Marine and Freshwater Research, 2018, **69**, 1525–1533
https://doi.org/10.1071/MF17377

Supplementary material

Extent, regional distribution and changes in area of different classes of wetland

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This Supplementary material provides:

- tables of global and regional areas, and changes in area, of inland, marine and coastal natural wetland classes and human-made wetland classes and their sources; and
- a more detailed assessment of the available data and information on area and area changes for each wetland class, supporting the derivation of the summary assessment provided in the main paper.

Global and regional areas, and changes in area, of inland, marine and coastal and human-made wetland classes and their sources

Table S1. Global and regional areas of inland, coastal and marine and human-made wetland classes and their sources

NA indicates no information available

Wetland classes/sub-classes	Wetland classes: global area (×10^6 km^2)	Wetland sub-classes: global area (×10^6 km^2)	Regional distribution (percentage of global area): Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania	Source(s)	Notes
1. Inland (natural) wetlands										
Rivers and streams	0.624		NA	NA	NA	NA	20	NA	Raymond *et al*. 2013	Previous estimate: Lehner and Döll 2004: 0.360 × 10^6 km^2. Allen and Pavelsky 2015 provide an area for North America: 0.124 × 10^6 km^2; 20% of Raymond *et al*.'s 2013 global area.
	0.662		NA	NA	NA	NA	NA	NA	Downing *et al*. 2012	
Natural lakes and pools	4.200		NA	NA	NA	NA	NA	NA	Downing *et al*. 2006	All lakes >0.1 ha.
	3.232		NA	NA	NA	NA	NA	NA	Messager *et al*. 2016	All lakes >1 ha. Previous estimate: Lehner and Döll 2004: 2.428 × 10^6 km^2.
Natural lakes (≥10 ha)		2.905							Downing *et al*. 2006	
		2.670	9	10	29	4	46	2	Messager *et al*. 2016	
Natural lakes and pools (<10 ha)		1.295	NA	NA	NA	NA	NA	NA	Downing *et al*. 2006	Lakes and pools 0.1–10 ha.
		0.562	NA	NA	NA	NA	NA	NA	Messager *et al*. 2016	Lakes and pools 1–10 ha. Calculated as the difference between Messager *et al*.'s areas for lakes >1 ha and lakes >10 ha
Peatlands	4.292		4	38	12	11	33	2	Xu *et al*. 2018	Previous estimate: Joosten 2010: 3.814 × 10^6 km^2.
a. Non-forested peatlands (bogs, mires and fens)		3.118	3	48	11	1	35	1	Joosten 2010	Previous estimate Lehner and Döll 2004 ('bog, fen, mire' classes): 0.708 × 10^6 km^2.
b. Forested peatlands		0.696	7	8	24	19	38	6	Joosten 2010	
c. Tropical and subtropical peatlands		1.505	18	34	Not present	46	Not present	2	Gumbricht *et al*. 2017	Oceania percentage distribution derived from Gumbricht *et al*. 2017 Supporting material. Previous estimates: Page *et al*. 2011: 0.439 × 10^6 km^2; and by subtraction of Joosten's (2010) temperate and boreal peatland area from total peatland area: 0.434 × 10^6 km^2.
d. Temperate and boreal peatlands		3.380	NA	NA	NA	NA	NA	NA	Joosten 2010	

Wetland classes/sub-classes	Wetland classes: global area ($\times10^6$ km^2)	Wetland sub-classes: global area ($\times10^6$ km^2)	Regional distribution (percentage of global area) Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania	Source(s)	Notes
Marshes and swamps (on alluvial soils), including floodplains	2.530		NA	NA	NA	NA	NA	NA	Lehner and Döll 2004	Covers: 'Freshwater Marsh, Floodplain' classes
a. Tropical freshwater swamps (incl. forests) on alluvial soils		1.460	38	24	Not present	33	Not present	5	Giesen 2018	Area of forested tropical freshwater swamps not separately available
Forested wetlands (alluvial soils)	1.165		NA	NA	NA	NA	NA	NA	Lehner and Döll 2004	Covers 'Swamp Forest, Flooded Forest' classes which may include both peat and alluvial soil forests.
Groundwater-dependent wetlands	NA		NA	NA	NA	NA	NA	NA		
a. Karst and cave systems		NA	NA	NA	NA	NA	NA	NA		Carbonate rocks with karst groundwater circulation may cover 14% (19 × 10^6 km^2) of global land area (Williams 2008), but no underground wetland area available.
b. Springs and oases		NA	NA	NA	NA	NA	NA	NA		
c. Other groundwater-dependent wetlands		NA	NA	NA	NA	NA	NA	NA		
2. Marine/coastal natural) wetlands										
Estuaries	0.660		NA	NA	NA	NA	NA	NA	Lehner and Döll 2004	Lehner and Döll's (2004) 'Coastal wetland' class. Previous estimate: UNEP-WCMC 2003; Agardy and Elder 2005 (~1200 major estuaries only): 0.500 × 10^6 km^2. 'Estuaries' are a non-exclusive wetland category, which can include unvegetated tidal flats, seagrass beds, saltmarshes, shallow marine systems and sometimes mangroves.
a. Unvegetated tidal flats		0.458	10	18	5	20	37	10	Schuyt and Brander 2004	
b. Saltmarshes		0.550	<1	10	21	3	41	25	Mcowen *et al*. 2017	Areas are from 43 of the 99 countries in which saltmarsh is known to occur, but these considered to cover most parts of the world in which there are major saltmarsh areas. Previous estimate: 0.068 × 10^6 km^2 (Schuyt and Brander 2004).
c. Coastal deltas		>0.030		NA	NA	NA	NA	NA	Coleman *et al*. 2008	Coleman *et al*. 2008 provides an area of 30 225 km^2 for 14 major coastal deltas
Mangroves	0.138		20	42	Not present	11[A]	15[B]	12	Giri *et al*. 2011; UNEP-WCMC 2011	

Wetland classes/sub-classes	Wetland classes: global area (×10^6 km^2)	Wetland sub-classes: global area (×10^6 km^2)	Regional distribution (percentage of global area) Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania	Source(s)	Notes
Seagrass beds	0.177		NA	NA	NA	NA	NA	NA	Spalding *et al*. 2003	
Coral reefs (warm water systems only)	0.284		8	41	Not present	11	1	39	Spalding *et al*. 2001	Cold water corals occur in marine waters deeper than 6-m permanent inundation and so are outside the scope of this assessment
Shellfish reefs	NA		NA	NA	NA	NA	NA	NA		
Coastal lagoons	NA		NA	NA	NA	NA	NA	NA		
Kelp forests	NA		NA	NA	NA	NA	NA	NA		
Shallow subtidal marine systems (<6-m depth)	NA		NA	NA	NA	NA	NA	NA		Estimated for Mediterranean Basin only: 0.042 × 10^6 km^2 (Mediterranean Wetland Observatory 2018)
Sand dunes, beaches or rocky shores	NA		NA	NA	NA	NA	NA	NA		
Coastal karst and caves	NA		NA	NA	NA	NA	NA	NA		
3. Human-made wetlands										
Water storage bodies										
a. Reservoirs		0.443	NA	NA	NA	NA	NA	NA	Lehner *et al*. 2011; http://atlas.gwsp.org/index.php?option=com_content&task=view&id=207&Itemid=68 (accessed 15 September 2017)	Previous estimates: 0.251 × 10^6 km^2 (Lehner and Döll 2004); 0.259 × 10^6 km^2 (Downing *et al*. 2006)
b. small (e.g. farm) ponds		0.077	NA	NA	NA	NA	NA	NA	Downing *et al*. 2006	
Agricultural wetlands										
a. Rice paddy		1.282	7	88	1	3	1	< 1	Salmon *et al*. 2015; IRRI World Rice Statistics (see http://ricestat.irri.org:8080/wrsv3/entrypoint.htm, accessed 20 July 2017)	Worldwide area is for rice paddy (irrigated and rain-fed) (Salmon *et al.* 2015); regional areas are for total rice production area (see http://ricestat.irri.org:8080/wrsv3/entrypoint.htm), 79% of which is rice paddy. Previous rice paddy estimate: 1.29 × 10^6 km^2 (Aselmann and Crutzen 1989)
b. Palm oil/pulpwood plantations (on peatlands)		0.002	NA	NA	NA	NA	NA	NA	Miettinen *et al*. 2012	Area is for SE Asia only. No area estimates are available for Africa or Latin America and the Caribbean, where peatland conversion to palm oil plantation is reported to be occurring
c. Wet grasslands	NA		NA	NA	NA	NA	NA	NA		
iii. Wastewater treatment wetlands/ constructed wetlands	NA		NA	NA	NA	NA	NA	NA		Area available only for USA: 0.004 × 10^6 km^2 (Dahl 2011)
Saltpans (salines/salinas)	NA		NA	NA	NA	NA	NA	NA		Area available for Mediterranean Basin only: 750 km^2 (Perennou *et al*. 2012)

https://doi.org/10.1071/MF17377

Wetland classes/sub-classes	Wetland classes: global area ($\times 10^6$ km^2)	Wetland sub-classes: global area ($\times 10^6$ km^2)	Regional distribution (percentage of global area)						Source(s)	Notes
			Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania		
Aquaculture ponds	NA		NA	NA	NA	NA	NA	NA		
Human-made karst and caves	NA		NA	NA	NA	NA	NA	NA		

[A]Latin America only

[B]North America and Caribbean. Previous estimates: 0.121×10^6 km^2 (Schuyt and Brander 2004); 0.152×10^6 km^2 (FAO 2007)

Table S2. Global and regional trends in the area of wetland classes and their sources

NA indicates no information available. Qualitative area changes are as follows: →, no change (±5%); ↓, decrease between –5 and –50%; ↓↓, decrease of more than –50%; ↑, increase between +5 and +50%; ↑↑, increase greater than 50%

Wetland class/sub-class	Wetland class: global area change (%)	Wetland sub-class: global area change (%)	Average annual rate of area change (% $year^{-1}$)	Global qualitative area change	Regional area change (percentage change)						Source(s)	Comments and notes
					Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania		
1. Inland (natural) wetlands												
Rivers and streams	NA		NA	↓	NA	NA	NA	NA	NA	NA	Downing *et al*. 2012; Raymond *et al*. 2013	
Natural lakes and pools	NA		NA	↓	NA	NA	NA	NA	NA	NA		
a. Natural lakes (>10 ha)		NA	NA	↓	NA	NA	NA	NA	NA	NA	Messager *et al*. 2016	Increases reported for some areas (e.g. Tibetan Plateau), but major decreases in at least some lakes in other areas (e.g. Aral Sea, Lake Chad, other African lakes, parts of western Europe) (see also Davidson 2014, Supplementary material).
b. Natural lakes and pools (<10 ha)		NA	NA	NA	NA	NA	NA	NA	NA	NA		
Peatlands	–0.97		–0.05	→	+0.69	–0.74	–4.92	+0.80	–0.11	–0.54	Joosten 2010	Area change 1990–2008
a. Non-forested peatlands (bogs, mires and fens)		+6.80	+0.38	↑	+1.72	+15.60	–2.57	+3.64	–0.11	+16.41	Joosten 2010	Area change 1990–2008
b. Forested peatlands		–25.32	–1.41	↓	–1.17	–80.26	–9.45	–0.15	0	–11.07	Joosten 2010	Area change 1990–2008
c. Tropical peatlands		–28	–2.55	↓	NA	–28	NA	NA	NA	NA	Miettinen *et al*. 2016	SE Asia only. Area change 2007–15. In part of SE Asia losses 2000–10 at a rate of –3.7% $year^{-1}$ (Wilcove *et al*. 2013)
d. Temperate and boreal peatlands		NA	NA		NA	NA	NA	NA	NA	NA		
Marshes and swamps (on alluvial soils), including floodplains	NA		NA	↓	NA	NA	NA	NA	0.0	NA		Decreases reported from parts of most regions, except N America: recent no change 2004–08 (Dahl 2011).
a. Tropical freshwater swamps (incl. forests) on alluvial soils		NA	NA	↓	NA	NA	NA	NA	NA	NA		

Wetland class/sub-class	Wetland class: global area change (%)	Wetland sub-class: global area change (%)	Average annual rate of area change (% $year^{-1}$)	Global qualitative area change	Regional area change (percentage change)						Source(s)	Comments and notes
					Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania		
Forested wetlands (on alluvial soils)	NA		NA		NA	NA	NA	NA	NA	NA		
Groundwater-dependent wetlands			NA									
a. Karst and Cave systems		NA	NA	→	NA	NA	NA	NA	NA	NA		Likely to be little area change, other than from physical destruction e.g. quarrying
b. Springs and oases		NA	NA		NA	NA	NA	NA	NA	NA		
c. Other groundwater-dependent wetlands		NA	NA		NA	NA	NA	NA	NA	NA		
2. Coastal (natural) wetlands												
Estuaries	NA		NA	↓–↓↓	NA	NA	NA	NA	–1.4 (USA)	NA	Airoldi and Beck 2007; Dahl 2011	Decreases reported from parts of most regions. Small decrease (–1.4%) in USA 2004–08 (Dahl 2011) following a –0.56% decrease 1998–2004 (Dahl 2006). See also area change sources in Davidson 2014, Supplementary material
a. Unvegetated tidal flats		NA	NA	↓–↓↓								Decreases reported from parts of most regions, recently especially SE Asia. See also area change sources in Davidson 2014, Supplementary material
b. Saltmarshes		NA	NA	↓	NA	NA	NA	NA	–2.8 (USA)	NA	Dahl 2011; Airoldi and Beck 2007	Widespread decreases reported for Europe (Airoldi and Beck 2007; Davidson 2018).
c. Coastal deltas		–52.4	–3.74	↓↓	NA	NA	NA	NA	NA	NA	Coleman *et al*. 2008	Area change 1986–2000, for 14 major deltas globally
Mangroves	–19.00		–0.76	↓	–13.9	–24.6	Not present	–11.0[A]	–23.3[B]	–9.6	FAO 2007	
Seagrass beds	–29		–5.00	↓	NA	NA	NA	NA	NA	NA	Waycott *et al*. 2009	Area change 1879–2005. Recent trend negative: –5% 1980–2005.
Coral reefs (warm water systems)	–19		NA	↓	NA	NA	NA	NA	NA	NA	Wilkinson 2008; UNEP-WCMC 2010	Area change is for percentage coral reef cover, not total area

Wetland class/sub-class	Wetland class: global area change (%)	Wetland sub-class: global area change (%)	Average annual rate of area change (% year^{-1})	Global qualitative area change	Regional area change (percentage change)						Source(s)	Comments and notes
					Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania		
Shellfish reefs	–85		NA	↓↓	NA	NA	NA	NA	–64 (USA)	NA	Beck *et al*. 2011; Zu Ermgassen *et al*. 2012	Area change since earliest available records. USA trends mostly 1885–1915 to 2000–10
Coastal lagoons	NA	NA	NA	↓	NA	NA	NA	NA	NA	NA		
Kelp forests	–0.018		<0.0001	→							Krumhansl *et al*. 2016	Area change 1952–2015. No clear regional trends, with increasing and decreasing area changes in adjacent parts of most regions.
Shallow subtidal systems	NA		NA	↓	NA	NA	NA	NA	NA	NA		As a consequence of rising sea-levels and 'coastal squeeze' in some regions small area decrease expected.
Sand dunes, beaches or rocky shores	NA		NA	NA	NA	NA	NA	NA	NA	NA		
Coastal karst and caves	NA		NA	NA	NA	NA	NA	NA	NA	NA		
3. Human-made wetlands												
Water storage bodies												
a. Reservoirs		+31.6	+0.75	↑	NA	NA	NA	NA	NA	NA	GRAnD database (see http://atlas.gwsp.org/index.php?option=com_content&task=view&id=207&Itemid=68, accessed 15 September 2017); Lehner *et al*. 2011	Area change 1970–2012. Major increase in total numbers of large dams since 1950s (Steffen *et al*. 2015).
b. small (e.g. farm) ponds		NA	NA	↑–↑↑	NA	NA	NA	NA	NA	NA	Downing *et al*. 2006	
Agricultural wetlands												
a. Rice paddy		+13.2	+0.62	↑	+146.2	+11.4	+95.8	–32.7	–16.8	–39.1	IRRI World Rice Statistics (see http://ricestat.irri.org:8080/wrsv3/entrypoint.htm, accessed 14 April 2017)	Area change 1980–2014 are for total rice production area, 79% of which is rice paddy (Salmon *et al*. 2015).
b. Palm oil/pulpwood plantations (on peatlands)		+39	+1.56	↑	NA	+39	NA	NA	NA	NA	Miettinen *et al*. 2012	SE Asia only, area change 1990–2007.

Wetland class/sub-class	Wetland class: global area change (%)	Wetland sub-class: global area change (%)	Average annual rate of area change (% year^{-1})	Global qualitative area change	Regional area change (percentage change) Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania	Source(s)	Comments and notes
c. Wet grasslands		NA	NA	↓	NA	NA	NA	NA	NA	NA	Airoldi and Beck 2007	Decreases in Europe; see also area change sources in Davidson 2014, Supplementary material
Wastewater treatment wetlands/constructed wetlands	NA		NA	↑	NA	NA	NA	NA	NA	NA	Dahl 2011; Liu *et al.* 2008	Increases in North America, China
Saltpans (salines/salinas)	NA		NA		NA	NA	NA	NA	NA	NA		
Aquaculture ponds	NA		NA		NA	NA	NA	NA	NA	NA		
Human-made karst and caves	NA		NA		NA	NA	NA	NA	NA	NA		

[A]South America only.

[B]Includes Caribbean. Area change 1980–2005.

https://doi.org/10.1071/MF17377

Assessment of the available data and information on area and area changes for each wetland class

Inland natural wetlands

Rivers and streams

The surface area of rivers and streams is hard to measure, particularly over large geographical scales, as they are largely narrow, linear features, and flooding in tropical areas can increases the areal extent of tropical rivers 100–1000-fold (Melack *et al*. 2009). Global area estimates vary with Raymond *et al*. (2013) most recently providing an upper estimate of 0.624×10^6 km^2, slightly smaller than Downing *et al*.'s (2012) upper estimate of 0.662×10^6 km^2, but larger than Lehner and Döll's (2004) estimate of 0.360×10^6 km^2. Area estimates for most regions are not available, except for North America: 0.124×10^6 km^2 (Allen and Pavelsky 2015), 20% of Raymond *et al*.'s global area estimate.

Consumptive use and inter-basin transfers have transformed several of the world's largest rivers into highly stabilised and, in some cases, seasonally non-discharging channels, and streamflow depletion is a widespread phenomenon (Falkenmark *et al*. 2007). All such changes will have reduced the surface area of rivers.

Lakes

The most recent global estimates of natural lake area are 4.200×10^6 km^2 for lakes >0.1 ha (Downing *et al*. (2006) and 3.232×10^6 km^2 for lakes >1 ha (Messager *et al*. 2016), both higher than a previous estimate of 2.43×10^6 km^2 (Lehner and Döll 2004). However, note that Lehner and Döll's lake area is, by inference, for permanent freshwater lakes only since they also provide separate are figures for 'pan, brackish/saline wetland' which includes salt and soda lakes and 'intermittent lake/wetland' which includes intermittent lakes. The main difference in the areas estimated by Downing *et al*. (2006) and Messager *et al*. 2016) arises from Downing *et al*.'s inclusion of lakes and pools of 0.1 ha to 1 ha, which are not included in Messager *et al*.'s estimates. Downing *et al*. (2006) estimated that there are over 277 $\times 10^6$ such very small lakes, with a global area estimate of 0.693×10^6 km^2, 16.5% of their estimated area of all lakes.

Messager *et al*. (2016) estimates 2.670×10^6 km^2 for lakes >10 ha, similar to Downing *et al*.'s (2006) estimate of 2.905×10^6 km^2. By subtraction the global area of lakes of 1–10 ha area is estimated as 0.562×10^6 km^2 from Messager *et al*. (2016), fairly similar to Downing *et al*.'s (2006) estimate of 0.602 $\times 10^6$ km^2.

Natural lakes >10 ha are widely distributed across all continents, with the largest areas in North America (including Central America and the Caribbean): 1.23×10^6 km^2 (46% of global area); and Europe, including Russia: 0.78×10^6 km^2 (29%), with much smaller total lake areas in Asia (10%), Africa (9%), South America (4%) and Oceania (2%) (Messager *et al*. 2016). Countries with the most lakes and the largest areas of lakes are Canada (880; 0.86 × 10^6 km^2), Russia (201; 0.67 × 10^6 km^2) and the USA (103; 0.34 × 10^6 km^2). By surface area, by far the largest natural lake is the Caspian Sea (0.34 × 10^6 km^2) followed by Lake Victoria (0.07 × 10^6 km^2) and three of the North American Great Lakes – Superior, Huron and Michigan (Messager *et al*. 2016).

Changes in the area of lakes indicate differences in area change between regions and lakes, but with many in decline (Pekel *et al*. 2016; UNEP 2007). An exception occurs on the Tibetan Plateau where many of the endorheic lakes (lakes in closed drainage basins) are expanding and new lakes are forming, leading to a 20% increase in area, 0.008 × 10^6 km^2 (Pekel *et al*. 2016). Lake expansion on the plateau has been linked to increased run-off from accelerated snow-and-glacier melt caused by higher temperatures and annual precipitation.

In contrast, the major decrease in the Aral Sea area has been well documented, with the rate of loss greatest between 1994 and 2009, though lately this has slowed and even partially reversed, with diversion of, and withdrawal from, the Amu and Syr rivers that once fed the lake having been the main causes of loss (UNEP 2012). Natural lakes in China decreased overall by 16% between 1950 and 2000 and 68% between the 1950s and 1989 in the Yangtze and Han River basins (An *et al*. 2007). Lake Urmia (I.R. Iran) decreased by 61% in area between 1969 and 2011 and in India all of Najafgarh Lake was drained between the 1960s and 1990 (Menon 1993).

In Africa, the surface area of Lake Chad decreased by 94.5% between 1983 and 2005 (Gao *et al*. 2011) and Lake Baringo (Kenya) decreased by 14% in area between 1986 and 2000 (Kiage *et al*. 2007). In Europe, Lake Amik (Turkey) was wholly drained between 1965 and 1987 (Kılıç *et al*. 2006); over one-third of the area of Macedonian (Greece) lakes was lost between 1930 and the mid-1980s (Jones and Hughes 1993), and Scottish lochs (natural lakes) decreased in area by 10% between 1947 and 1988 (Mackey *et al*. 1998).

Peatlands

Peatlands, including both forested and non-forested inland peatlands but not including intertidal organic soil wetlands, form a large part, perhaps ~33%, of the area of global inland permanently and seasonally inundated wetlands reported by Davidson *et al*. (2018). Peatlands are estimated as covering 4.232 × 10^6 km^2 (Xu *et al*. 2018), a considerably larger area than the previous estimate of 3.814 × 10^6 km^2 in 2008 (Joosten 2010).

Regionally, the largest areas of peatlands are in Asia (38%), North America (33%), Europe (12%) and Latin America and Caribbean (11%), with much smaller peatland areas in Africa (4%) and Oceania (2%) (Xu *et al*. 2018). Peatlands also occur in the Antarctic and sub-Antarctic islands, but their area is very small (<1% of the global peatland area). In total, 82% of global peatland area is non-forested mires (bogs and fens) (3.118 × 10^6 km^2), with largest areas are in North America (48% of this area), North America (35%) and Europe (11%) (Joosten 2010). Forested peatlands are estimated to cover 0.696 ×

10^6 km^2 (Joosten 2010), with largest areas in North America (38%), Europe (24%) and Latin America and Caribbean (19%).

Tropical and subtropical peatland area has been recently estimated as 1.505 × 10^6 km^2 (Gumbricht *et al*. 2017), a much larger area than the 0.385 × 10^6 km^2 of tropical peatlands estimated by Page *et al*. (2011). In considerable part this is because much larger areas of tropical peatland have now been identified in Latin America (Amazon Basin) and in Africa (Congo Basin) (see e.g. Lähteenoja *et al*. 2012; Dargie *et al*. 2017). Such areas had previously been recognised as wetlands (e.g. Lehner and Döll 2004), but not as on peat soils. A much larger proportion of tropical peatlands are now recognised to be in Latin America and the Caribbean (46%), with smaller proportions in Asia (34%) and Africa (18%) and ~2% in Oceania (Gumbricht *et al*. 2017).

Even the larger area now estimated for tropical peatlands a much smaller area than that of 3.38 × 10^6 km^2 (88% of global area) estimated for temperate and boreal peatlands. Largest areas of temperate peatlands are in Russia (1.241 × 10^6 km^2) and Canada (1.133 × 10^6 km^2) (Xu *et al*. 2018).

Between 1990 and 2008 there was a very small overall decrease in the extent of all peatlands (–0.97%) (Joosten 2010). The largest area decrease was in Europe (–4%). Area change in all other regions was ±<1%.

However, these overall figures mask major differences in area trends between non-forested and forested peatlands. The global area of non-forested peatlands increased by +7%, with largest increases in Oceania (+16%) and Asia (+16%) (Joosten 2010). Area change in other regions was much smaller (±<3%). In contrast, forested peatlands decreased globally by –25%, with by far the largest percentage decrease in Asia (–80%), with smaller decreases in Oceania (–11%) and Europe (–10%). Total changes in these areas suggest that broadly in these regions there has been conversion of forested to non-forested peatlands, but this may be only part of the story. In south-east Asia (Peninsular Malaysia, Sumatra and Borneo) ~0.018 × 10^6 km^2 of peat swamp forest was lost between 2007 and 2015, an area decrease of –28%, largely through their conversion to oil palm and pulpwood plantations (Miettinen *et al*. 2016). In part of SE Asia (Malay Peninsula, Borneo, Sumatra, and Java), between 2000 and 2010, peat swamp forests experienced a much higher rate of deforestation (–3.7% $year^{-1}$) than did lowland forests (–1.6% $year^{-1}$) or montane forests (–0.1% $year^{-1}$), and are being lost most quickly in Sumatra (–5.2% $year^{-1}$) followed by Borneo (–2.8% $year^{-1}$) (Wilcove *et al*. 2013).

European bogs, fen and mires decreased by –3.5% from 1990 to 2000. A total of 90% of raised bogs in Netherlands were destroyed in the 20th century, and in Scotland 44% of lowland mires and 21% of blanket mires were lost between 1947 and 1988 (Mackey *et al*. 1998), and 15% of Flow Country blanket mires between 1970 and 1987 (Stroud *et al*. 1988).

Marshes and swamps

The global extent of marshes and swamps on alluvial soils is not well established but is known to be large. Lehner and Döll (2004) estimated the global area of freshwater marshes and floodplains as 2.53 $\times 10^6$ km^2, ~25–31% of their global wetland area. Tropical freshwater swamps on alluvial soils, some of which are forested, occur mostly on floodplains, with a total estimated area of 1.46 $\times 10^6$ km^2, 38% occurring in Africa, 33% in South America, 24% in Asia, and 5% in Australasia (Giesen 2018).

Swamp and flooded forests on alluvial soils have been estimated as covering 1.17 $\times 10^6$ km^2 (Lehner and Döll 2004). This may be an underestimate as areas of some major seasonally flooded forest systems such as in the Amazon and Congo Basins are considered to be generally underestimated in global wetland assessments. For the Amazon Basin wetland area has been estimated as 0.480 $\times 10^6$ km^2, with the main-stem Amazon floodplain forests covering 0.098 $\times 10^6$ km^2 (Junk *et al*. 2014). However, conversely 1.17 $\times 10^6$ km^2 may be an overestimate, given that some large areas of tropical forested wetlands have recently been recognised as forested peatlands in the Amazon and Congo Basins (Lähteenoja *et al*. 2012; Dargie *et al*. 2017).

A global area trend for swamps and marshes is not available, but there have been decreases in many regions. In Asia, freshwater swamps in China decreased by 23% and the area of natural marshland in north-east China by 55% from 1950 to 2000 through their conversion to agricultural land, and on the West Songnen Plain 74% of marshes were converted between 1954 and 2008 (An *et al*. 2007; Huang *et al*. 2010; Wang *et al*. 2011). The Mesepotamian Marshes (Iraq) were massively drained between the 1970s and 2000s, but since then there have been major re-flooding and restoration efforts leading to reinstatement of marshes and swamps over a substantial area, with almost 60% of the marsh area present in the mid-1970s having been at least partially restored by the late 2000s – but owing to reduced river water flows the marsh area is currently shrinking again (Becker 2014).

In North America, there was a small (+1%) overall increase in area of marshes and swamps in the USA 2004–09, largely a consequence of wetland restoration and creation activities (Dahl 2011), but in the prairie pothole Dakota region of the USA, 28–35% of natural pothole wetland area was converted to agriculture between 2001 and 2011 (Johnston 2013). On the Canadian shoreline of Lake Ontario by the late 1970s some 43% of marshes may have been lost since the 18th century, and 70% of prairie wetlands (Whillans 1982).

In Europe, in the Po Delta, Italy and estimated 98% of freshwater marshes have been converted since the start of the 20th century; 94% of Macedonian (Greece) marshes between 1930 and the mid-1980s (Jones and Hughes 1993), and 76% of Estonian floodplains between 1950s and 1990s (Kimmel *et al*. 2010). Overall, European inland vegetated wetlands decreased by 3% from 1990 to 2006 (EEA 2010).

In other regions, 13% of the freshwater marshes of the Kafue Flats (Zambia) were converted from 1984 to 1994 (Munyati 2000); 88% of wetlands in the Cauca River Valley (Colombia) were drained from the 1950s–1989 (Naranjo 1993), as were 15% of New Zealand North Island freshwater wetlands between 1979 and 1983 (Ministry of the Environment 1997).

Groundwater-dependent wetlands

Areas of underground wetlands, notably in karst and cave systems, are particularly challenging to measure, even more so than for surface wetlands. 13.2% of the global land surface is formed of carbonate rock outcrops, under which underground cave wetlands will occur widely, including in the Middle East and Central Asia, Europe, Russia and North America (Beltram 2018). Carbonate rocks with underground karst groundwater circulation may cover 19 × 10^6 km^2 of global land surface (Williams 2008). Given that such systems are largely surface porous, there may be little spatial overlap with surface water systems and so they will likely form a major component of inland natural wetland area, but no area specifically of these underground wetlands is available.

Springs are widespread around the world, as are oases in arid and semi-arid zones. Although no area estimates are available, their global areas are likely to be small. Many other wetlands are groundwater-dependent, either wholly or partly, permanently or seasonally (Eamus and Froend 2006), but there are no estimates of the area or proportion of inland wetlands which are groundwater-dependent.

Marine and coastal natural wetlands

Estuaries

Lehner and Döll (2004) give a global area of 0.660 × 10^6 km^2 for their 'coastal wetland' class, which includes 'lagoon, delta, mangrove, estuary, coastal wetland and tidal wetland' classes from their sources. The global area of 1200 major estuaries has been estimated as approx. 0.500 × 10^6 km^2 (UNEP-WCMC 2003; Agardy and Alder 2005). This figure is likely to include areas of saltmarshes and un-vegetated tidal flats, but it is not clear if it also includes mangroves. Regional distribution data is not available, but major estuaries occur in all regions of the world (except the Antarctic) although there are relatively few in Africa, with those being mostly in western Africa (Agardy and Alder 2005).

Tidal flats and saltmarshes

The global area of unvegetated tidal flats has been estimated as 0.458 × 10^6 km^2 (Schuyt and Brander 2004). Regionally, the largest areas of un-vegetated tidal flats are in North America (37%), Latin America and the Caribbean (20%) and Asia (18%), together forming 75% of the global resource (Schuyt and Brander 2004).

Saltmarshes are the main type of vegetated wetland in the coastal intertidal zone in high latitudes, the major areas being largely in temperate zones, particularly in regions with high tidal ranges such as around the North Atlantic. The global extent and distribution of coastal tidal saltmarshes has not been comprehensively assessed. The most recent estimate of global area is a minimum of 0.550 × 10^6 km^2, from 43 of the 99 countries in which saltmarsh is known to occur, but this is considered to cover most

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parts of the world in which there are major saltmarsh areas (UNEP-WCMC 2017). Regionally, the largest areas of saltmarsh are in North America (41%), Oceania (Australia) (25%) and Europe (including the Russian Federation) (21%), together forming 87% of the global resource (Mcowen *et al*. 2017).

In Asia, there have been major losses of tidal flats and marshes: 28% of tidal flats existing in the 1980s in the Yellow Sea (China, Republic of Korea, Democratic Republic of Korea), had been lost by the late 2000s (at a rate of –1.2% annually), and from historical maps up to 65% of tidal flats have been lost over the past five decades (since the mid-1950s) (Murray *et al*. 2012, 2014). In China, coastal wetland losses have been variously reported as –16% (1990–2000), –40% (1978–2008) and –51% (1950–2000) at annual rates of between –1.0 and –1.6% per year, with the fastest rate over the most recent time-period (An *et al*. 2007; Gong *et al*. 2010; Niu *et al*. 2012). In the Republic of Korea, at least 20% of intertidal wetlands were converted between 1987 and 2005 (Republic of Korea 2009).

In North America, 24% of USA estuarine intertidal area was lost between 1922 and 2004, and losses in some regions of the USA even greater: for example, 50% of saltmarshes in the Mississippi Delta between 1956 and 2004. More recently, losses have been much smaller: saltmarshes decreased by only –0.7% between 1998 and 2004 (Bernier *et al*. 2006). In the USA between 2004 and 2009, non-vegetated estuarine area increased by 2.2%, but saltmarshes decreased by a further 2.8% – attributed largely to impacts of coastal processes including sea-level rise rather than land-claims (Dahl 2011). In Canada, losses by 1985 have included 65%) of the Atlantic coastal salt marshes, 70% of Pacific estuarine marshes and 80% of the Fraser River Delta, British Columbia (Government of Canada 1991).

In Europe, there have been long-term and widespread losses of coastal wetlands, exceeding 50% losses by the end of the 20th century on many parts of the coast (Airoldi and Beck 2007). Between 1990 and 2000 European coastal habitats decreased in area by ~–1% (EEA 2007). On just 18 of Britain's 155 estuaries a total of at least 890 km^2 had been claimed by the 1990s: 37% of their former area and an almost 25% loss of the overall British estuarine resource (Davidson *et al*. 1991). In south-east England, 25% of saltmarsh is estimated to have been lost in the last quarter of the twentieth century through erosion and conversion, with losses continuing (Davidson *et al*. 1991). Wadden Sea saltmarshes decreased by –33% between 1950 and 1984, and 56.5% of Rhone delta saltmarshes were lost between 1942 and 1984 (European Commission 1995). Such losses are now being partially counterbalanced by saltmarsh restoration through an increasing number of 'managed realignment' schemes in north-west Europe (Wolters *et al*. 2005), but overall areas are small.

Coastal deltas

Of 52 major coastal deltas globally, Coleman *et al*. (2008) estimates the area of 14 of these deltas as 0.030×10^6 km^2. All 14 major deltas assessed have decreased in area (Coleman *et al*. 2008). Some wetland loss was through coastal erosion converting coastal vegetated wetlands to open water

(5104 km^2) but a much larger area (10 786 km^2) was lost through human conversion for agricultural and industrial uses, an overall loss of –52.4% over just 14 years (1986–2000). Largest reported area losses have occurred in the Shatt al Arab (6699 km^2), Ganges-Brahmaputra (4290 km^2), Indus (1595 km^2) and Yukon (1100 km^2) deltas. Only small area losses (<100 km^2) were reported from the Danube, Mackenzie, Mahanadi, Niger and Nile deltas. Other reported delta area losses include: Don Delta (–22%: 1980s–1990s), Kuban delta (–48%: 1930s–1970s), Camargue (–31%: 1942–1974) (Tamisier 1992). Most of the world's medium and large sized coastal deltas are currently receiving less sediment than the need to grow to keep pace with rising sea-levels. Hence their areas are generally decreasing (Giosan *et al.* 2014).

Mangroves

Mangroves are widely distributed around the shorelines of tropical and subtropical regions of the world. Global mangrove area in 2000 was estimated as 0.137×10^6 km^2 in 118 countries and territories in the tropical and subtropical regions of the world (UNEP-WCMC 2011; Giri *et al*. 2011). The largest extent of mangroves is in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). Approximately 75% of world's mangroves are found in just 15 countries, the largest areas being in Indonesia (0.031×10^6 km^2), Australia (0.009×10^6 km^2) and Brazil (0.009×10^6 km^2) (2000 estimates; Giri *et al*. 2011).

Global mangrove area was estimated to have decreased by 19% between 1980 and 2005, with the largest area loss being in Asia (–25%) (FAO 2007).

Seagrasses

Seagrasses are widely distributed around temperate and tropical shores around the world, occurring both intertidally and particularly in the shallow subtidal zone. They are most diverse in south-east Asia (UNEP-WCMC 2005; Short *et al*. 2007). Their global extent is estimated as 0.177×10^6 km^2 (Spalding *et al*. 2003; Short *et al*. 2018).

The global area of seagrass beds has been decreasing in all parts of the world, temperate and tropical, since at least the 1890s (Waycott *et al*. 2009). Overall, the measured area of seagrass loss was 3370 km^2 between 1879 and 2006, representing 29% of the maximum area measured. The rate of decline in seagrass meadows has accelerated over the past eight decades, from –1% year^{-1} before 1940 to –5% year^{-1} after 1980. The largest losses have occurred after 1980: in total, a loss of 35% of seagrass area. Overall, 58% of sites assessed declined, 25% increased, and 17% exhibited no detectable change. Sites with area increases are in Western Europe and part of the Atlantic coast of the USA, but their areas are small.

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Coral reefs

Warm water coral reefs are widely distributed in subtropical and tropical latitude seas between 30°N and 30°S (Spalding *et al*. 2001). By far the largest coral reef areas, totalling 80% of global area, are in Asia (41%) and Oceania (39%) and in particular in Indonesia (18% of the global area) and Australia (17%). Cold water coral reefs are increasingly being discovered to be more widespread than previously thought (Freiwald *et al*. 2004), mostly from high latitudes where they occur in deep water, but also as in the tropics where they thrive at even greater depths. Their area of is not known but recent studies suggest that global coverage could equal, or even exceed, that of warm-water reefs.

A global area change for warm water coral reefs is not available, but coral cover has been decreasing worldwide (Wilkinson 2008). As hard structures, the overall area of coral reefs does not change substantially except where, for example, physical dredging or infilling, occurs. Coral reef change assessments largely concern changes in the percentage of live coral cover in reefs. By 2008, there had been an effective loss of 19% the original global area cover of coral reefs; a further 15% are seriously threatened with loss within the next 10–20 years; and a further 20% are under threat of loss in the next 20–40 years (Wilkinson 2008). However, 46% of the world's reefs are still regarded as being relatively healthy and not under any immediate threats of destruction. These reefs are generally either well managed or are remote from large land masses and human disturbances (e.g. in the Red Sea, the Maldives, Seychelles and Chagos archipelago in the Indian Ocean, and Papua New Guinea and many small atolls and islands in the Pacific Ocean) (Jackson *et al*. 2014).

In the Caribbean, although the rate of coral loss has slowed in the 1990s–2000s compared to the 1980s, significant declines are continuing. Average coral cover for 88 locations with coral data in the Caribbean declined from 34.8% in 1970–1983 to 16.3% in 1999–2011 (Jackson *et al*. 2014). In Mexico, the area of coral reefs around Veracruz Port decreased by 41% between 1907 and 2007 through landfill and development of port infrastructure (Valadez-Rocha and Ortiz-Lozano 2013).

Shellfish reefs

Shellfish reefs are widespread in temperate coastal regions and also occur tropically and sub-tropically in Latin America and the Caribbean and southern North America. They remain widespread in the intertidal and shallow subtidal coastal regions of the world, despite ~85% of historical oyster reefs having been completely destroyed (Beck *et al*. 2011). Many remaining reefs are in poor condition. A global assessment assessed the condition of oyster reefs across 144 bays and 44 ecoregions found that, in comparison with past abundance, more than 90% of reef area has been lost in 70% of bays and 63% of ecoregions. In many bays, more than 99% of oyster reefs have been lost and are functionally extinct. Overall, 85% of oyster reefs have been lost globally since records began. Regions with functionally extinct oyster reefs are particularly Australia, the North Sea and Atlantic coast of Europe and the Pacific coast of North America. Remaining reefs in fair to good condition are mostly in the Gulf of Mexico and Caribbean, Latin America and New Zealand (Zu Ermgassen *et al*. 2012).

In Europe, native oyster reefs were ecologically extinct by the 1950s along most European coastlines and in many bays well before then (Airoldi and Beck 2007). In the USA, since the start of the 20th century, there has been a 64% decline in the spatial extent of oyster habitat and an 88% decline in oyster biomass over time, suggesting that many remaining reefs are in degraded condition (Airoldi and Beck 2007).

Coastal lagoons

Coastal lagoons are widespread, occurring along nearly 15% of the world's shorelines, with lagoons largely backing barrier coasts (Kusky 2005). The global area of coastal lagoons is not known. The largest proportions of coastlines which are barrier coasts are in Africa (18%) and also in North America, with 14% in Asia, 12% in Latin America and the Caribbean, 11% in Australia and only 5% in Europe. In the United States, lagoons are found along more than 75% of its eastern and Gulf coasts. In the Mediterranean region, there ~400 coastal lagoons, covering a surface of over 0.006×10^6 km^2 (Cataudella *et al*. 2014).

Kelp forests

Kelp forests are distributed widely around northern and southern temperate coasts, in the north Pacific and north Atlantic, along the Pacific and southern Atlantic coasts of Latin America, southern Africa and Australia and New Zealand. A recent first global assessment identified a small global average area decline (at –0.018% year^{-1}) between 1952 and 2015, but this trend masks great regional variation in trends, with declines in 38% of ecoregions for which there are data (–0.015 to –0.18% year^{-1}), but increases in 27% of ecoregions (0.015 to 0.11% year^{-1}), and no detectable change in 35% of ecoregions (Krumhansl *et al*. 2016). There are no clear geographical patterns in these area change trends, with increasing and decreasing area changes in adjacent ecoregions in most parts of the world. In Europe, 20th century losses, sometimes leading to virtual local disappearance, of kelp and other macroalgae beds have been widespread including in Iceland, Norway, Britain and Ireland, Sweden, Denmark, Finland, Germany, Lithuania, Italy, France, Spain, Croatia and Romania (Airoldi and Beck 2007).

Shallow subtidal marine systems. These areas, defined by Ramsar Convention (1971) as being those of up to 6 m of permanent inundation by marine waters, can be expected to form a major component of coastal and nearshore marine wetlands. However, these areas have not been measured, except for the Mediterranean Basin: 0.042×10^6 km^2; Mediterranean Wetland Observatory 2018). No global or regional areas are available.

Human-made wetlands

Reservoirs

It is estimated that globally there are ~2.8 × 10^6 reservoirs or impoundments larger than 0.1 ha worldwide, and 16.7 × 10^6 when including those larger than 0.01 ha (Lehner *et al*. 2011). Their combined area is estimated at 0.443 × 10^6 km^2 (GRAnD database, see http://atlas.gwsp.org/index.php?option=com_content&task=view&id=207&Itemid=68, accessed 15 September 2017). The largest numbers of dams are in North America (particularly USA), Asia (particularly China) and Europe. There are now in excess of 30 000 large dams globally, compared with ~5000 in 1950. While the number of large dams constructed worldwide has increased greatly since the 1950s, in all parts of the world, the rate of increase appears to have slowed since 2000 (Steffen *et al*. 2015).

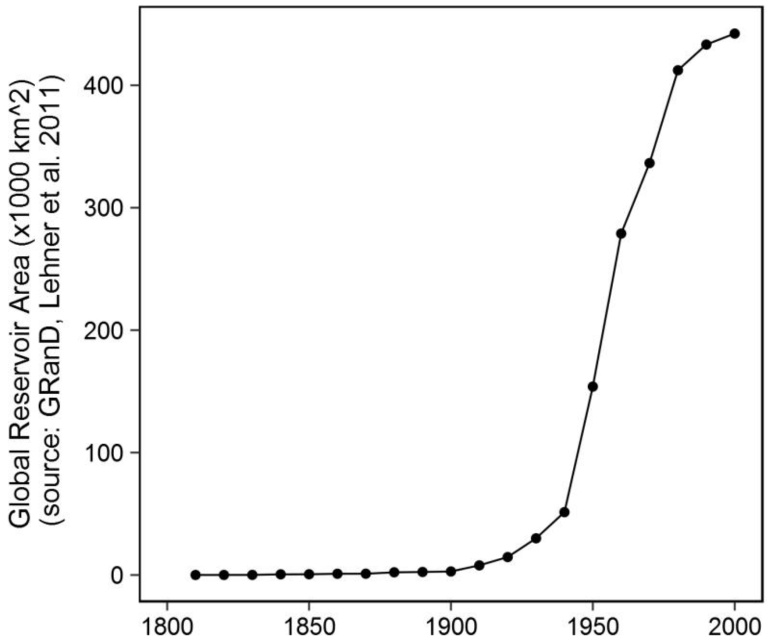

Fig. S1. Global trend in reservoir area (source: GRAnD database, see http://atlas.gwsp.org/index.php?option=com_content&task=view&id=207&Itemid=68, accessed 15 September 2017; Lehner *et al*. 2011).

As for the number of dams constructed, the global area of reservoirs has progressively increased: particularly rapidly from the 1950s to the 1980s, and recently more slowly (Fig. S1). Global reservoir area increased by 0.289 × 10^6 km^2 (188% increase) between 1950 and 2010, with 0.106 × 10^6 km^2 (32% increase) being between 1970 and 2010 (GRAnD database, see http://atlas.gwsp.org/index.php?option=com_content&task=view&id=207&Itemid=68; Lehner *et al*. 2011). It is not clear if these estimates include such impoundments as gas oil field lakes and mine tailings ponds.

Small (e.g. farm) ponds

Downing *et al*. (2006) estimated the global area of farm ponds as 0.077×10^6 km^2. Downing *et al*. (2006) also reported that the area of farm ponds is increasing in many parts of the world, particularly in semi-arid areas, and at average rates of 0.7% year^{-1} in Great Britain and 1–2% year^{-1} in parts of the USA.

Rice paddy

Rice paddy area is estimated as 1.282×10^6 km^2, of which 0.66×10^6 km^2 (51%) is irrigated paddy and 0.63×10^6 km^2 (49%) is rain-fed paddy (Salmon *et al*. 2015). The most recent estimate of global area of rice production (which includes rice paddy but also upland dry rice areas) is 1.635×10^6 km^2 (see http://ricestat.irri.org:8080/wrsv3/entrypoint.htm, accessed 20 July 2017), of which rice paddy forms 79%. A total of 88% of the global area of rice production is in Asia, stretching from India and Nepal in the west to Japan, South Korea, and Taiwan in the east, from China in the north to Timor-Leste in the south. Proportionally much smaller rice areas occur in other regions.

There are no estimates available of change in rice paddy area. Since 1965, rice production area has increased by 0.38×10^6 km^2, a 30.2% increase from 1965 to 2014 (Fig. S2), although the change varies between regions with an increase of 26% in Asia, and larger increases in the smaller areas in Europe (36%) and particularly Africa (270%), but small area declines in Latin America and Caribbean (–9%), North America (41%) and Oceania (134%). These average regional changes mask different change directions in different countries: for example in Asia, although rice production area has increased in most countries it has decreased others such as Japan and Taiwan (see http://ricestat.irri.org:8080/wrsv3/entrypoint.htm, accessed 20 July 2017).

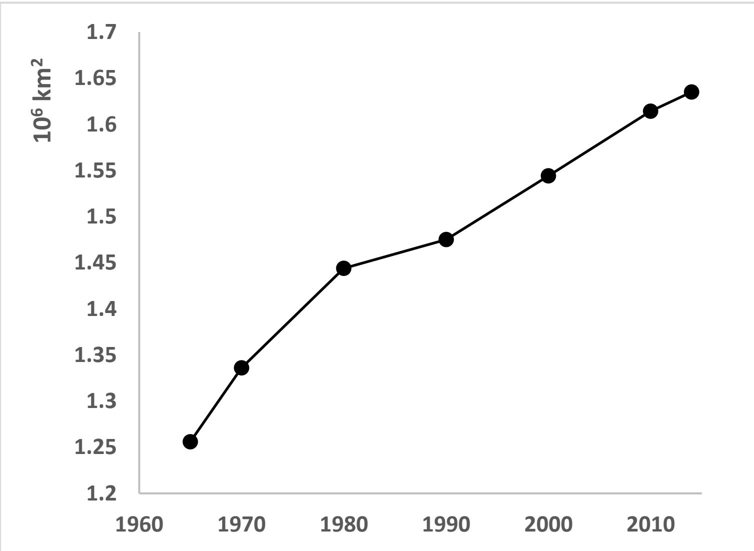

Fig. S2. Increase in global rice production area from 1965 to 2014 (source: http://ricestat.irri.org:8080/wrsv3/entrypoint.htm, accessed 20 July 2017).

Oil palm plantations

Oil palm plantations, planted on drained wetlands (peatlands), in South-east Asia have increased since 1990, and in 2015 managed land covered 50% (7.8×10^6 ha) of all peatlands, increasing from 11% in 1990 and 33% in 2007. Industrial plantations have nearly doubled their extent on peatlands since 2007 and now cover 27% of peatlands (Miettinen *et al*. 2016). Plantations are also reported as increasing in Africa and Latin America, but areas are not available.

Agricultural wet grasslands

In Europe, and some other parts of the world, areas of floodplain wetland and sloping fens have for millennia been managed as agricultural wet grasslands, for stock grazing and fodder cropping. Similar grasslands have developed coastally, behind the artificial embankment of estuaries. Global and regional areas are not known, but many areas are now much smaller than previously through their conversion to intensive agriculture and urban and industrial developments, for example in south-east England (Thornton and Kite 1990).

Wastewater treatment wetlands

Many, mostly small, wastewater treatment wetlands have been constructed, with others created for other purposes such as amenity and mitigation of wetland losses. No global area estimates are available. In the USA, there are almost 150,000 ha of industrial ponds and a further over 326,000 ha of urban ponds: a total area of 0.004×10^6 km^2 (Dahl 2011). There are also an increasing number (at least 223 by 2008) of wastewater treatment wetlands (of up to 1 ha area) in China (Liu *et al*. 2008).

Salt production pans

Salinas (salt production pans) are widespread in parts of the world where the climate is warm enough for rapid saline water evaporation. No global or regional area estimates are available, but in the Mediterranean in the 1990s there were 165 salinas (90 of which were still producing salt) and a total area of 750 km^2 (Perennou *et al*. 2012).

Aquaculture ponds

Aquaculture ponds for commercial fish and shellfish production are also widespread, and most frequent in China, India, Viet Nam, Bangladesh, and Egypt, and also well developed in France, Greece, the Czech Republic, Austria and Hungary in Europe, and the Lao People's Democratic Republic and Nepal in Asia (FAO 2016). No global or regional area estimates are available.

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