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Worth of wetlands: revised global monetary values of coastal and inland wetland ecosystem services

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Abstract. In this study, we have re-estimated the 2011 global monetary values of natural wetland ecosystem services using new information on the areas of different coastal and inland wetland classes, and included estimates for forested wetlands. The 2011 global monetary value of natural wetland ecosystem services is now estimated at Int$47.4 trillion per year, 43.5% of the value of all natural biomes. Despite forming only ~15% of global natural wetland area, coastal wetlands are estimated to deliver 43.1% (Int$20.4 trillion per year) of the total global ecosystem services monetary value of all natural wetland classes. There is a need to further refine these value estimates by factoring in other determinants of wetland ecosystem service monetary value, by disaggregating unit monetary values to each wetland class and by updating unit monetary values with more recent sources, especially for ecosystem services with no, or few, value estimates.

Additional keywords: economic benefits, forested wetlands, lakes, mangroves, marshes, Ramsar Convention, rivers, salt marshes, seagrasses.

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Introduction

Costanza *et al.* (1997) demonstrated the major contribution of wetlands (both inland and coastal) to the global monetary value of the ecosystem services of natural biomes, estimating that the 1997 value of wetland ecosystem services was a minimum of US$14.9 trillion per year (45% of the global total). Costanza *et al.* (2014) updated these figures based on improved biome area information and more comprehensive estimates of unit (per hectare) monetary values, largely from de Groot *et al.* (2012), with an estimate of the minimum monetary value of natural wetland ecosystem services, updated to 2011 values, of US$50.7 trillion per year, or 41% of the global total across all biomes.

The wetland area estimates used by Costanza *et al.* (1997, 2014) were constrained by the limited availability and accuracy of information on areas of different wetland biomes at those times. The total wetland areas applied to the wetland biomes that were used in 1997 and 2014 were 9.72×10^6 and 8.3×10^6 km^2 respectively. Estimates of global wetland area have been generally increasing over time, due largely to improvements in remote sensing methods (Davidson *et al.* 2018). However, although some recent estimates of the areas of different wetland classes have reported larger areas than previously, others have reported considerably smaller areas (Davidson and Finlayson 2018, 2019). Taken together, these recent estimates provide a minimum global area of natural coastal and inland wetlands of 13.2×10^6–14.2×10^6 km^2 (Davidson and Finlayson 2019). Thus, the monetary values of Costanza *et al.* (1997, 2014) for the ecosystem services provided by wetlands may be either under- or overestimates. Underestimates are likely to be particularly the case for inland wetlands, with Costanza *et al.* (1997, 2014) using areas of only 3.7×10^6 km^2 in 1997 and 2.3×10^6 km^2 in 2014, whereas Davidson and Finlayson (2018) estimated minimum inland natural wetland area as 11.8×10^6–12.8×10^6 km^2.

Herein we revisit the global monetary value of the ecosystem services of natural wetlands by applying recent information on the global areas of different wetland classes (Davidson and Finlayson 2018, 2019) to the unit values of wetland ecosystem services provided by de Groot *et al.* (2012) and Costanza *et al.* (2014) to generate revised global flow values for wetlands.

Materials and methods

We apply the Ramsar Convention's scope of natural wetlands, covering inland wetlands, and coastal and nearshore marine wetlands (hereafter called 'coastal wetlands') to a 6-m depth of permanent inundation (Ramsar Convention 1971). We do not cover human-made wetlands *sensu* Ramsar Convention (1971; e.g. reservoirs, rice paddy, fish ponds, salt pans) because no

Table 1. 2011 global monetary values of ecosystem services from different natural wetland classes and non-wetland biomes
Unit values are from Costanza *et al.* (2014); wetland class areas are from Davidson and Finlayson (2018, 2019); areas for 'other biomes' are from Costanza *et al.* (2014)

Wetland classes (Davidson and Finlayson 2018)	Biome (Costanza *et al.* 2014)	Mean 2011 unit value (2007 Int\$ ha^{-1} $year^{-1}$)	Area ($\times 10^6$ ha)	Total global 2011 value ($\times 10^{12}$ Int\$ $year^{-1}$)
Coastal wetlands				
Coral reefs	Coral reefs	352 915	28.4	10.02
Estuaries	Coastal systems[A]	28 917	66.0	1.91
Seagrass beds	Coastal systems[A]	28 917	78.8	2.28
Unvegetated tidal flats	Coastal wetlands[B]	193 845	12.8	2.48
Salt marshes	Coastal wetlands[B]	193 845	5.5	1.07
Mangroves	Coastal wetlands[B]	193 845	13.8	2.68
Total coastal wetlands			210.2	20.44
Inland wetlands				
Non-forested peatlands	Swamps and floodplains	25 682	311.8	8.01
Tropical forested peatlands	Tropical forest	5382	36.2	1.95
Temperate and boreal forested peatlands	Temperate and boreal forest	3137	33.4	1.05
Marshes and swamps (alluvial)	Swamps and floodplains	25 682	253	6.5
Forested wetlands (alluvial)	Tropical forest; temperate/boreal forest	3460	117	4.05
Natural lakes	Lakes and rivers	12 512	371.6	4.65
Rivers and streams	Lakes and rivers	12 512	64.3	0.81
Total inland wetlands			1187.3	27.00
Total all wetlands			1397.5	47.44
Other natural biomes	Open ocean	660	33 200	21.91
	Continental shelf	2222	2660	5.91
	Grass and rangelands	4166	4418	18.41
	Tropical dry forest	5382	1161	6.25
	Temperate and boreal dry forest	3137	2913	9.14
Total other natural biomes			44 352	61.62
Total all wetland classes and other natural biomes			45 749.5	109.06

[A]Described by de Groot *et al.* (2012) as including 'sea-grass fields, shallow seas of continental shelves, rocky shores and beaches'.
[B]Described by de Groot *et al.* (2012) as including intertidal areas such as 'tidal marshes and mangroves'.

values for such human-made wetlands are provided by de Groot *et al.* (2012) or Costanza *et al.* (2014).

For global areas of different natural wetland classes or biomes, we use recent area estimates summarised by Davidson and Finlayson (2018), as updated by Davidson and Finlayson (2019) for some coastal wetland classes.

De Groot *et al.* (2012) provide values for only three broad natural wetland 'biomes' (coastal systems, coastal wetlands and inland wetlands) and separately for coral reefs. Costanza *et al.* (2014) used similar wetland biomes, but used separate areas of estuaries, seagrass and algal beds and tidal marsh and mangroves. The category of 'swamps/floodplains' in Costanza *et al.* (2014) appears to be the same as the 'inland wetlands' category of de Groot's *et al.* (2012), which de Groot *et al.* (2012, supplementary material) note includes 'floodplains, swamps/marshes and peat lands'.

It is not yet possible to further disaggregate the de Groot and Costanza wetland biome unit area monetary values to provide separate values for each of the natural wetland classes considered by Davidson and Finlayson (2018) (R. de Groot, pers. comm.). So, for each wetland class for which a global area is available from Davidson and Finlayson (2018, 2019) we allocated the most relevant unit area monetary value from Costanza *et al.* (2014), as indicated in Table 1.

Large areas of natural wetlands, in both tropical and temperate and boreal regions, are forested (Davidson and Finlayson 2018). However, de Groot *et al.* (2012) and Costanza *et al.* (2014) provide unit area monetary values for only the broad biomes of 'tropical forest' and 'temperate/boreal forest' and not separately for wetland and dryland forests. Here, we make the assumption that these forest biomes include both wet and dry forests. Tropical and temperate and boreal 'dry' forest areas were recalculated as the difference between the area of all forests and of forested wetlands in each biome. For Davidson and Finlayson's (2018) wetland class 'forested wetlands on alluvial soils', separate areas are not available for tropical and temperate and boreal regions. Pending the availability of separate area estimates for these forested wetland classes, we estimated the contribution of tropical and temperate and boreal unit values to this wetland class by assuming *pro rata* areas to be the same as for all forests: 52% tropical (including subtropical) forest area and 48% temperate and boreal area (Keenan *et al.* 2015), which may be a potential further source of uncertainty in our revised value estimates.

Applying the 2011 mean unit values from Costanza *et al.* (2014) to Davidson and Finlayson's (2018, 2019) wetland class areas, we recalculated 2011 aggregate global monetary flow values. Here we look only at natural biomes, and so do not

Table 2. Regional coastal and inland natural wetland class 2011 total ecosystem service flow values
Regions are those applied by the Ramsar Convention (2015). Regional areas of wetland classes used for these calculations are from Davidson and Finlayson (2018, 2019). However, regional areas are not available for all wetland classes of Davidson and Finlayson (2018)

Wetland class	Total ecosystem service value (2011 value; $\times 10^{12}$ Int\$ year^{-1})					
	Africa	Asia	Europe	Latin America and Caribbean	North America	Oceania
Coastal						
Coral reefs	0.82	4.18	0	1.12	0.10	3.98
Unvegetated tidal flats	0.29	1.09	0.12	0.27	0.38	0.29
Salt marshes	0.01	0.11	0.22	0.03	0.44	0.27
Mangroves	0.54	1.04	0	0.54	0.23	0.32
Seagrasses	0.01	0.57	0.16	0.03	0.43	1.09
Total coastal	1.66	6.98	0.50	2.00	1.57	5.94
Inland						
Non-forested peatlands	0.24	3.84	0.88	0.08	2.8	0.08
Forested peatlands	0.21	0.24	0.69	0.57	1.11	0.18
Lakes	0.42	0.47	1.35	0.19	2.14	0.09
Total inland	0.87	4.55	2.92	0.84	6.05	0.35
Total coastal and inland	2.53	11.53	3.42	2.84	7.62	6.29

include the human-made biome of 'cropland' in Costanza *et al.* (2014).

The coastal and inland natural wetland values reported here will be minima because areas are not available for some wetland classes, specifically for inland classes of groundwater-dependent wetlands and for coastal classes of shellfish reefs, coastal lagoons, kelp forests, shallow subtidal marine systems and sand dunes, beaches and rocky shores (Davidson and Finlayson 2018, 2019).

In addition to global areas, regional areas are available for some natural wetland classes (Davidson and Finlayson 2018, 2019). For coastal wetlands, regional areas are available for coral reefs, salt marshes, unvegetated tidal flats, seagrass beds and mangroves. For inland wetlands, regional areas are available for non-forested peatlands, forested peatlands and lakes. We calculated regional contributions to global monetary values for these wetland classes.

For five natural wetland classes (unvegetated tidal flats, mangroves, seagrass beds, non-forested peatlands and forested peatlands) both a recent total area and an annual change in area are available (Davidson and Finlayson 2018, 2019). For these wetland classes, we calculated an annual change in global monetary value of their ecosystem services.

Results

At 2011 values, Costanza *et al.* (2014) estimated the global monetary flow value of wetland ecosystem services as Int\$50.7 trillion per year. Our recalculations using more recent wetland class areas and including forested wetlands update this figure to Int\$47.4 trillion per year at 2011 values (Table 1), 43.5% of the global total value (Int\$109.1 trillion per year) of the ecosystem services of all natural biomes. This is a similar percentage to the 41–45% provided by earlier estimates (Costanza *et al.* 1997, 2014).

Our results re-emphasise the major contribution of the monetary value of ecosystem services delivered by natural coastal wetlands: Int\$20.4 per year at 2011 values (Table 1). This is 43.1% of the global monetary value of ecosystem services provided by all inland and coastal natural wetlands, despite coastal wetlands being estimated as forming only ~15% of the area of all natural wetlands (Table 1; Davidson and Finlayson 2019). Inland natural wetlands are estimated as delivering Int\$27.0 trillion per year at 2011 values (Table 1).

The largest contributions to the global monetary value of coastal wetland services, from available assessments of wetland areas and values, are from coral reefs, which deliver Int\$10.0 trillion per year (almost half (49%) of total coastal wetland value). Mangroves (13%), unvegetated tidal flats (12%), seagrass beds (11%) and estuaries (9%) each deliver important but lower monetary values (Table 1).

For inland natural wetlands, the largest contributions are from vegetated non-forested wetlands (non-forested peatlands and marshes and swamps on alluvial soils), delivering Int\$14.5 trillion (53% of total inland wetland ecosystem service value). Forested wetlands deliver Int\$7.1 trillion per year (27% of inland wetland value), and the ecosystem services from open water wetlands (lakes and rivers) deliver Int\$5.5 trillion per year (20% of inland wetland value).

Regional ecosystem service monetary values could be calculated for wetland classes together forming 63.9% of the area of coastal and inland wetland classes for which areas are available. The largest contributions to ecosystem service values come from Asia (33.7% of the regional total), North America (22.3%) and Oceania (18.4%) for the wetland classes covered (Table 2). The largest values for coastal wetlands were from Asia and Oceania, whereas the largest for inland wetlands were from North America, Asia and Europe (Table 2).

For natural coastal wetlands, in predominantly temperate regions (Europe, North America) the largest ecosystem service monetary values come from salt marshes, seagrasses and tidal flats, whereas in predominantly tropical regions (Africa, Asia, Latin America and the Caribbean and Oceania) they come from coral reefs, and in Africa, Latin America and the Caribbean they also come from mangroves (Table 2).

Table 3. Annual rates of change in 2011 global ecosystem service monetary values, derived from rates of natural wetland class area change (from Davidson and Finlayson 2018, 2019) and the total global monetary flow values in Table 1

Wetland class	Annual rate of change in area (% year^{-1})	Annual change in global value ($\times 10^{12}$ Int$ year^{-1})
Unvegetated tidal flats	−0.184	−0.0046
Mangroves	−0.215	−0.0058
Seagrass beds	−5.00	−0.0255
Non-forested peatlands	0.38	0.0304
Forested peatlands[A]	−1.41	−0.0423
Total		−0.0478

[A]Sum of tropical and temperate and boreal forested peatland values.

For natural inland wetlands, the pattern is more variable. In Africa and Europe, the largest monetary values come from lakes; in Latin America, the Caribbean and Oceania they come from forested peatlands, in Asia they from non-forested peatlands and in North America they come from non-forested peatlands and lakes (Table 2).

For the five natural wetland classes for which both a global area and an annual rate of change in area is available (Davidson and Finlayson 2018, 2019), we estimate the annual loss of ecosystem service value is Int$47.8 million, with the largest loss in monetary value being from forested peatlands (Table 3).

Although it is not yet possible to assess fully which ecosystem services are delivering the most monetary value from each natural wetland class, some insights come from the ecosystem service unit values in de Groot *et al.* (2012) for their broad wetland biomes. Much of the monetary value delivered by all natural wetland biomes comes from regulating services, especially water-related services. This ranges from 47% of total value from lakes and rivers to 49% from coral reefs, and from 68% from inland wetlands to 88–89% from coastal systems and coastal wetlands.

For coastal systems, major monetary value comes from erosion protection (86% of total monetary value) and food (4%) as a provisioning service. For natural coastal wetlands, waste treatment and water purification contributes 84% of total monetary value. For coral reefs, much of their monetary value comes also from erosion protection and from the cultural service of recreation and tourism (together being 71% of the total value). Inland natural wetlands deliver a wide range of water-related regulation services, with moderation of extreme events, water flow regulation, waste treatment and water purification, erosion prevention and nutrient cycling together contributing 62% of the total monetary value of their ecosystem services. Major value from lakes and rivers is delivered by fresh water supply (42% of total value) and recreation and tourism (50%).

Discussion

Our re-evaluation of the monetary values of wetland ecosystem services in comparison with other natural biomes reaffirms the major value of natural wetlands in their delivery of benefits supporting people's livelihoods and well-being, as reported previously by Costanza *et al.* (1997, 2014), de Groot *et al.* (2012) and Russi *et al.* (2013). Although forming only ~3% of global surface area, we now estimate that natural wetlands are delivering 43.5% of the total global monetary value of ecosystem services from natural biomes. This is a similar proportion to the 41–45% previously estimated by Costanza *et al.* (1997, 2014). Wetlands are delivering 58.4% of the value of all global inland and coastal natural biomes (i.e. excluding values from open oceans and continental shelf areas).

Both by unit area monetary value and by global monetary value, natural coastal wetlands are of particularly great importance to human society: although they form only ~10% of the total area of natural wetlands (Davidson and Finlayson 2018, 2019), they deliver a much higher proportion (43.1%) of the total monetary value of ecosystem services delivered by natural wetlands.

However, our estimates must be considered as approximations because we have had to allocate the same unit monetary value figures from the very broad wetland biomes used by de Groot *et al.* (2012) and Costanza *et al.* (2014) to several different wetland classes. It is unlikely that each of these classes is delivering the same monetary flow value. It should be a priority to disaggregate unit values to each of the wetland classes of Davidson and Finlayson (2018) so as to derive more precise monetary values for the ecosystem services of each class. If value and new areal estimates become available for human-made wetlands, and for other non-wetland biomes, similar reanalyses will be needed.

For the purpose of direct comparison with previous monetary value assessments, we used the same simple unit value transfer approach as Costanza *et al.* (1997, 2014). However, this may not be the most relevant valuation approach to apply, as has been acknowledged by Costanza *et al.* (1997), and other recent approaches, including the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (see https://www.ipbes.net/, accessed 10 January 2019), which calls for complementing monetary values with a pluralistic approach to recognising the diversity of values (Pascual *et al.* 2017).

The value transfer approach also does not take into account potentially important sources of variation in the determinants of wetland monetary value, such as human population, income, ecosystem scarcity, complex interdependencies among services, sustainable use levels and fragmentation (Brander *et al.* 2012). For future analyses of the monetary value of wetland ecosystem services, we urge that any further re-estimation of wetland monetary values factors in such variables for each unit monetary value source so as to improve the way in which wetland ecosystem service monetary values are estimated.

de Groot *et al.* (2012) and Costanza *et al.* (2014) provide no, or very few, unit monetary value estimates for a considerable number of ecosystem services considered to be of importance in natural wetlands (Finlayson *et al.* 2005; Davidson 2010). For lakes and rivers, these services include most water-related regulating services; for other inland wetlands, they include regulation of water flows, erosion protection, nutrient cycling, pollination and inspiration for culture, art and design, and for coastal wetlands they include climate regulation, regulation of water flows, moderation of extreme events, waste treatment and water purification, erosion prevention, nutrient cycling and inspiration for culture, art and design. Therefore, we consider that the wetland ecosystem service monetary values reported here must be considered to represent underestimates. It should be a priority to seek to improve the unit monetary value dataset for natural wetlands with additional sources that may have become available since the compilation of de Groot *et al.* (2012), particularly so as to include such 'missing' ecosystem services.

There are recognised limitations to current monetary valuation approaches (e.g. Brander *et al.* 2012), and it is but one measure of the overall benefits that wetlands deliver to people. In addition to monetary values, it is necessary to consider different world views of value, including, for example, aesthetic, spiritual or totemic values (de Groot *et al.* 2006; Kumar *et al.* 2017). It is also important to recognise that ecosystem service values such as those reported here are not market or tradable values because markets do not exist for many such ecosystem services. Nevertheless, the great monetary value delivered by wetlands through their ecosystem services is an important message for policy and decision makers.

However, despite the evidence available now for over 20 years of this great monetary value, natural wetlands are continuing to be destroyed (Davidson 2014; Dixon *et al.* 2016; Darrah *et al.* 2019) and the degradation of remaining natural wetlands is becoming increasingly widespread (N. C. Davidson, L. Dinesen, S. Fennessy, C. M. Finlayson, P. Grillas, A. Grobicki, R. J. McInnes, and D. A. Stroud, unpubl. data; R. J. McInnes, N. C. Davidson, C. Rostron, and M. Simpson, unpubl. data). It seems that information on the monetary value of wetland ecosystem services is still not sufficiently understood and recognised by policy and decision makers. Consequently, policies and decisions to convert and destroy natural wetlands, with increasingly negative effects on people's livelihoods and well-being, rather than to maintain such wetlands continue.

Conflicts of interest

Nick Davidson, Robert McInnes and C. Max Finlayson are editors for *Marine and Freshwater Research* but did not, at any stage, have access to this manuscript while it was under peer review, as is the standard practice when handling manuscripts submitted by an editor to this Journal. *Marine and Freshwater Research* encourages its editors to publish in the Journal and they are kept totally separate from the decision-making processes for their manuscripts.

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