

Background

Turloughs are topographic depressions in karst, which are intermittently flooded on an annual cycle via groundwater sources and have substrate and/or ecological communities characteristic of wetlands. Most of them are located in the west of Ireland and developed on carboniferous limestone (figure 1). Turloughs provide a habitat for many protected flora and fauna species and are designated a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC) as well as GWDTEs under the Water Framework Directive (WFD). There are an estimated 483 turloughs in Ireland (Kimberley & Coxon, 2013). Indeed, the majority of turloughs globally occur within Ireland and so the State has an international obligation to protect them. Hydrology is the primary driver of these unique ecosystems (Naughton et al., 2012), and so a rigorous understanding of the flooding regime is required in order to assess their conservation and future sustainability. The water-bodies supporting GWDTE's are also protected under the WFD and it is important to establish whether the status of these groundwater bodies is impacting on the functioning of the GWDTE's and if so, what measures can be introduced to mitigate this impact.

A common definition of ecosystem services as the benefits that people obtain from ecosystem has been provided by the Millennium Ecosystem assessment (MEA, 2005), which offers the four categories of provisioning, regulating, supporting, and cultural ecosystem services. Another definition describes ecosystem services as the functions of ecosystems that provide benefits to people (Mace et al., 2012). A unifying classification system has been brought forward with the Common International Classification for Ecosystem Services (defined here as the contributions that ecosystems make to human well-being, CICES, Haines-Young and Potschin, 2013). This builds on the approach of the MEA, though with the difference that in the CICES classification supporting services are classed as intermediate services. It uses three main categories with some sub-categories: provisioning, regulating and cultural ecosystem services.

Methods

A study of 22 turlough in the West of Ireland was funded by the National Parks & Wildlife Service of Ireland and it integrated hydrological, biological and chemical nutrient data (Waldren et al., 2015). Following up from this study, 7 turloughs were selected which reflected different hydrological regimes and ecosystem characteristics. They are located in the west of Ireland, in counties Clare, Galway, Mayo, and Roscommon (figure 3).

Monthly samples of water were taken in 2019-2020, as well as soil samples and greenhouse gas measurements. The relevant ecosystem provided by the turloughs were selected from the CICES classification. Parameters analysed for waters were pH, electrical conductivity, alkalinity, chlorophyll a, total and soluble reactive phosphorus, total and total oxidised nitrogen, chlorides, sulphate and silicates, dissolved organic carbon. Parameters analysed for the soils were total organic carbon, total nitrogen, total and soluble reactive phosphorus. Greenhouse gases determined were carbon dioxide, methane and nitrous oxide.

Based on the data present in the previos study, a qualitative assessment of ecosystem services was performed and is presented here. Afterwards, the single ecosystem services will be quantified using different models and tools in biophysical units and in monetary terms. Different development scenarios might also be evaluated.

Results

Turloughs typically fill in the autumn and dry up in summer, though some of them retain significant amounts of water (Caranavoodaun, Coolcam, Lough Coy, Lough Gealain). Their hydrology can be described by two main models: flow through and surcharge tank. In the flow through model both inflow and outflow occur at the same time. Inflow can be from direct rainfall, surface runoff, epikarst (shallow groundwater) and deep conduits. In this model there is a constant flow of groundwater through the system and residence times are smaller than the other model. In the surcharge tank model the turlough acts as supplemental storage for groundwater. The turlough is connected to the groundwater through swallow holes or estavelles (where water both enters and leaves the turlough). The relationships between turlough water and groundwater are regulated by their respective hydraulic heads. During filling periods there is no discharge from the turlough and during recessions turlough water is released back to the groundwater conduit. Blackrock, Lough Gealain, can be described by the flow through model while Lough Coy, can be described by the surcharge tank model. Some of the turloughs show a unimodal flooding regime which is mainly subject to the seasonal flooding/receding regime (with Coolcam representing a clear example), while on the other spectrum Lough Aleenaun shows various flooding events which are correlated with rain patterns. Blackrock also receives superficial waters from the Owenshree river and is also subject to quick flooding events. Receiving drainage from peatlands in the Slieve Aughty mountains, together with Lough Coy, it shows characteristic dark waters. These two turloughs are connected and part of a the Gort-Kinvarra chain which includes several turloughs and springs. Skealaghan is subject to large temporal and spatial variation in its hydrological regime and fluctuations in water level are intrinsically linked to rainfall.

An overview of the hydro-ecological characteristics of the 7 turloughs can be found in Tables 1, 2 and 3. A quantification/valuation of some ecosystem services provided by the turloughs can be found in Tables 4 and 5.

Table 1. hydro-ecological characteristics of the 7 turloughs studied

	Location (County)	Area (ha)	Hydrology and soils	Hydroperiod (days)	Biodiversity
Blackrock	Galway	59.3	Deep with short duration flooding and damicorn deposits	159	10 vegetation communities. Potentilla anserina-Potentilla anserina, Ranunculus, Lichen grassland also abundant.
Caranavoodaun	Galway	48	Medium depth with intermediate duration flooding and gravel and sand/dell deposits. Conduit system. Shallow epikarst	205	12 vegetation communities mapped. Echiochloa polystachya-Ranunculus, Ranunculus dominating.
Coolcam	Roscommon	67.3	Medium depth with long duration flooding and peat, mud and alluvial deposits.	346	15 vegetation communities. Polygonum amphibium, Open water and blackcoats polystachya-Ranunculus ferns dominating.
Lough Aleenaun	Clare	107.3	Deep with short duration flooding and mud, peat, mud and organic shallow	158	6 vegetation communities. Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus.
Lough Coy	Galway	36	Conduit system with alluvial and mineral shallow soils.	187	8 vegetation communities. Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus.
Lough Gealain	Clare	17.3	Shallow epikarst with alluvial and organic shallow soils.	212	9 vegetation communities. Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus, Ranunculus.
Skealaghan	Mayo	28	Medium depth with intermediate duration flooding, with sand/dell and fen peat deposits.	211	12 vegetation communities. Potentilla anserina-Carex, Carex, Carex, Carex, Carex, Carex.

Table 2. hydro-ecological characteristics of the 7 turloughs studied

Turlough	TP (µg/l)	SRP (µg/l)	TN (mg/l)	TON (mg/l)	Chl a (µg/l)	ThCP ratio	pH	Colour (mg l ⁻¹ PCU)	Turbidity (NTU)	Trophic status based on OECD 1989
Blackrock	32.16	27.10	1.72±0.04	1.21±0.37	13.07.7	38	7.88	72	2.7	Eutrophic
Caranavoodaun	11.24	2.21	0.30±0.04	0.86±1.42	2.82±0.8	398	13.16	26	2.2	Mesotrophic
Coolcam	34.21	4.44	1.27±0.04	0.50±0.59	18.12.11	45	8.17	23	3.4	Mesotrophic
Lough Aleenaun	31.214	5.65	1.26±0.04	1.01±0.28	9.21±2.8	48	10.04	14	5.5	Mesotrophic
Lough Coy	42.116	21.110	1.41±0.04	1.06±0.25	5.32±0.6	36	7.86	72	2.5	Eutrophic
Lough Gealain	4.1	1.47±0.1	0.30±0.04	0.30±0.12	13.07.7	189	13.17	8	0.7	Oligotrophic
Skealaghan	20.45	6.45	0.92±0.04	0.50±0.65	6.94±2.2	37	10.07	28	1.7	Mesotrophic

Turlough	TP (µg/l)	SRP (µg/l)	TN (mg/l)	TON (mg/l)	Chl a (µg/l)	ThCP ratio	pH	Colour (mg l ⁻¹ PCU)	Turbidity (NTU)	Trophic status based on OECD 1989
Blackrock	35.21	16.10	1.22±0.36	1.22±1.15	4.7	49	7.93	104	5.9	Mesotrophic
Caranavoodaun	48.27	12.10	1.74±1.07	1.26±1.49	176.8	18	7.87	35	17.0	Eutrophic
Coolcam	21.00	10.04	0.76±0.56	1.31±1.80	81.1	55	7.58	25	5.5	Mesotrophic
Lough Aleenaun	30.16	15.67	1.14±1.26	1.25±1.80	20.1	49	8.08	22	5.8	Mesotrophic
Lough Coy	47.39	27.59	1.14±0.59	0.81±0.83	37.0	23	8.08	69	6.6	Eutrophic
Lough Gealain	9.25	8.65	0.35±0.32	0.44±0.48	8.5	60	7.91	15	6.8	Oligotrophic
Skealaghan	30.28	11.58	0.95±0.40	0.35±0.12	16.2	32	7.77	31	9.5	Mesotrophic

Table 4. Relative importance of the ecosystem services of the 7 turloughs studied

Turlough	Water provision for humans	Water provision for cattle and grazing	Nutrient retention	Carbon sequestration	Flood regulation	Habitat preservation	Tourism/recreation	Aesthetic/spiritual value
Blackrock	X	X		X	XX	X		
Caranavoodaun	X			XX	X	XX	X	X
Coolcam	X	X	X	XX	X	XX		X
Lough Aleenaun	X	X		X	X	X		X
Lough Coy	X	X		X	X	X		
Lough Gealain		X	X	XX	X	XX	XX	XX
Skealaghan	X	X	X	XX	X	X		

Table 3. Eco-hydrological status of turloughs for conservation. Green: favourable, orange: inadequate, red: bad (from Waldren, 2005)

Turlough	Type (based on soil characteristics)	Hydrological Functions Assessment	Water Quality Assessment	Biological Responses Assessment	Overall S&F Assessment
Blackrock	MIN				
Coolcam	MIN				
Lough Coy	ORG				
Caranavoodaun	ORG				
L. Aleenaun	ORG				
Skealaghan	ORG				
L. Gealain	MAR				

Table 5. Partial valuation some ES of Blackrock and Lough Gealain turloughs. Carbon sequestration was estimated using flux balances surveyed through the closed chamber method)

ES	Biophysical units	Monetary value (€)
Blackrock		
Carbon sequestration	230 tonnes/year	10134 (price per tonne of € 40.06)
Lough Gealain		
Recreation	17000 visitors per year to National Park	

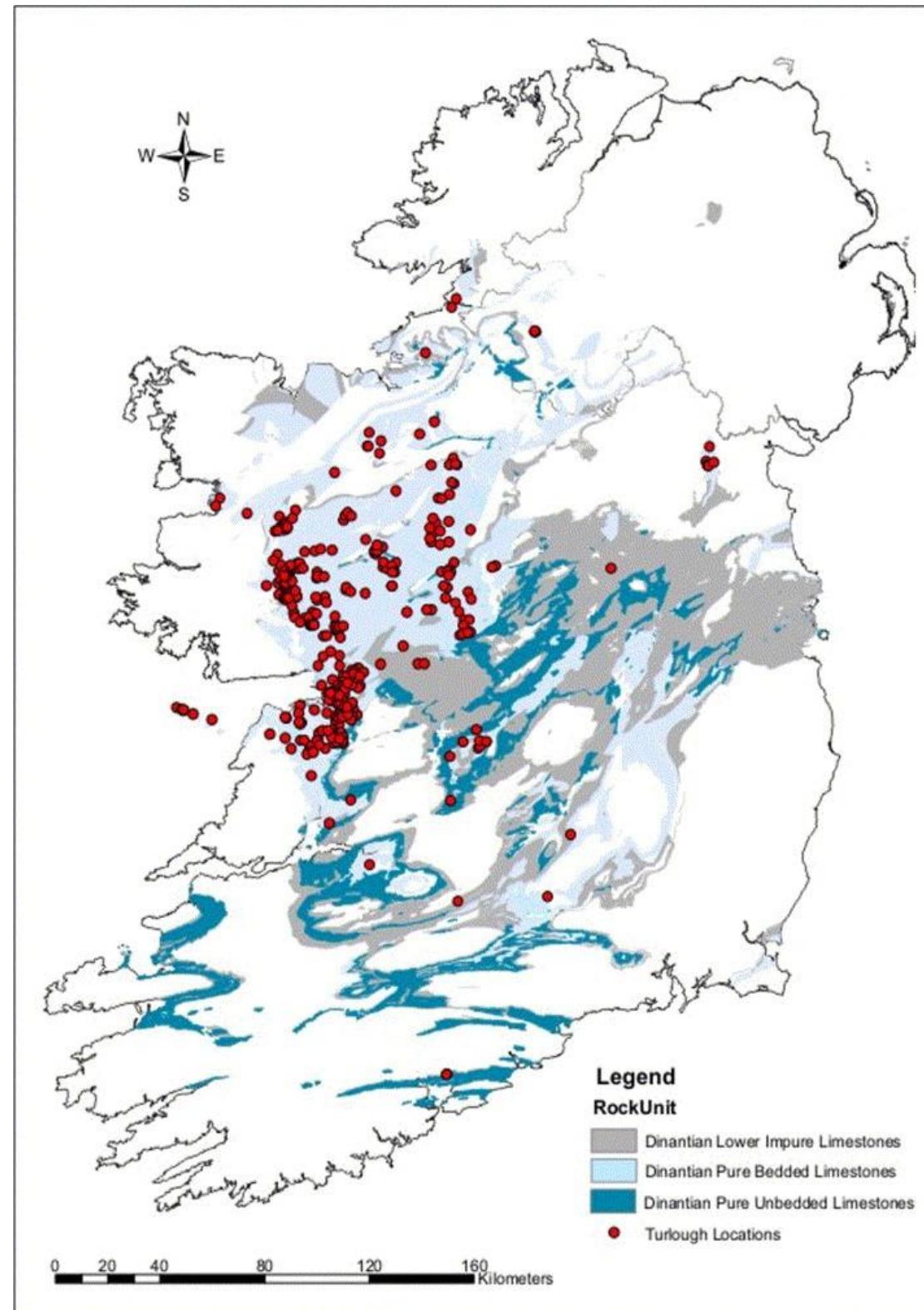


Figure 1. Location of Irish turloughs

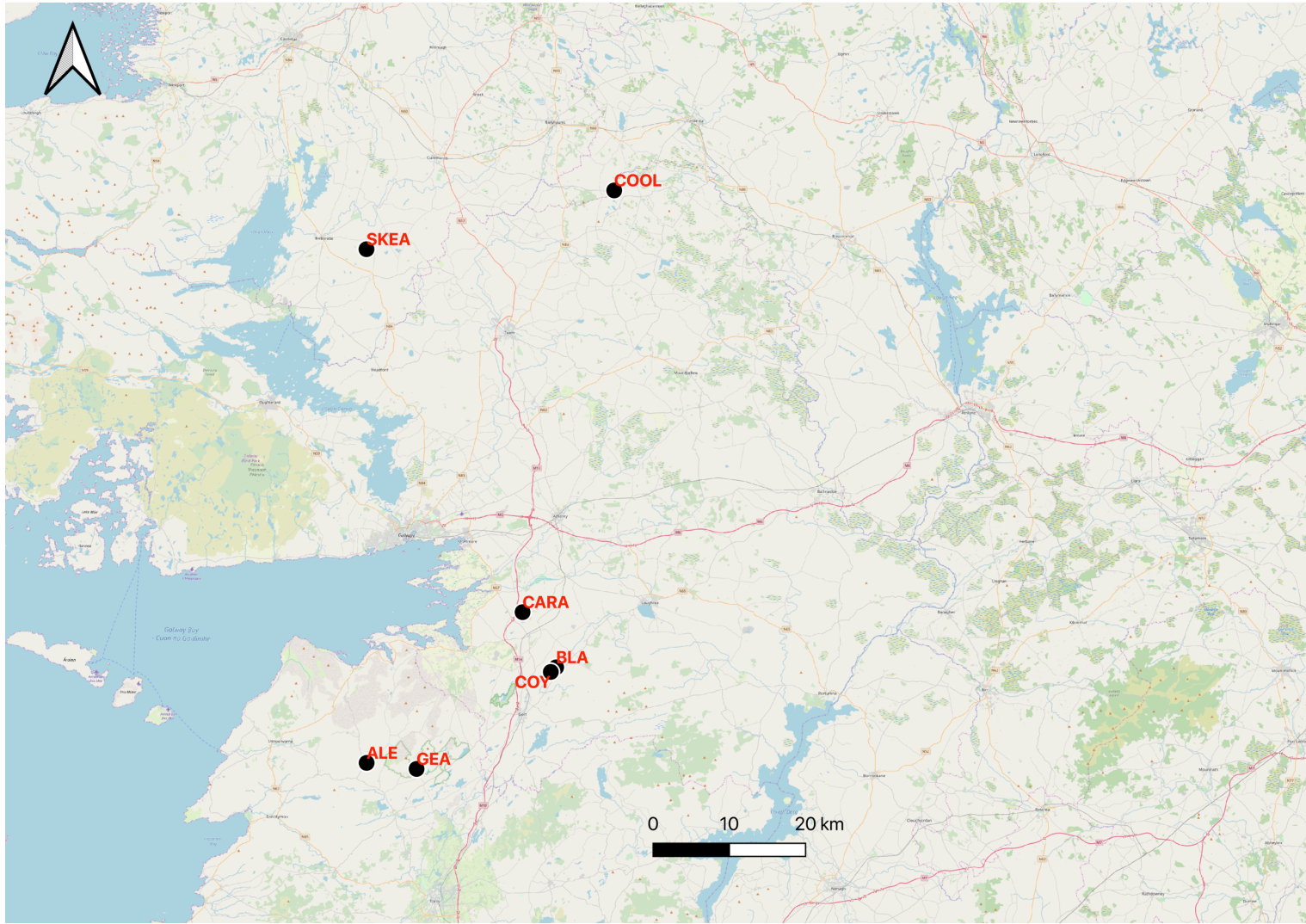


Figure 3. Location of the studied sites. Ale: Lough Aleenaun, Bla: Blackrock, Cara: Caranavoodaun, Cool: Coolcam, Gea: Lough Gealain, Ske: Skealaghan

Discussion

Wetlands have been recognised as some of the most important and most valuable ecosystems on Earth. Turloughs are intermittent inland wetlands, therefore showing both the characteristics of wetlands and of terrestrial habitats. The ecosystems services of wetlands are subject to increasing interest because of the range and value of ecosystem services they can provide. One popular evaluation has been performed by De Groot et al. (2012) and for inland wetlands recognises regulating services (flood risk reduction, nutrient retention, carbon sequestration) as the most valuable (Table 5). Similar results are expected for turloughs, especially for the flood risk reduction service

There seems to be enrichment in nutrients in Caranavoodaun, Lough Gealain and Skealaghan. Blackrock has the highest floodwater extension as well as water depths, therefore providing the highest amounts of water. Lough Gealain is important for tourism. Caranavoodaun and Lough Gealain have the best ecosystem conditions. For carbon sequestration, turloughs with peaty soils and woody vegetation will have a higher value.

Turloughs can both alleviate flooding in their basins and soils but also cause it, following exceptional rainfall events. Drainage is one of the main threats to turloughs as it alters their flooded regime, so that plants and soils are affected. It is sometimes proposed to alleviate flooding to nearby houses. This is the case for the Gort lowlands (where Blackrock and L. Coy are located) where a flood alleviation scheme is being implemented. This ecosystem service can be calculated by the avoided damage costs method.

Turloughs are very important culturally and some of them for tourism. For example, Lough Gealain is located in the Burren National Park and received an average 17000 thousands of visitors annually. The relevant authorities, like NPWS (or the Burren Centre for Lough Gealain) have been contacted to have figures about tourist visits. Alternatively, interviews can be performed with tourists asking about their expenses at the site and how much they would be willing to pay (willingness to pay method). Other methods that can be used are surveys that can establish the willingness-to-pay of tourists therefore incorporating additional non-market values.

Table 5. Value of different types of Ecosystem Services of inland wetlands in \$/ha/year, 2007 prices levels (from De Groot et al., 2012).

Provisioning services	1659
Regulating services	17364
Habitat services	2455
Cultural services	4203
Total Economic Value	25682

Conclusion

Small inland wetlands have been recognised as providing important ecosystem services and are not as well studied as the bigger ones. Their importance for some ecosystem services like carbon sequestration, flood risk alleviation and habitat preservation might then be overlooked.

More than 300 turloughs are present in Ireland and they are protected under the Water Framework Directive (WFD, Directive 2000/60/EC). As they host protected fauna and flora, they are also designated as a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC).

Quantification of the ecosystem services of turloughs can help better inform the appropriate stakeholders when deciding on conflicting developments and can also help in specific accounting projects like carbon accounting schemes and ecosystem service quantification and mapping like the Mapping and Assessment of Ecosystems and their Services (Maes, 2013).

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