-tailed Godwits (*Limosa lapponica*) roosting on the bank of an aquaculture pond, Yalujiang National Nature Reserve, Liaoning Province. (*b*) Bar-tailed Godwits and Grey Plovers (*Pluvialis squatarola*) roosting on bank of an aquaculture pond, Hebei Province. (Photos: D. S. Melville.)

Fig. S20. Farming of sea cucumbers (*Apostichopus japonicas*) has expanded greatly since the early 2000s. (Photo: D. S. Melville.)

Fig. S21. Sea cucumber aquaculture ponds have artificial reefs that provide sheleter and food, but make the ponds unsuitable for shorebirds when they are drained. (Photos: D. S. Melville.)

Fig. S22. Juvenile *Potamocorbula laevis* are harvested in large quantities to be used as feed for prawns. (Photo: D. S. Melville.)

Fig. S23. Harvesting of clams: (*a*–*b*) by hand; or (*c*) using suction pumps, which may be mounted on small floating rafts, or on fishing vessels. Collateral damage to benthic organisms from use of pumps is thought to be extensive, but is unstudied. (Photos: D. S. Melville.)

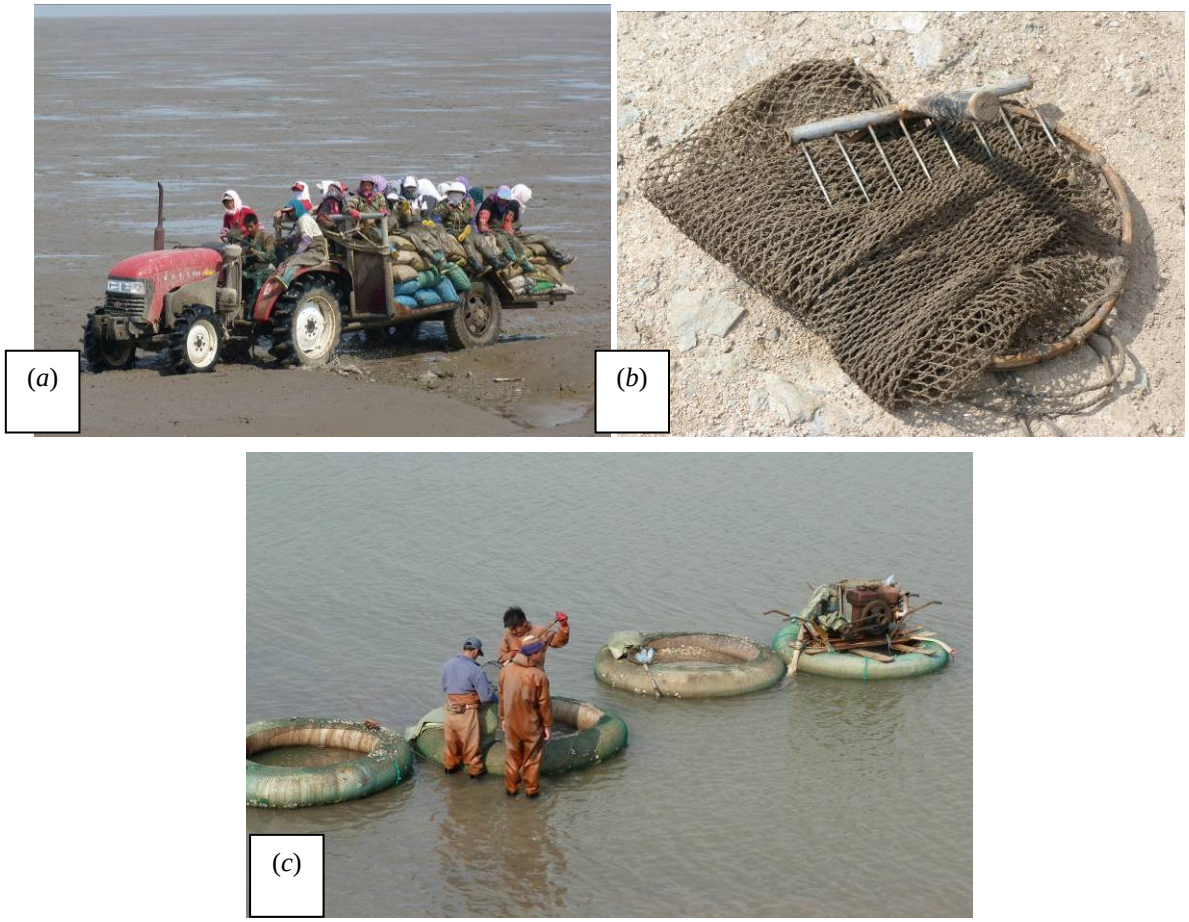


Fig S24. Examples of commercially harvested molluscs: (*a*) *Mactra veneriformis*, (*b*) *Sinonovacula constricta*, and (*c*) *Bullacta exarata*. (Photos: D. S. Melville.)

Spat of bivalves such as *Mactra veneriformis*, *Meretrix meretrix*, razor clam (*Sinonovacula constrica*), and *Ruditapes* [*Venerupis*] *philippinarum* (Fig. S24) are reared industrially in heated nursery houses and then seeded on tidal flats. Spat may travel long distances between hatchery and tidal flat, for example *S. constricta* from Zhejiang being seeded on flats in Liaoning Province, a distance of >1000 km. China has introduced 93 coastal and marine plant species and 89 animal species (Tang *et al*. 2013). Some of these are now of significant economic importance (e.g. Bay Scallops (*Argopecten irradians*)). Others, however, have become problems. The mud snail *Bullacta exarata*, although native to southern and eastern China, was introduced to Laizhou Bay, Shandong Province, where it now occurs in very high densities (>160 individuals m^{-2}) (Du *et al.* 2010) and reportedly has replaced *Umbonium thomasi* and *Mactra veneriformis* (Tang *et al*. 2013), the latter being an important prey species for some shorebirds, and of commercial importance.

Before seeding tidal flats, the areas may be cleared of unwanted organisms, such as potential predators, through spraying with the organophosphorus pesticide triazophos (Lin and Yuan 2005; Fig. S25). This practice apparently started in Zhejiang Province (X. J. Wen, pers. comm.) but has been spreading and is now known from some areas within the Yellow Sea. Triazophos has been reported causing gross and serum biochemical changes in birds (Ghaffar *et al*. 2015) but it is not known whether shorebirds are directly affected by poisoning. However, they may be affected by reduced prey stocks following poisoning of tidal flats and the killing of burrowing organisms may affect sediment characteristics, with potential trophic cascade effects.

S. constricta are seeded in the spring, at a density of 1000–1500 kg ha^{-1} (MacAlister Elliott and Partners Ltd 2000), and *Rutipaes* [*Venerupis*] *philippinarum* at a density of 3000–4000 individuals per square metre (Zhang and Yan 2006). Spat sown on tidal flats provide potential food for shorebirds, in particular Great Knots. However, people are often employed to scare birds away from seeded areas using firecrackers until the spat have settled (this may be several weeks).

Subtidal artificial reefs, using rocks and oyster shells in polyethylene mesh bags, have been created in some areas, such as Jiaozhou Bay, Shandong Province, for production of sea cucumbers (Zhang *et al.* 2015) but the effect, if any, of such farming practices on intertidal habitats is not known.

Fig. S25. Workers heading out to the tidal flats near Rudong, Jiangsu Province, to spray pesticide on the mudflat, particularly to kill glycerid polychaetes. More than 20 people did this for at least 6 h over the low tide on 27 April 2015 (T. Piersma, in litt.). (Photo: © T. Piersma.)

Fig. S26. Harvesting of polychaetes, at Dongying, Shandong Province. (*a*) Buses bring harvesters to the coast. (*b*) Intertidal flats are dug over. (*c*) The harvest is weighed. (*d*) Worms ready for export. (Photos: D. S. Melville.)

(*c*)

(*d*)

In some areas polychaetes are harvested by hand, digging on the higher tidal flats, in some cases including areas with *Spartina*. The worms are exported to Japan for use as fishing bait and to Europe for use in aquaculture. European imports in 2003 were valued at $US 716 000 (E Costa *et al*. 2006). Details of such harvesting are sketchy, but at Dongying, Shandong Province, only large worms were taken, and the smaller ones left. We estimated that, in May 2014, one person harvested about 50 kg per day, so the 181 people on the mudflat would have taken ~900 kg per -day. Melville (1997) reported that some 60 t of worms were harvested annually from the core area of the Yancheng National Nature Reserve, Jiangsu Province. These worms are taken by species such as Eurasian and Far Eastern Curlews (*Numenius madagascariensis*).

In Canada, commercial harvesting of the polychaete *Glycera* was found to reduce populations of the amphipod *Corophium* and reduce foraging efficiency of Semipalmated Sandpipers (*Calidris semipalmatus*) (Shepherd and Boates 1999). There are now controls on the worm harvest, although recent data suggest increased numbers of *Corophium* in harvested areas (Fisheries and Oceans Canada 2009). In Europe reported impacts have varied between species and localities (Blake 1979; Beukema 1995; de Carvalho *et al.* 2013) but are of sufficient concern that management guidelines have been prepared (Fowler 1999). The effects of worm harvesting in China have not been studied.

Disturbance of shorebirds by harvesters has been reported in the Netherlands (van den Heiligenberg 1987), although Fearnley *et al.* (2013) found little effect in England. Large numbers of people (hundreds) are often involved in coastal areas in China and disturbance effects may increase in future as intertidal areas become smaller as a result of land claim, and birds and people increasingly compete for both space and resources. This a topic requiring further research.

Fig. S27. Nets for culturing the seaweed *Pophrya yezoensis*, Jiangsu Province. (Photo: D. S. Melville.)

The red alga *Porphyra yezoensis* (nori) is grown extensively on fixed nets and semi-floating raft frames in the coastal area of Jiangsu Province. Fixed nets in intertidal areas are often preferred because the regular exposure to air reduces problems with competitive algal species and reduces the incidence of disease (Chen and Xu 2005). The area used for culturing *Porphyra* increased from 9460 ha in 2003 to 22 974 ha in 2008 (Liu *et al*. 2009), and 38 260 ha in 2010 (Li 2013), with the industry centred around Yancheng (10 000 ha) but extending from Nantong in the south (8667 ha) to Lianyungang in the north (4307 ha) (Liu *et al*. 2010; Huo *et al.* 2015). At Yancheng, nori rafts extend for up to 11 km offshore, and individual lines of racks are ~100 m long, with ~7 m between lines; one series of such lines of racks may extend >1 km with 50–60 m open spaces between them (Fig. S28). The racks are seeded in October and harvest occurs in May, thus overlapping with the northward migration of shorebirds.

Previous studies of the effects of racks for culturing oysters (*Crassostrea gigas* and *C. virginica*) on shorebirds (Kelly *et al*. 1996; Hilgerloh *et al*. 2001; Burger *et al*. 2015) have surveyed much smaller extents of racks than those currently found in China. In these studies, the response of shorebirds to the presence of oyster racks varied between species, but the interpretation of results was potentially confounded by environmental variables, such as changes in patterns of sedimentation and erosion around racks, which affected the benthos. Both Kelly *et al*. (1996) and Burger *et al*. (2015) noted that the landscape structural effects of racks might make sites less attractive to shorebirds, especially larger species, by reducing the field of view and compromising escape in the event of predator attack. It seems likely that the very large areas of *Porphyra* racks are reducing the numbers of shorebirds using parts of the Chinese coast, but study is required to determine the extent of effects, if any.

Non-commercial seaweeds also grow on the rafts and are removed at the time of harvest, being discarded to the sea where they have created massive green algal blooms, dominated by *Ulva prolifera* (Zhou *et al.* 2015). These have become a feature of the southern Yellow Sea in early summer since 2007; in 2012, algal blooms affected an area of 36 450 km^2 (Liu *et al*. 2015*b*). The increase in frequency of and area covered by such blooms is also probably associated with worsening water quality along the Jiangsu coast resulting from increased nutrient loads (Xing *et al.* 2015). Farmers reported cleaning racks using sulphuric and nitric acid to kill algal spores and disease organisms (Y. Chen and D. S. Melville, unpubl. data); the waste material falling to the tidal flat where it is likely to affect invertebrates.

Fig. S28. Lines of *Porphyra* (nori) nets or racks, ~11 km offshore of the Jiangsu coast, 28 November 2013. (Image: Google Earth, dated 28 November 2013, accessed 12 May 2015.)

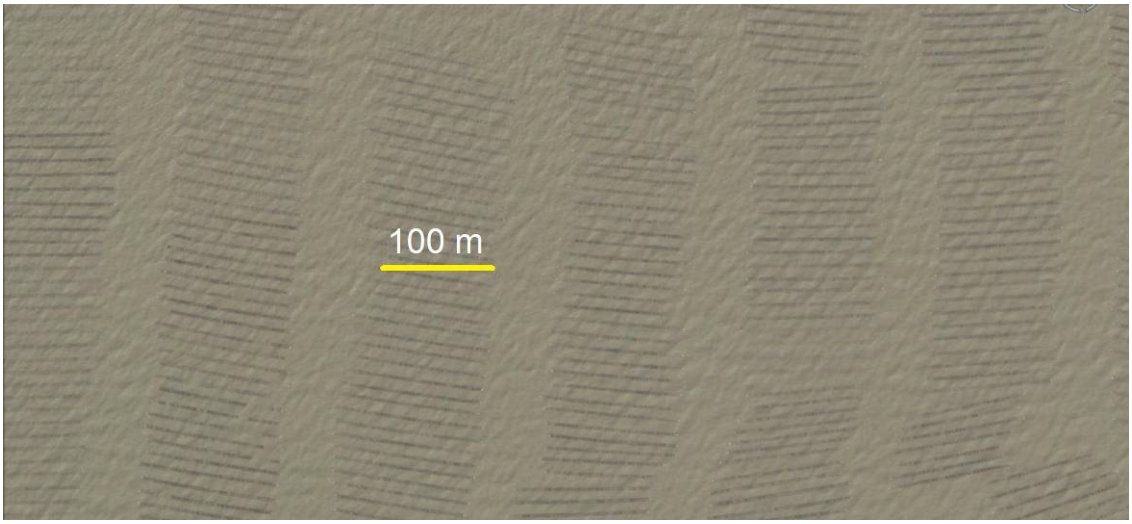


Fig. S29. Biofilm collected from the margins of a tidal channel dries in the sun, Shuangtaizihekou National Nature Reserve, Liaoning Province. This dried biofilm is used as probiotic for aquaculture. (Photos: D. S. Melville.)

Pollution

A project is underway to find an alternative to Dichlorodiphenyltrichloroethane (DDT) for use in anti-fouling paint, and one factory in Tianjin apparently closed in 2011 (UNDP 2011). Persistent organic pollutants occur in high concentrations in coastal waters, especially in Bohai (Bao *et al*. 2012), are widespread in bivalves around the Bohai and northern Yellow Sea (Jin *et al.* 2008; Zhang *et al*. 2009), and potentially pose a threat to shorebirds.

Mercury pollution is of concern, especially methylmercury which biomagnifies in the food chain (Eisler 1987). China is responsible for ~40% of global by-product emissions of mercury to the atmosphere, much coming from coal-fired power stations (Pacyna *et al*. 2010). Luo *et al*. (2012) noted increased mercury levels associated with chlor-alkali facilities and Huang *et al*. (2008) recorded elevated mercury levels in sediments adjacent to a salt industry facility in northern Jiangsu. Mercury occurs in biota at levels that are considered to be unsafe for human consumption (Luo *et al.* 2012) and levels are likely to increase as a result of emissions from the growing number of coal-fired power stations and a variety of industries. Upgrading chlor-alkali facilities, however, should remove this source of pollution.

Pollution from aquaculture facilities, including uneaten feed, nutrients, disinfectants and various other chemicals are a matter of concern. Shrimp-ponds around the Bohai and Yellow Seas were estimated to have discharged 1.03×10^8 m^3 of waste water daily in 2002, with the total amount of uneaten feed discharged amounting to more than 1.2×10^5 t (Cao *et al.* 2007). Discharged water from shrimp-ponds also contains elevated levels of nitrogen and phosphorous (Table S5).

Antibiotics have been widely misused in aquaculture in China. The European Union prohibited import of shrimps from China owing to high levels of chloramphenicol (Xie & Yu 2007), and the main source of sulfonamides, antibiotic-resistant bacteria and antibiotic-resistant genes in *Escherichia coli* was from aquaculture and wastewater treatment plants (Na *et al.* 2014). Rico *et al*. (2012) report that 17 different antibiotics have been used in aquaculture in China, and that ~75% of antibiotics administered as feed subsequently enter the wider environment. However, it appears that there is scope for changing behaviour of farmers to adopt more benign methods of aquaculture in return for certification that would enable them to achieve higher prices (Ortega *et al*. 2014). Antibiotics are also discharged to the coastal environment from sewage treatment plants. Antibiotics may affect shorebirds as a result of impacts on microalgae working through the food chain. A wide range of antibiotics has been reported from bivalves in the Bohai, with levels exceeding maximum residue limits (Li *et al*. 2012), and tetracycline-resistant bacteria have been found in Jiaozhou Bay, Shandong Province (Dang *et al.* 2008). Antibiotic-resistant bacteria have been reported from a variety of shorebirds (Veldman *et al*. 2013) and there is a possibility that shorebirds may spread such organisms along their migratory routes (Santos *et al*. 2012). The study of the gastro-intestinal microbiota of

shorebirds is only just starting (Grand *et al*. 2015) and the potential effect of antibiotic-resistant bacteria on shorebirds is unstudied.

Microplastics, which were identified by Sutherland *et al*. (2012) as a possible future threat to shorebirds through food-chain effects, are known from the Yangtze River estuary (Zhao *et al*. 2014) and are probably widespread (Qiu *et al.* 2015).

Fig. S30. (*a*) Wooden fishing boats are treated with anti-fouling paint containing DDT. In 2010, 250 t of DDT were used in paint manufacture. A United Nations Development Programme-funded project is researching alternatives. (*b*, *c*) Large quantities of 'medicines' are often used in aquaculture ponds and there is concern regarding the potential effects of treated water is discharged to tidal areas. (Photos: D. S. Melville.)

Table S5. Amount of discharge of wastes from shrimp aquaculture around the Bohai and Yellow Seas in 2002 (after Cao *et al.* 2007)

N, nitrogen; P, phosphorous; COD, chemical oxygen demand

Region	Area under aquaculture (ha)	Wastewater discharge (m^3)	N (t)	P (t)	COD (t)
Liaoning Province	39 258	35.3×10^8	353	35.3	7060
Hebei Province	20 755	18.7×10^8	187	18.7	3740
Tianjin Municipality	2960	2.7×10^8	27	2.7	540
Shandong Province	60 428	50.4×10^8	504	50.4	10 080
Jiangsu Province	14 073	12.7×10^8	127	12.7	2540
Total	180 833	141.91×10^8	1334.8	183.8	28 847.5

Tourism

Development of tourist attractions is a growing business, especially near large population centres. Tianjin (population 14 million) is only 120 km (a 29-min high-speed train journey) from Beijing (population 21 million) and is currently undergoing extensive development of tourist attractions in the Binhai Tourism Zone, which covers 45 km^2 of land and 74 km^2 of 'water' (Anon. 2010). Tianjin's current coastal attractions include the Binhai Aircraft Carrier Theme Park and the Tin Hau/Mazu Cultural Park, which is due to open in 2016. The entire park is on reclaimed land (Liu 2015), part of a 30-km^2 reclamation site that included subtidal areas. Much of the remaining tidal area around Tianjin, which continues to support internationally important populations of 11 species of shorebirds (Bai *et al.* 2015), as well as most of the world population of Relict Gull (*Larus relictus*) (Townsend 2015), is likely to be lost to further reclamation, including for marina and housing development.

Beach nourishing is increasingly being used to maintain sandy beaches subject to erosion, as at Beidaihe, Hebei Province, or to create new sandy beaches for tourism in areas where the natural shoreline is silt or mud, such as at Tianjin (Luo *et al*. 2015), and Jinzhou, Liaoning Province. High levels of human disturbance at created sand beaches are likely to deter birds, and prey may be reduced by deposition of sand (Peterson *et al.* 2006).

Ecotourism is seen as a major growth industry in China, and many nature reserves have developed tourist attractions that often include displays of captive birds. Coastal reserves often display Red-crowned Cranes (*Grus japonensis*), which are large, culturally significant, and fairly easy to maintain in captivity, whereas shorebirds are very seldom seen. Emphasis is often on entertainment rather than education or increasing public awareness.

At Panjin, Liaoning Province, the 'red sea' of *Suaeda* growing on the upper tidal flats is an important tourist attraction. A tourist highway toll road has been constructed along the coast and visitors can view the tidal flats from specially constructed walkways and platforms, thus giving value to the naturally occurring saltmarsh and tidal flats. In contrast, exotic *Spartina* was deliberately planted at Rudong, Jiangsu Province, to create a 'yellow sea of grass' on the Yellow Sea coast as a tourist attraction but the *Spartina* is now spreading rapidly and encroaching on intertidal areas where Spoon-billed Sandpipers stage on both northward and southward migration.

At Gao Sha Ling, in Tianjin, access to the coast is controlled by the local community and tourists can pay to collect shellfish (10 renminbi per person), as well as hiring rubber boots and buckets. We were advised that ~1000 people visited daily in the off season but that up to 10 000 people may be present daily in the busy season. This section of coast continues to support important shorebird populations, at least at times when fewer tourists are using the beach (Y. Chen and D. S. Melville, unpubl. data).The 'Disco on the Sea' at Rudong, Jiangsu Province, is another clam-harvesting attraction (Nantong Travel Bureau 2015).

Along much of the Yellow Sea coast, waders are difficult to see, with roosting and foraging sites often not readily accessible. However, at Yalu Jiang Estuary National Nature Reserve, Liaoning Province, large flocks of waders often roost close to the seawall and attract many bird photographers, although these can also cause disturbance, for example using firecrackers to make the birds fly to obtain more spectacular photographs. The Dandong Birding Festival, held at Yalu Jiang Estuary National Nature Reserve, organised by the Dandong Tourism Bureau, attracted large numbers in May 2014, and a new visitor centre and bird watching houses were constructed for the event (Woodley 2014).

Fig. S31. Tourism development in coastal Tianjin. (Image: Google Earth, dated 15 March 2015, accessed 12 May 2015.)

Fig. S32. The 42.3-m tall statue of Mazu/Tian Hau, the Chinese goddess of the sea, is the centrepiece of the Tianjin Mazu Cultural Park, and situated ~6 km offshore on a newly reclaimed site. (Photo: D. S. Melville.)

Fig. S33. Artist's impression of the Sino Australia Royal Yacht City, Tianjin, which is being developed in the area of Bohai Bay where most of the world population of Relict Gull (*Larus relictus*) stages on migration. The area is also important for shorebirds such as Asian Dowitcher (*Limnodromus semipalmatus*). (Image: *China Daily USA* (Li 2011), Photo: D. S. Melville.)

Fig. S34. A ‘red sea’ of *Suaeda* is an important tourist attraction in Panjin, Liaoning. (Photos: D.S. Melville.)

Fig. S35. Tourists gather shellfish at Gao Sha Ling, Tianjin. (Photo: D. S. Melville.)

Hunting

Commercial hunting of shorebirds has long been practised on China's coasts. Markets in the late 1800s and early 1900s had a variety of species for sale (La Touche 1931–34) and Cheng (1963) reported on the economic importance of several species of shorebird noting, for example, that the flesh of the Common Redshank (*Tringa totanus*) was edible, whereas that of Eurasian Curlew was 'very tasty', and that both species were often hunted for food. In 1985 a container load of frozen waders was imported to Hong Kong but sales of birds was poor (Parrish & Melville 1985) and apparently no further imports were made (D. S. Melville, unpubl. data).

Apart from an indication that one market in Shanghai sold 36 000 'snipe' a year (Wade 1910), it was not until the late 1980s and early 1990s that any attempt was made to determine the size of commercial harvests in China. Tang & Wang (1995) estimated that harvests around the Shanghai area accounted for 6800–10 000 birds on southward migration, the most commonly caught species being Red-necked Stints (*Calidris ruficollis*) (15.5%), Dunlin (*Calidris alpina*) (10.7%), Bar-tailed Godwits (10.1%) and Common Greenshanks (*Tringa nebularia*) (9.2%). On northward migration harvests were much larger, estimated at 32 200–52 700 birds, with the most frequently caught species being Great Knot (42.4%), Sharp-tailed Sandpiper (*Calidris acuminata*) (9.3%), Red Knot (8.6%) and Whimbrel (*Numenius phaeopus*) (8.0%). Birds were caught using clap nets with live decoys. By the mid-1990s commercial harvesting of waders around Shanghai had largely ceased due to a combination of legal protection and changing economic conditions; several of the highly skilled trappers are now employed by Chongming Dongtan National Nature Reserve to catch birds for banding (Tang *et al*. 2011).

Sport hunting of snipes (*Gallinago* spp.) was common in the marshlands, for example around Shanghai (Styan 1910) and Hong Kong (Aymas 1930). Sport hunting was starting to happen by the mid-1980s, including on nature reserves (D. S. Melville, unpubl. data), but the ban on owning firearms that was implemented in 1996 has greatly reduced recreational hunting, although it still occurs to some extent (Ma *et al*. 2012) and its impact on shorebirds is likely to be small.

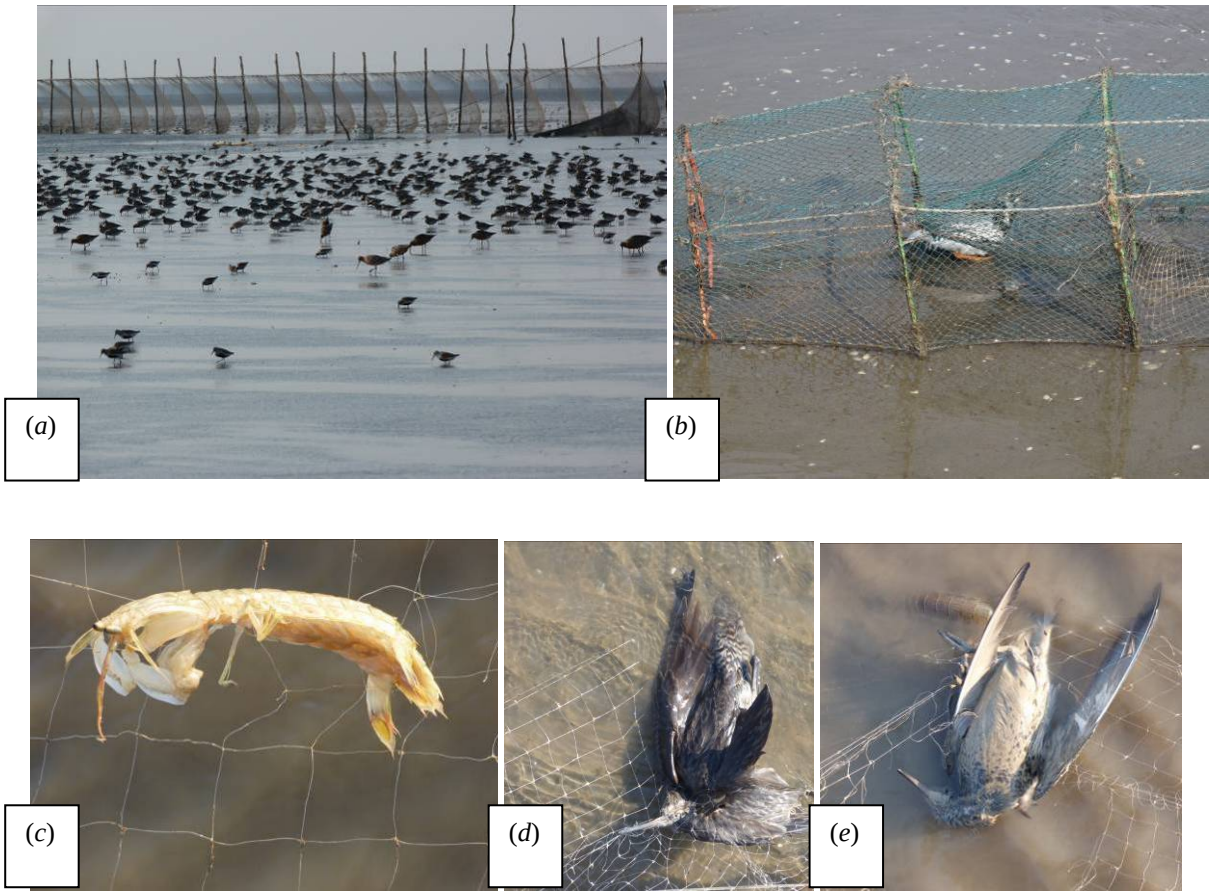
The most commonly used poison for waterfowl is the carbamate pesticide carbofuran mixed with grain. Interviews with fishermen in Shandong revealed that a pesticide known locally as '666' (the organochloride pesticide hexachlorocyclohexane) is mixed with small crabs, which are spread on tidal flats to catch 'curlews' (Y. Chen and D. S. Melville, unpubl. data). It is likely that bycatch of such waterfowl hunting includes other species that feed on crabs, notably Saunders' Gull, which has been found dead in the Yellow River Delta (Y. Chen and D. S. Melville, unpubl. data). At Rudong, Jiangsu Province, poisoned shrimps are placed at roosting and feeding sites and a variety of waders killed (Clark *et al*. 2015). In some instances it remains unclear whether apparent poisoning is deliberate or may result from the use of triazophos in aquaculture activities (see section on Aquaculture, above).

In addition to intentional hunting, birds are also accidentally caught in nets set for fish and mantis shrimp (*Oratosquilla oratoria*) exposed at low tide, and in funnel traps set for crab and fish. Such birds drown on the next high tide if they are not taken by fishermen. Ruddy Turnstones (*Arenaria interpres*) seem to be particularly prone to capture in crab traps at Yalujiang, Liaoning Province (D. S. Melville, personal observation), whereas at Nanpu, Hebei Province, birds caught in nets included Common Greenshanks (*Tringa nebularia*), Marsh Sandpipers (*Tringa stagnatilis*) and Terek Sandpipers (*Xenus cinereus*) (Anon. 2012*b*). The number of such fatalities is not known, but up to 25 birds a day were reported caught at Nanpu (Anon. 2013*b*), and 71 were recorded in ~350 m of net at Rudong, Jiangsu Province, in September 2015, including one Spoon-billed Sandpiper (G. Anderson, personal communication). This suggests that over the course of the northward migration potentially tens of thousands of birds are killed along the coast.

Fig. S36. Birds found dead ~5 km inland at Rudong, Jiangsu Province. These birds were among many apparently deliberately poisoned in a grassland area; there were also mist-nets and loudspeaker systems at the location. The dead birds shown are a Whimbrel (*Numenius phaeopus*), Little Whimbrel (*Numenius minutus*), Pacific Golden Plover (*Pluvialis fulva*), Yellow Wagtails (*Motacilla flava*), and a Yellow-billed Grosbeak (*Eophona migratoria*). The Little Whimbrel is one of only three shorebirds protected in China. (Photo: © Hannu Jännes.)

Fig. S37. Weiguo Jin, a former bird hunter, now uses his Wilsternetting skills to catch waders for banding at Chongming Dongtan National Nature Reserve, Shanghai. (Photo: D. S. Melville.)

Fig S38. (*a*) Fish traps, which often extend for >1 km across tidal flats, are a common feature of the coast but pose no threat to shorebirds other than offering a perch for an occasional hunting Peregrine Falcon (*Falco peregrinus*). (*b*) Fish and crab traps do, however, catch shorebirds, such as Ruddy Turnstones (*Arenaria interpres*). (*c*–*e*) Monofilament nets set for (*c*) mantis shrimps *Oratosquilla oratoria* catch species such as (*d*) Bar-tailed Godwits (*Limosa lapponica*) and (*e*) Great Knots (*Calidris tenuirostris*).



Nature reserves

Zheng *et al.* (2012) report a 20% reduction in the area of coastal wetland reserves (compared with 8% wetland reserve reduction nationally) in the period 1978–2008, noting that 'This is because coastal wetland reserves are often located in developed areas with heavy population pressure, where land use often changes as a result of government policy'. They also found that 'poor' reserves were located in Tianjin, the northern Shandong coast and Jiangsu Province.

Fig. S39. Changes to the boundary of Yalujiang National Nature Reserve, Liaoning Province. (*a*) In 2007 the reserve boundary was changed to facilitate the expansion of Dandong Port to the east of the reserve. (*b*) A further boundary change was implemented in 2012, which significantly reduced the Experimental Area on the western and eastern sides of the Reserve, but resulted in an increase in the core area. Red, core area; Yellow, buffer area; Green, experimental area.

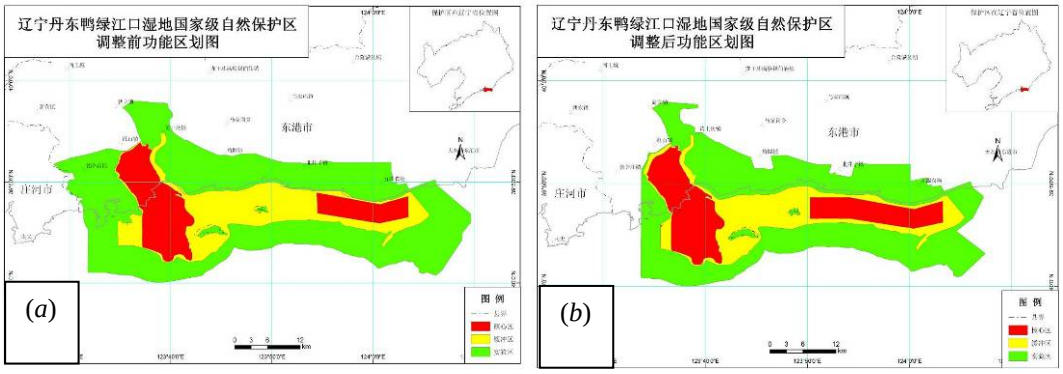


Table S6. Changes in area of Yalujiang National Nature Reserve, Liaoning Province, 1997–2013 (also see Fig. S39)

	2013	2007	1997
Core area	16 000	14 082	14 642
Buffer area	20 000	24 674	71 057
Experimental area	45 430	62 244	22 358
Total	81 430	101 000	108 057

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