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The unusual alga *Gonyostomum semen* (Ehrenberg) Diesing 1866 and its occurrence in Scottish freshwater lochs

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Gonyostomum is a genus of freshwater algae in the class Raphidophyceae, phylum Heterokontophyta (Guiry & Guiry, 2024). Although five species have been described from Europe (Koreiviene *et al*., 2012), only one – *G. semen* – has been recorded from the British Isles (John *et al.*, 2011) with the first record reported in 1933 (Malin Smith, 1933).

Living *G. semen* cells are motile, bright green in colour, ovoid in shape with a rather flattened body, and are easily recognised. The cells possess two flagella, one pointing forward and the other, when seen from the side, pointing backward, although in the photographs only one flagellum can be clearly seen (Fig. 1). The cells lack a cell wall, but several discoid chloroplasts are visible together with a number of rod-like trichocysts. Trichocysts, also known as muciferous bodies, are of unknown function, and can be ejected under stress. This can result in water bodies becoming slimy and causing skin irritation (Cronberg *et al*., 1988).

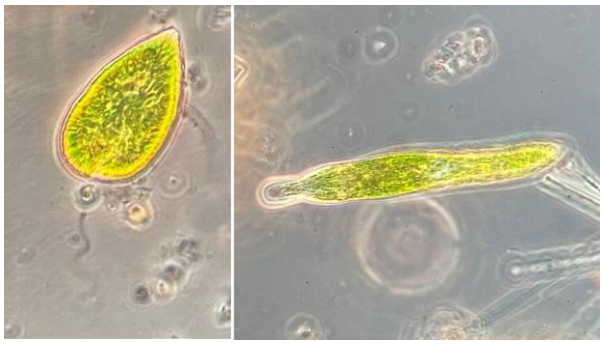

Fig. 1. Live *Gonyostomum semen* cells, Loch Merkland, Sutherland, 25th October 2023. Left image shows top view of cell, which is 70 µm long and 30 µm wide. Right image shows side view of cell, which is 12 µm deep. (Photos: J. Krokowski)

Analysis carried out by the Scottish Environment Protection Agency (SEPA) requires all samples to be preserved with Lugol's solution with enumeration carried out using the standard methodology (Brierley *et al*., 2007). During preservation, trichocysts may be ejected and, because they lack a cell wall, cells may disintegrate, lose their unique identification features, and become difficult to identify. Examples of preserved burst cells are shown in Fig 2.

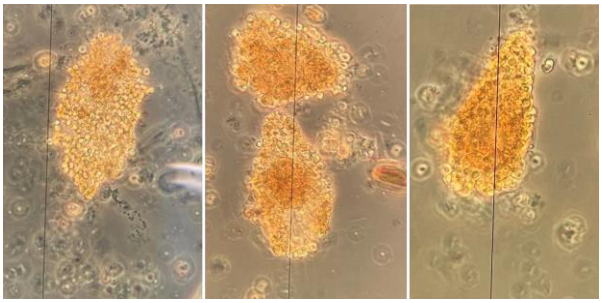

Fig. 2. Examples of burst *Gonyostomum semen* cells from Lugol's preserved samples, Loch Merkland, , Sutherland, September 2023. Cells are approximately 50-70 µm long. The darker round object in the middle image, lower cell, is the cell nucleus. The black lines are part of an eyepiece graticule. (Photos: J. Krokowski)

G. semen was noted in Swedish lakes in the 1940s and in Norwegian and Finnish lakes in the 1970s, and is generally found in humic waters with increasing occurrence reported in recent decades mainly from Scandinavian and Baltic countries (Hagman *et al.,* 2015). A rapid increase of *G. semen* has been linked to climate change (increasing spring, autumn and annual temperatures) (Rohrlack, 2020) and to anthropogenic activities in the catchments causing increasing browning and inputs of both organic matter (dissolved organic carbon - DOC) and nutrients, which are creating favourable conditions for this species (Hagman *et al*., 2015, 2019, 2020). Dispersal of the alga can also be driven by autumnal migratory birds (Rengefors *et al.,* 2021).

In Scotland, *G. semen* has been occasionally recorded in high abundance from a small number of freshwater lochs (Table 1). These are monitored by SEPA mainly during July, August and September as part of the freshwater loch monitoring programme, although no records were evident prior to 2009 when detailed loch monitoring and analysis began.

The Scottish records of *G. semen* are all from lowland, humic waters and all, apart from Loch Awe north basin, Argyll and Loch Ness, Invernessshire, are shallow water bodies, with relatively high colour and DOC concentrations. The most northerly record is from Loch Hempriggs, Caithness, and the most southerly from Loch Ken, Dumfries & Galloway. Although no single mechanism has been demonstrated for increases in DOC in waters in the U.K. (Worral & Burt, 2007), increasing surface temperatures could potentially lead to increasing microbial activity, enhanced decomposition and increased DOC production, potentially leading to more favourable conditions for *G. semen* (Hagman, 2020; Rohrlack, 2020).

Water body	Year	Month	Biovolume ($mm^3 L^{-1}$)
Loch Insh, Invernessshire	2009	July	<0.01
	2009	September	0.06
	2011	August	<0.01
Gartmorn Dam, Clackmannanshire	2009	August	0.03
Upper Lochan nan Lagasdail, Harris	2011	September	0.22
Loch Ness, Invernessshire	2012	July	0.07
	2012	August	0.12
	2012	September	0.01
	2014	September	0.03
	2016	September	0.01
	2018	July	0.01
	2018	August	0.01
	2018	September	0.01
Carron Valley Reservoir, Stirlingshire	2013	July	<0.01
	2013	August	0.11
	2013	September	0.04
Loch Ken, Dumfries & Galloway	2015	July	1.89
	2015	August	3.79
	2015	September	0.05
	2017	August	<0.01
Loch Awe north basin, Argyll	2015	August	0.01
	2017	July	0.01
	2017	September	<0.01
	2023	July	<0.01
Loch Kinord, Aberdeenshire	2017	May	<0.01
	2017	August	<0.01
	2017	September	0.10
	2022	July	112.0
	2022	August	0.68
	2022	September	0.48
Loch Ard, Stirlingshire	2017	August	<0.01
	2017	September	0.07
Loch Midgale, Sutherland	2018	July	0.02
	2018	August	<0.01
	2018	September	<0.01
Loch Awe south basin, Argyll	2018	August	<0.01
	2018	September	0.01
Loch Moan, Dumfries & Galloway	2022	August	3.9
	2022	September	22.9
Loch Ochiltree, Dumfries & Galloway	2022	July	0.65
	2022	September	9.0
Loch Maberry, Dumfries & Galloway	2022	July	0.02
	2022	August	0.03
	2022	September	7.21
Loch Venachar, Stirlingshire	2023	August	0.05
Loch Tralaig, Argyll	2023	August	<0.01
Loch Merkland, Sutherland	2023	July	0.02
	2023	August	0.04
	2023	September	<0.01

Table 1. Scottish records of *Gonyostomum semen*. Biovolume = volume of cells in a unit amount of water.

It is therefore not clear if *G. semen* is increasing its habitat range and frequency due to climate change and changes in anthropogenic activities in the catchments, or whether the alga is rare or missed in analysis due to its change in morphology following preservation, making clear identification difficult.

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