A report on the possibility that Lough Derg and Lough Mask formerly contained the marl lake habitat (code 3140)

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Cover photo: *Chara dissoluta* in Lough Derg

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INTRODUCTION

At present both Loughs Derg and Mask are known to be ecologically damaged but several features suggest they were both marl lakes in part (EU habitat type 3140) in the recent past. These features include:

1) lake basin geology, in both cases Carboniferous limestone is the major rock type and alkalinity is high;
2) small amounts of cyanobacterial crust, a characteristic feature of marl lakes (see Roden *et al.,* 2020) still exists, if in very damaged condition, in both lakes (*e.g*. Hare Island, Lough Derg, and Carrigeenacoheroe, Lough Mask);
3) rock erosion patterns associated with marl lakes and crust are known from both lakes, (authors' unpublished observations);
4) some charophytes associated with marl lakes still persist in a few places in both lakes;
5) some historical accounts suggest a marl lake environment formerly occurred in both loughs.

The former ecological status of the loughs is important in setting a baseline for any restoration work and also in emphasising the extent of 3140 lakes in Ireland and the severe damage they have suffered.

This report describes a 2022 survey designed to collect data to test the idea that both lakes are/were marl lakes, at least in part.

METHODS

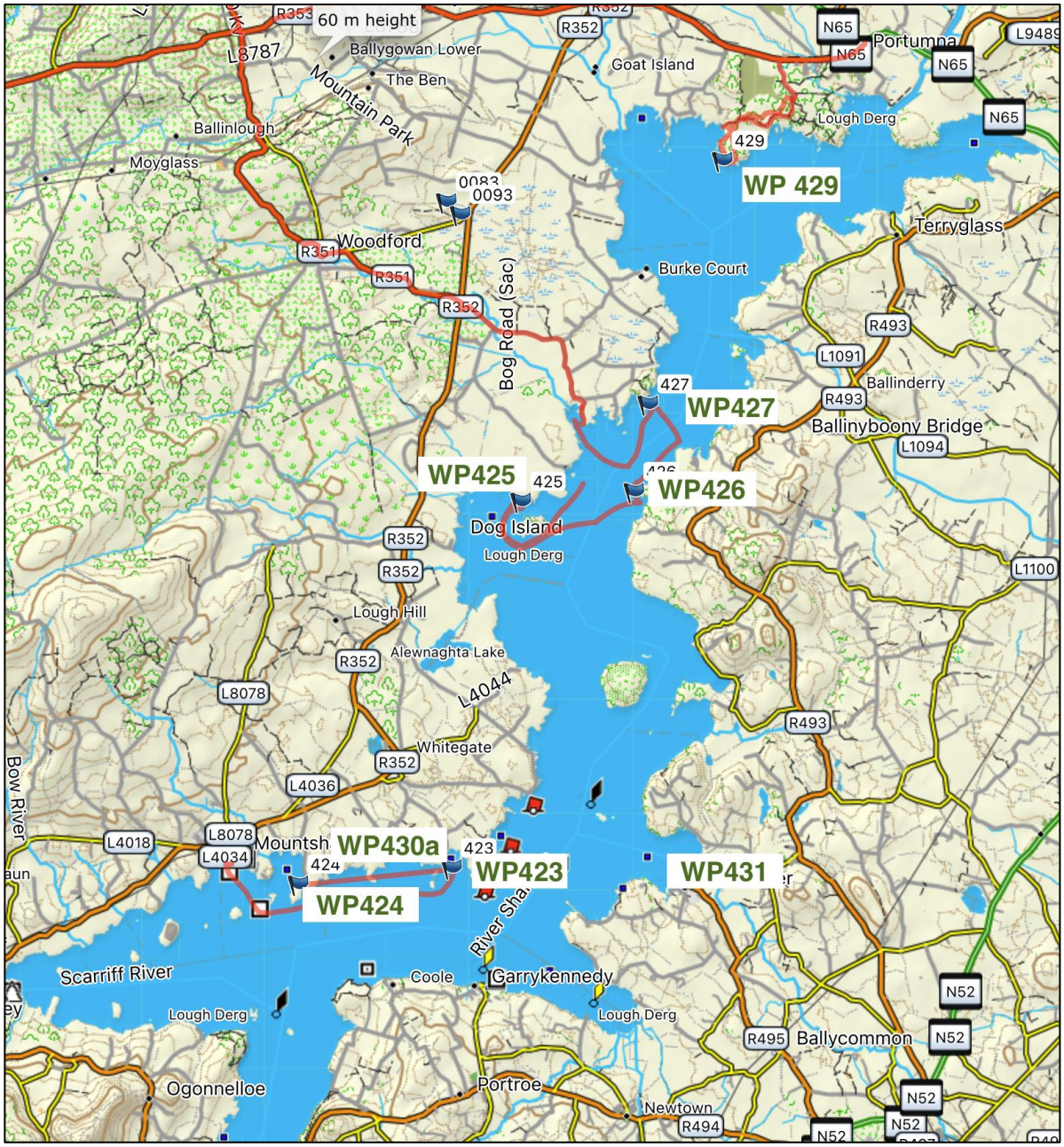
Several approaches were used to obtain the necessary data

1) Crust quality was assessed using the methods of Doddy *et al*. (2019)
2) Relict marl lake charophyte species present were assessed both by snorkel, grapnel and shore survey
3) The methods of Roden *et al*. (2020) were used to determine current euphotic depth and vegetation zonation
4) The extent of characteristic egg-box rock erosion (a possible indicator of marl lakes, see Roden *et al*. (2021)) both above and below water surface were determined by snorkel and shore survey
5) Old records of charophytes in the lakes were determined using the data base assembled by N. Stewart.

Table 1 lists the location and dates of sampling trips and Maps 1 and 2 show the location of sampling points.

Table 1. Survey locations and dates. See also Maps 1 and 2 below.

Date	Survey type	Location	Grid reference	waypoint	transect	crust sample	People
16/06/2022	boat	**Derg**, Church Bay	R762865, R726860	423 424	2		PM, CR
20/06/2022	boat	**Derg**, Rossmore	R777945, R804948, R805968	425 426 427	3		PM,CR
12/07/2022	shore	**Mask**, Shore exploration					CR
28/07/2022	shore	**Mask**, Curramore Point	M145649	500	1		ER, CR
03/08/2022	shore	**Derg**, Portumna	M823021	429	1		MC, CR,JR
05/08/2022	shore	**Mask**, Robe River mouth	M150660				SS, CR
10/08/2022	shore	**Derg**, Clery's Point	R748869	430a	1		DM,CR
19/08/2022	shore	**Mask**, Inishmaine	M126596	430	1		PG,SS,CR
31/08/2022	boat	**Mask**, north, Aghinish Rocks	M123683, M145665, M150668	432 433	3		PM,CW,CR
08/09/2022	boat/ grapnel	**Derg**, Dromineer	R812861	431	1		DM,JB,CR
12/09/2022	shore	**Mask**, Carrigeenacoheroe Caher Point	M143615, M140631	441 436		2	PD,CR
13/09/2022	boat	**Mask**, Long Island	M143615, M140623	442	2		PM,CR
19/09/2022	boat	Drone test Lough **Corrib**					PM, CR, HL,
18/10/2022	shore	**Derg**, Youghal Bay Clery's Pt, Carrick	R748869 R802834 R820900	See Doddy 2023		2	PD,DM, CR



Map 1. Lough Derg showing sampling points designated as waypoints; see Table 1 for further details

Map 2. East shore of Lough Mask showing sampling locations listed as waypoints and shown as green circles

RESULTS

VEGETATION AND FLORA

Lough Derg

The species recorded in the survey are listed in Table 2. The charophyte flora includes ten species of *Chara*, two of *Nitella*, and one each of *Nitellopsis* and *Tolypella*. This is a large part of the Irish charophyte flora and includes three species on the Red Data list (Stewart and Church, 1992), but also two species which are probably recent introductions (*Nitellopsis obtusa* and *Nitella mucronata*). Unfortunately, many of these species were only found at a single location, Clery's (or 'Cleary's') point. *Chara dissoluta* (*denudata*) however, appears at several locations in the south of the lake, constituting a new record for the lake and the Shannon river.

Few other taxa are of note. *Cladophora aegropila* (lake balls) occurs at one location, several sheltered harbours have a floating leaved community including several *Lemna* species, Frogbit *Hydrocharis morsus-ranae*, Water-soldier *Stratiotes aloides* and Water-violet *Hottonia palustris.*

The remainder of the flora is largely typical of eutrophicated limestone lakes. The introduced *Elodea nuttallii* and *E. canadensis* are widespread, as are *Nuphar lutea*, *Sparganium emersum*, *Lemna trisulca* and *Potamogeton lucens*. *Cladophora* spp. are also common attached to rocks or free floating.

Unlike marl lakes in good condition, there is little evidence of distinct depth zonation of the flora. The euphotic depth is always less than 5 m and only a few species form large dominant populations. Such species include *Nitellopsis obtusa*, *Sparganium emersum*, *Chara dissoluta*, *Fontinalis antipyretica* and, in one place, *Chara aspera*. Most species occur as small populations at varying depths but the present data do not demonstrate a regular zonation. Figure 1 shows the maximum depth recorded for each species. The depth range of 2.8 m is very narrow, with a minimum of 1 m for *Schoenoplectus lacustris* to a maximum of 3.8 m for *Nitella flexilis* (*Nitella mucronata* was only encountered once and the greater depth of 4.8m is an outlier). Charophytes as a percentage of total vegetation cover are generally low except at Clery's Point where *C. aspera* is abundant in places. The exceptions to this statement are *Nitellopsis obtusa* which forms very large stands at depths close to the euphotic depth in several places, and *Chara dissoluta,* which forms large stands at two places, Cloonoolia Bay and off Dromineer.

Not only is the euphotic depth very shallow but exposed or semi exposed shores consisting of rocks and boulders to a depth of 1.5-2 m are largely unvegetated. Below this depth, soft sediments occur to the euphotic depth. Most macrophytes occur on the sediment with few plants on the rocky slope. Thus most of the macrophyte vegetation is confined to a band little more than 2.5 m deep, possibly too narrow for significant zonation to occur.

One site, Clery's Point is exceptional, the substrate is white marl-like sediment, exposed rocks are covered with cyanobacterial crust and charophytes are common. The rare *Chara tomentosa* occurs in shallow water along with *Chara aculeolata*, *Chara virgata* var. *annulata* and *Chara curta*, while *Chara aspera* occurs at depths below 1.5 m, forming extensive carpets in places. Below 3 m, *Sparganium emersum*, *Nuphar lutea* and *Potamogeton lucens* occur, as in other Lough Derg sites.

Table 2. Species recorded at Lough Derg

Date	16/06/2022	16/06/2022	20/06/2022	20/06/2022	20/06/2022	03/08/2022	10/08/2022	08/09/2022
Way point	423	424	425	426	427	429	430	431
Euphotic depth (m)	3		3	3	3.5	3.5	>5	5
Snorkel Transect	y	y	y	y	y	y	y	y
Cladophora aegropila			1			1		
Chara aculeolata							1	
Chara aspera							1	
Chara contraria								1
Chara curta							1	
Chara dissoulta		1						1
Chara globularis								1
Chara tomentosa							1	
Chara virgata			1				1	
Chara vulgaris		1						
Cladophora			1	1	1	1		
Elodea canadensis		1	1		1	1		1
Fontinalis antipyretica		1	1	1				1
Lemna trisulca	1	1	1			1		1
Myriophyllum spicatum				1	1			1
Nitella flexilis								1
Nitella mucronata								1
Nitella opaca								1
Nitellopsis obtusa				1	1			1
Nuphar lutea	1	1	1	1	1	1	1	
Potamogeton perfoliatus		1					1	
Potamogeton berchtoldii						1		1
Potamogeton friesii		1						1
Potamogeton lucens		1	1				1	1
Potamogeton pectinatus		1					1	
Schoenoplectus lacustris	1				1	1		
Sparganium sp.		1	1	1	1	1	1	1
Sparganium emersum		1				1	1	
Stratiotes aloides			1		1			
Tolypella glomerata		1	1					1
Utricularia vulgaris		1				1		1
Zannichellia palustris	1	1		1		1	1	
Zebra Mussel	1			1		1		

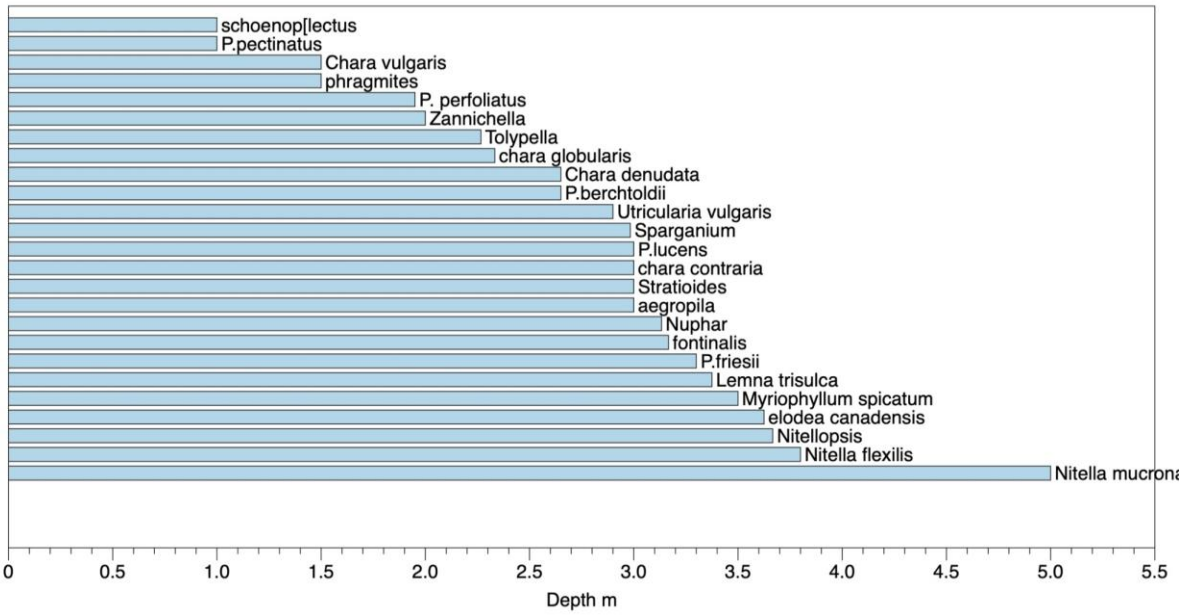


Figure 1. Maximum recorded depths of Lough Derg macrophytes

Lough Mask

The species recorded in Lough Mask are shown in Table 3. Seven charophytes were noted including *Chara dissoluta*, not previously recorded from Lough Mask. *Chara subspinosa* (*rudis*) was the only species found in Mask that was not recorded from Lough Derg (although it was recorded there in 1993). The remaining species were also recorded in Lough Derg and, again, include taxa such as *Elodea canadensis*, *Lemna trisulca*, *Nuphar lutea*, *Potamogeton lucens* and *Cladophora*. A less common species, *Potamogeton praelongus*, was also recorded.

At several exposed Lough Mask sites, vegetation is very scant with no clear euphotic depth definable due to a near total absence of macrophytes and bare exposed limestone, *e.g*. Caher Point WP436. A similar situation was recorded by Roden *et al*. (2020) from three transects taken in 2012. In contrast, several enclosed bays have well developed carpets of charophytes and cyanobacterial crust. Euphotic depth however is only 4.0 m or less at all sites surveyed. Consequently, as in Lough Derg, a clear zonation is difficult to discern. Large patches of several species were encountered, and typical marl lake species including *Chara curta*, *Chara subspinosa*, *Chara virgata*, *Chara contraria* and *Chara dissoluta* are present. While no one transect contained all the species listed, their depth distribution corresponds in part to the pattern described in Roden *et al*. (2020). *Chara curta* occurs close to the surface, while *Chara subspinosa* occurs in slightly deeper water and *Chara dissoluta* occurs close to the euphotic depth at Aghinish rocks. As noted in Roden *et al*. (2020), macrophytes including *Elodea canadensis*, *Potamogeton lucens* and *Lemna trisulca* occur at the euphotic depth, a characteristic of more eutrophic marl lakes. Unlike Lough Derg, no extensive charophyte beds were encountered close to the euphotic depth.

Table 3. Species recorded at Lough Mask

Date	28/07/2022	19/08/2022	13/09/2022	13/09/2022	31/08/2022
Location	Curramore Point	Inishmaine	Carrigee-nacoheroe	Long Island	Aghinish Rocks
Waypoint	500	430	437	442	432
Euphotic depth (m)	3	4	Too shallow	3.5	3.9
Transect	y	y	y	y	y
Chara aculeolata			1		1
Chara aspera			1		
Chara contraria			1	1	1
Chara curta			1	1	
Chara dissoluta					1
Chara subspinosa	1		1	1	1
Chara virgata	1	1	1	1	1
Cladophora		1			1
Elodea canadensis	1	1	1	1	
Fontinalis antipyretica		1			
Lemna trisulca	1			1	
Myriophyllum alterniflorum		1	1		
Myriophyllum spicatum	1		1		
Nuphar lutea	1	1			
Potamogeton friesii	1		1	1	
Potamogeton lucens			1	1	1
Potamogeton nitens		1			1
Potamogeton pectinatus			1		
Potamogeton perfoliatus		1			1
Potamogeton praelongus	1				
Schoenoplectus lacustris	1				
Zebra Mussel	1	1	1		1

Historical Records of the Flora

Lough Derg

There is an extensive historical archive of charophyte records from Lough Derg dating from the late 19th century (see Figure 2). It can be seen that the despite unsystematic collection and lack of snorkel survey, a substantial charophyte flora was recorded by 1900. All the species found in marl lakes are repeatedly recorded with the exception of *Chara dissoluta*, a deep water species. These data imply that the charophyte flora was widespread at the time. In the last thirty years, however, several species are not or only very infrequently recorded (*e.g.* *Chara aspera*, *Chara aculeolata*). More recently, the lake has been frequently systematically sampled by the EPA and the specimens collected identified by N. Stewart. If the species remained common, they should have been collected. In contrast, the EPA surveys have frequently collected new species such as *Nitellopsis obtusa* and *Nitella mucronata* and *Nitella flexilis*. In this survey, some old species records have been confirmed, but only as small marginal populations. A surprising addition has been *Chara dissoluta*, only known from marl lakes elsewhere and possibly overlooked in the past.

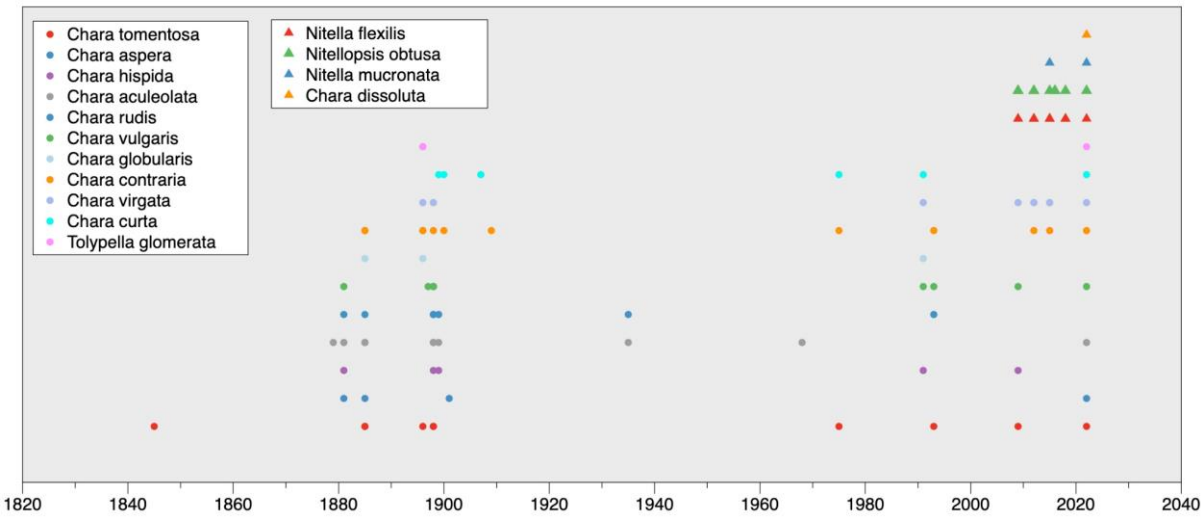


Figure 2. Historical records of charophytes in Lough Derg

Lough Mask

Unfortunately, there are very few historical records from Lough Mask so a similar analysis of the flora is not possible.

Cyanobacterial Crust or Krustenstein

Roden *et al*. (2020) show that a shallow water calcareous cyanobacterial crust is found in all marl lakes in good condition. Doddy *et al*. (2019) demonstrate that, as these lakes become more eutrophic, crust chlorophyll content increases and in lakes in poor or bad condition the crust declines or vanishes. If Lough Mask or Lough Derg were once marl lakes, one would expect large areas of crust on rocky shores. Such crust is known from some locations in both lakes and was sampled by P. Doddy in September and October 2022. Some crust was collected at Youghal Bay, Carrick Shore and Clery's Point, Lough Derg and at

Carrigeencoheroe and Caher Pier in Lough Mask. The results of the sample analysis are given in Doddy (2023) and are summarised as follows.

In Lough Derg samples from two open water stations, Youghal Bay and Carrick Shore had the highest chlorophyll concentrations as yet recorded from Irish marl lake crust samples (156 µg/cm^3) while the Clery's point sample (68 µg/cm^3) was comparable to eutrophicated lakes such as Derravarragh or Ennell. These readings indicate a very heavily eutrophicated lake.

In Lough Mask, the open lake shore sample at Caher Point was typical of badly eutrophicated water (97 µg/cm^3), while the enclosed Carrigeenacoheroe Bay values (39 µg/cm^3) indicated noticeable but less severe nutrient enrichment. These results show that the characteristic marl lake feature, cyanobacterial crusts still persists in both lakes but in an extremely damaged condition.

Sub-littoral rock surfaces are very different in both lakes (Figures 4 and 5). In Lough Mask (Figure 5), nearly all limestone rock is bare and extremely eroded with very extensive pitting and etching. In Lough Derg (Figure 4), bare rock is rarely encountered, instead rocks are masked by a calcareous soft-ish friable layer that often joins neighbouring boulders and extends to about 3 m depth. This deposit was encountered at six locations throughout the lake. Its rough soft surface is often colonised by *Cladophora* spp., *Zannichella palustris* and *Chara vulgaris*. Zebra mussels are found both on and within the deposit. It is easily prised off with a knife, but can be several centimetres deep, eventually yielding to hard limestone. The nature and origin of the deposit is not yet established but it may be "fossil" cyanobacterial crust.

Prior to this survey, D. Minchin collected examples from Lough Derg up to 10 cm thick that, when dried, resemble coral or tufa but are very light and fragile. Most deposits are tunnelled. Treatment with dilute acetic acid results in effervescence, and eventual dissolution, leaving a residue which under magnification seems to include cell walls of filamentous and coccoidal organisms. This dissolution indicates a calcareous nature.

By filing and sanding sections, the internal structure can be seen. It consists of radial layers several millimetres deep consisting of vertical elements separated by narrow dark bands. Sections of living cyanobacterial crust collected at Lough Mask show some resemblance to the Lough Derg material (Figure 7). The most obvious difference being the gelatinous consistency of the living crust compared to the friable brittle consistency of the Lough Derg samples. In addition, an obvious chlorophyll-rich green layer is replaced by a narrow dark layer in the latter. In Lough Carra it is noticeable that crust subject to excess nutrient becomes hardened and less gelatinous than healthy crust, often with extensive dark rust coloured staining in places (C. Roden personal observation).

Erosion of Limestone as an Indicator of Cyanobacterial Crust

Roden *et al*. (2021) show there is evidence of rock erosion under cyanobacterial crusts in the shallow sub-littoral of Irish marl lakes. They report that many limestone boulders covered by crust are largely dissolved away or consist of a hard core-stone surrounded by clay- or marl-like soft material underlying the actual crust. There is a similarity between this material and the soft clayey material underlying the tufa like deposits found in Lough Derg.

An even more striking phenomenon of some marl lakes is the egg-box weathering so dramatically visible on the shore of Lough Mask. However, the level of this lake was lowered

in the 19th Century and much of the now exposed pitting would have been covered prior to the event. As noted above, most sub-littoral limestone is now bare in Lough Mask. It is clearly very sharply etched into pinnacles, spikes and arches not seen above water level. Similar etching was noted in Lough Corrib limestone rock, under cyanobacterial crust at a depth of 3 m in 2012 and again in 2022.

Removal of living crust from small sub littoral boulders in Lough Mask (Figure 8) showed the underlying rock is covered by a whitish clay/marl layer which, when removed, shows the core-stone to be pitted in an incipient egg-box pattern.

As the lake level of Lough Derg is all but constant since the construction of Ardnacrusha dam, there is no exposed rocky shore zone as occurs in more pristine limestone lakes. Occasional stones with characteristic egg-box weathering were noted at Youghal Bay, Mount Shannon and Portumna. The most impressive display of these stones however is at the entrance gate of Portumna Castle built prior to the dam construction: hundreds of egg-box weathered stones are used in its construction. It is most probable that the stones were taken from the lake shore, thus demonstrating that Lough Derg shares a very characteristic feature of other Irish marl lakes.

DISCUSSION

WERE/ARE MASK AND DERG MARL LAKES?

Roden *et al*. (2020) propose several features that define Irish marl lakes on limestone in good condition. Features include:

1) Alkalinity > 100 mg/l
2) Euphotic depth > 7 m
3) A flora dominated by charophytes and including *Chara curta*, *Chara subspinosa* (*rudis*) and *Chara virgata*
4) At least four separate charophyte and cyanobacterial crust depth zones.

More recently, Roden *et al*. (2021) explored the possibility that marl lakes were also the site of egg-box weathering of limestone rock, possibly due to cyanobacterial crust action.

In both lakes, alkalinity is known to exceed 100 mg/l and both are on largely limestone bedrock. In neither lake does euphotic depth exceed 7 m, but this is also the case for known marl lakes damaged by excess water colour or total phosphorus. Both lakes have unexpectedly rich charophyte floras of seven species in Mask and 15 in Derg including *Chara curta*, *Chara subspinosa* and *Chara virgata* (*Chara subspinosa* has not been seen in Derg since 1993). In both lakes, the rare *Chara dissoluta* was recorded, a species otherwise only known from marl lakes in Ireland. It is also evident that Derg had a more widespread charophyte flora in the past.

A defining character of Irish marl lakes on limestone rock (as opposed to calcareous drift) is an extensive cyanobacterial zone in shallow water. This zone occurs in a few places in both lakes. The very extensive tufa like deposits in Lough Derg are most easily explained as dead calcareous remnants of former cyanobacterial crust; it is difficult to propose any other origin for this unusual deposit. If this is the case, Lough Derg once had huge shallow water areas of cyanobacterial crust, a unique feature of marl lakes. Furthermore, this “fossil crust” extends to a depth of 2-3 m. In marl lakes in good condition, such a wide crust zone is usually followed by charophyte zones extending below 7 m.

Egg-box pitting or weathering is confined to the shores of marl lakes, to the best of the authors' knowledge. Its presence in both lakes may indicate their marl lake nature. Both lakes have many characteristics of marl lakes and the flora and vegetation contain no species characteristic of other lake types. Instead the remaining flora is that of eutrophicated water bodies, including common species such as *Lemna trisulca*, *Nuphar lutea* and *Potamogeton lucens*.

In conclusion, the simplest explanation of the marl lake features seen in both lakes is that they were formerly marl lakes in good ecological condition, but now are very severely damaged with merely relict features of marl lakes.

Using the assessment scheme of Roden *et al*. (2020), both lakes would be characterised as in bad conservation condition due to shallow euphotic depth (<7 m), less than four vegetation zones, and low C+K score. The scores from the crust analysis also indicate very severe eutrophication.

THE CURRENT CONDITION OF THE LAKES

At present, the ecology of both lakes is characterised by an abundance of zebra mussels, but in Lough Mask the greater part of the sublittoral is desert-like with bare rock and few plants. In complete contrast, Lough Derg appears to be evolving into a new ecosystem with very large areas of deep water vegetation of the introduced species *Nitellopsis obtusa* and *Nitella mucronata*, as well as angiosperms such as *Elodea nuttallii*.

An interesting feature in both lakes is that a few bays retain a charophyte-dominated vegetation. These include Clery's Point in Lough Derg and Carigeenacoheroe in Lough Mask. In both bays, the substrate is a whitish marl, water clarity is good, living cyanophyte crust remains and charophytes are the dominant vegetation. Why this habitat remains was not determined, but one possibility is upwelling of groundwater from underground springs.

FURTHER WORK

This is a preliminary investigation, and largely field based. Further investigations of the Derg "tufa" and palaeolimnological work would test our hypothesis that formerly large parts of Derg and Mask were characteristic marl lake habitat (EU code 3140) and whose decline constitutes a severe loss of heritage comparable to the loss of our raised bogs.

Acknowledgements: We would like to thank Áine O Connor for her support and discussions about this work. We were helped by many people when sampling including Jan-Robert Baars and his team from UCD, who also provided berths for DM and CR on a Lough Derg Cruise. Moya Cannon, Paul Gosling, Eivlin Roden, John Roden, Sabine Springer and Carl Wright helped with sampling. Heather Lally (ATU Galway) kindly allowed the use of equipment to analyse cyanobacterial crust.

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PHOTOGRAPHS

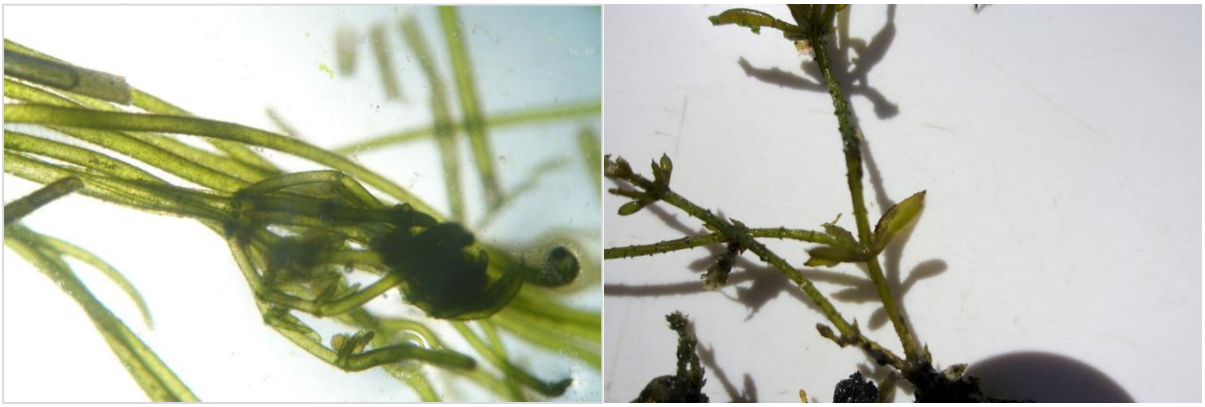

Figure 3. *Chara dissoluta* and Chara *tomentosa* from Lough Derg.

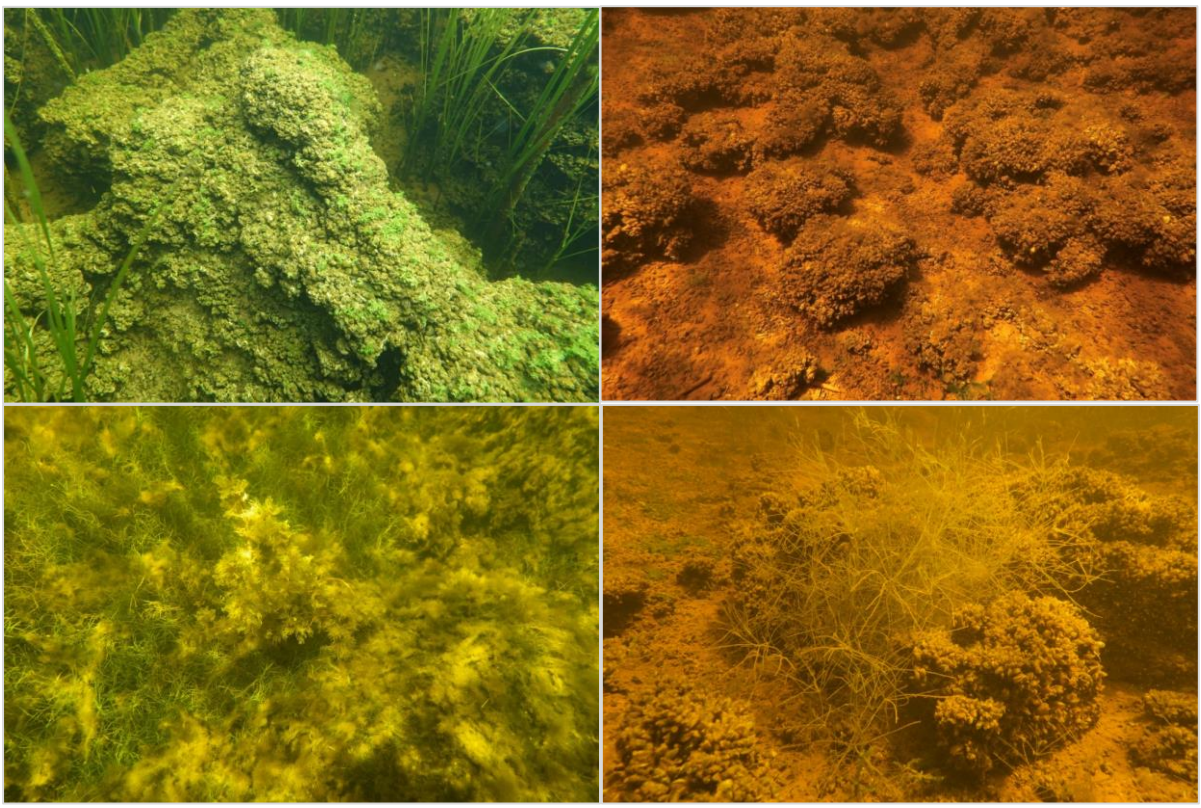

Figure 4. Lough Derg vegetation (clockwise from top left): Shallow water (50 cm) "tufa" formation with *Schoenoplectus lacustris*; midwater (1.5 m) tufa formation with Zebra mussels; *Nitellopsis obtusa* growing at base of rocky slope (3 m) amongst Zebra mussel covered rocks; Tufa covered with *Cladophora* and *Zannichella palustris*.

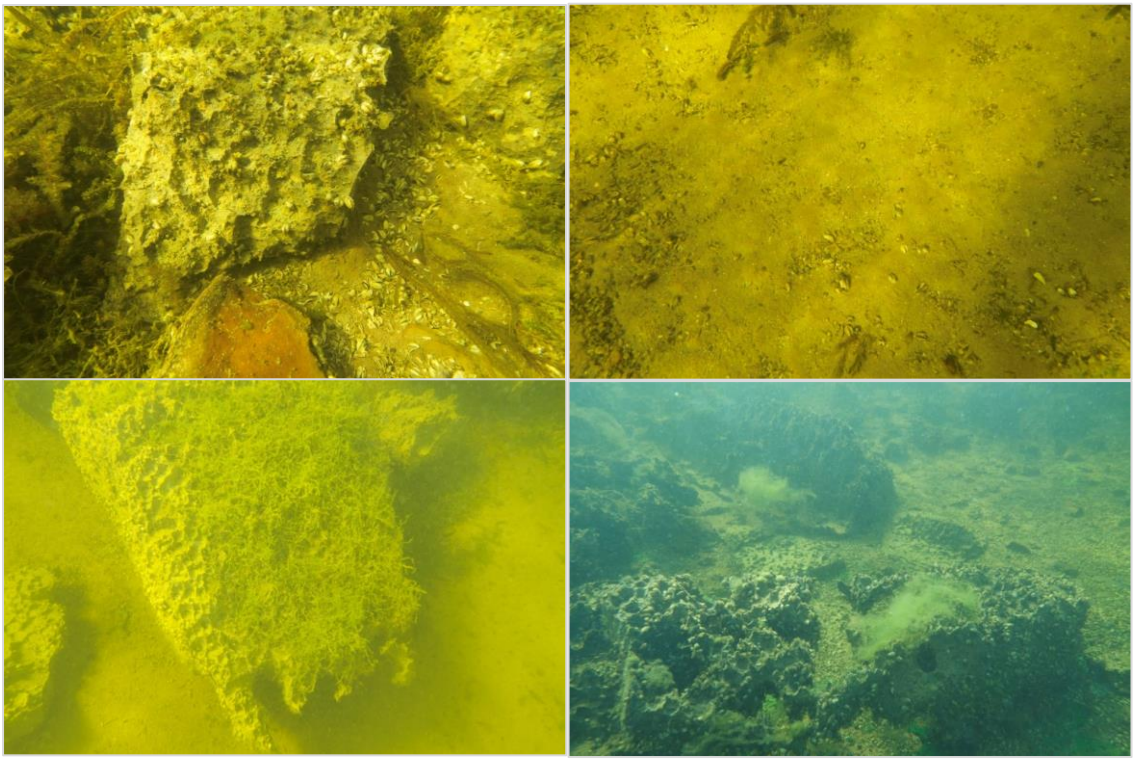

Figure 5. Lough Mask vegetation (clockwise from top left): Shallow water (50 cm) bare limestone and some *Chara virgata* and *Myriophyllum alterniflorum*; midwater (1.5 m) bare soft sediment with Zebra mussels; Zebra Mussel covered rocks, heavily pitted and eroded at 3 m; Chara virgata growing on limestone boulder at 2 m.

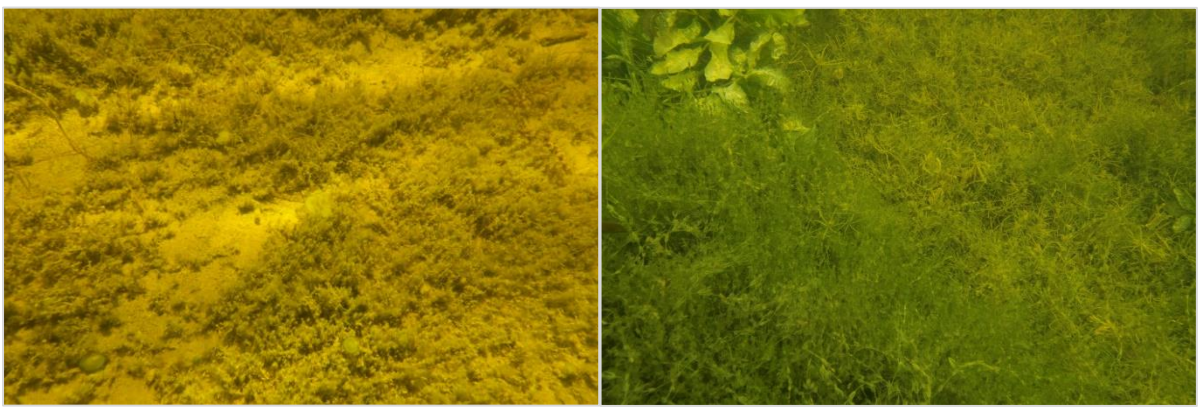

Figure 6. Charophyte vegetation, *Chara aspera* in Lough Derg (left), and *Chara virgata* and *Chara subspinosa* in Lough Mask (right)

Figure 7. A comparison between the Lough Derg "Tufa" and living cyanophyte crust taken from a submerged boulder in Lough Mask.

Figure 8. A sub littoral boulder from Lough Mask with cyanophyte crust removed to show underlying rock with egg-box weathering.