ECOLOGY AND ANNUAL CYCLE OF *MYXAS GLUTINOSA* (O.F. MÜLLER) (GASTROPODA: LYMNAEIDAE) IN LLYN TEGID, NORTH WALES

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Abstract Myxas glutinosa *was feared extinct at all of its British sites for several years before it was rediscovered in Llyn Tegid (North Wales) in 1998. Results of a study of this population over eleven years are described in this paper. At Llyn Tegid it is restricted to the littoral zone, occurring exclusively beneath boulders and other large stones in silt-free areas. Unlike some populations in Ireland where it does not hide under rocks, the snails occur at low densities, and compared to these and many of the extinct British populations they are small when mature (shell height rarely reaching 10 mm). Repeated sampling of populations for biometrical study suggested that* M. glutinosa *has an annual life cycle in the lake, with snails reaching full size and reproductive maturity in late winter or spring, shortly before their death. The possible significance of sudden changes in the water-level of Llyn Tegid and its toxic algal 'blooms' for the conservation of* M. glutinosa *are discussed.*

Key words Myxas glutinosa, *Llyn Tegid, Snowdonia, lacustrine snails, annual cycle, water depth, cyanobacteria, conservation*

INTRODUCTION

The glutinous snail *Myxas glutinosa* (O.F. Müller 1774) (Gastropoda: Lymnaeidae) is Britain's rarest freshwater snail. In Britain it is a Red Data Book category 1: endangered species (Bratton, 1991), a species of principle importance on schedules 41 and 42 of the NERC Act (2006) in England and Wales respectively and protected by inclusion in Schedule 5 of the Wildlife and Countryside Act 1981. The species is listed in the IUCN *Red List of Threatened Animals* as Data Deficient (formerly Vulnerable) (IUCN, 2013).

A review by Whitfield *et al.* (1998) reported that, although *M. glutinosa* extends from the Arctic Circle to the Alps, it is now very local throughout this range (e.g. in France: Mouthon & Vimpère, 2014) and thought to be extinct in several countries, including England (cf. Wells & Chatfield, 1992). The latter review showed that the species was widespread, although scarce over much of Britain prior to the 1950s, but recorded at only one site since 1970 (in Oxfordshire), being last found there in 1993. As surveys by Ian Killeen in 1998 of other former strongholds in Windermere and the Basingstoke Canal proved negative, it was feared that *M. glutinosa* had become extinct in Britain by 1998. Natural England (2010) declared the species extinct in England.

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The only confirmed records of *M. glutinosa* in Wales are from its largest natural lake, Llyn Tegid (Bala Lake) which lies on the southern fringes of Snowdonia. *M. glutinosa* records for this lake were quite numerous between 1852–1953 (McMillan & Millott, 1954; Dunn, 1961; Whitfield *et al.*, 1998), but deliberate searches in 1960, 1964 and 1989 (the last of these by Peter Hope Jones and Marcus Yeo) failed to relocate the species and it was feared extinct. However, as described below, a survey in 1998 was successful in relocating it and established the presence of *M. glutinosa* along about 75% of the lake shore (Willing & Holyoak, 1998). The species can easily be identified in the field because the mantle extends over much of the outside of the shell when the animals are active (Fig. 1), whereas the mantle of *Lymnaea* and *Radix* species does not cover the exterior of the shell. Surprisingly our field observations (Willing & Holyoak, 1998) revealed that within the lake, *M. glutinosa* occurred only *beneath* substantial rocks (larger cobbles and boulders) and that it was not found on soft sediments or aquatic vegetation. Elsewhere it is usually found crawling on the exposed surfaces of stones or on aquatic vegetation and soft sediments (e.g. Carlsson, 2001; Holyoak, 2004).

During 1999–2002 we carried out unsuccessful searches for the species at 24 other lakes in Snowdonia and on the island of Anglesey and

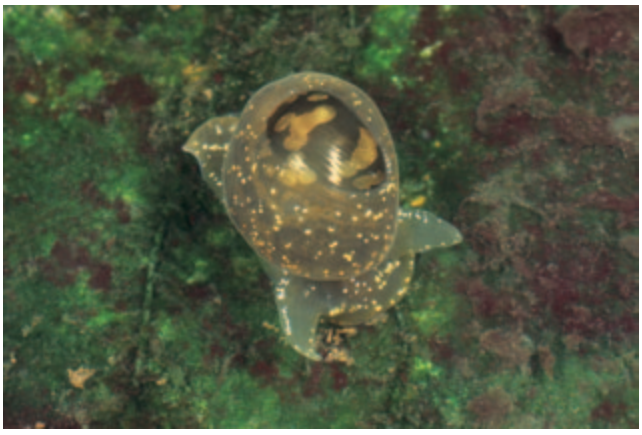

Figure 1 *Myxas glutinosa* from Llyn Tegid (note that mantle extends over the shell); length of animal *ca* 7 mm. Photo by M .J. Hammett.

Figure 2 *Myxas glutinosa* as seen on lower surface of rock removed from shallow water in Llyn Tegid (October 2009). Length of animals *ca* 5–6 mm.

made more detailed studies of it at Llyn Tegid. The distribution of *M. glutinosa* around the lake was mapped in some detail and divers investigated the depths to which it descends. In order to clarify aspects of the life history of *M. glutinosa* in the lake, eight fixed monitoring stations were established and these were revisited several times each year from spring to late autumn until 2001 and then in the autumn only in 2002, 2005 and 2009 (Willing, 2004, 2006, 2010) to obtain population counts, and collect samples for measurements of shell-length and size of genitalia. This paper describes results from these studies carried out between 1998–2009 and makes comparisons with data on the habitats and seasonality of the species elsewhere in Britain, in Ireland (Holyoak, 2004, 2005; GAH, pers. obs.) and in southern Finland (Carlsson, 2001).

Methods

Llyn Tegid is a large deep lake, some 9 km long, up to 2 km wide and 43 m in depth, its surface at 158 m above sea-level, occupying a glaciated valley that was ice-filled during the last (Devensian) glaciation. See Duigan *et al.* (2003) for a more detailed description. Away from the inlet streams at its south-western end, the shores are of cobble- to boulder- sized metamorphic rocks of slaty lithologies, although the rock is covered by silt and clay at depths beneath those affected by wave action. The catchment has an upland character with pastoral farmland, sparse habitation and very little arable land. Its acidic siliceous bedrock results in a base-poor lake (circumneutral to mildly acidic) with mean pH of 7.1 and oligotrophic to mesotrophic (relatively low) productivity and nutrient levels (Burgess *et al.*, 2006). Away from its silty south-western banks, there is scanty submerged or emergent aquatic vegetation (of the Littorelletea uniflorae, the Isoëto-Nanojuncetea, or both). The molluscan fauna is restricted in variety and number: ten gastropod species, including *M. glutinosa*, were recorded; these mainly grow to rather small sizes (Willing & Holyoak, 1998; Willing, 2004). The Gwyniad, a whitefish, is of considerable conservation importance because it is regarded as a speces endemic to the lake (*Coregonus pennantii* Valenciennes 1840) by IUCN. It is found there together with 15 other fish species (some of which may be predators of gastropods in the lake) including the introduced ruffe *Gymnocephalus cernua* (Linnaeus) (Leah, 2003).

A barrage (sluice-gate outlet) allowing control of water levels in Llyn Tegid was constructed in 1955 at Dee Bridge, Bala. Since then the flow of water out of the lake has been deliberately adjusted (nowadays by Natural Resources Wales: NRW). This intervention causes lake levels to rise following heavy rainfall by delaying the release of water into the River Dee to avoid flooding downstream. These actions also maintain moderate levels in the lake in dry weather to benefit boating and other water sports. The NRW 'lake sill level' at Dee Bridge is at 159.06 m above Ordnance Datum and used as a reference point in discussion of lake levels throughout this paper (abbreviated to NRWSL in Tables 1, 2 and 4).

Table 1 Numbers of *Myxas glutinosa* recorded at survey and monitoring sites at Llyn Tegid, September 1998 to November 1999.

Survey Dates	Sept 1998	June 1999	Aug. 1999	Oct. 1999	Nov. 1999
Approx. search time per site (hours):	2	S1: 2 S2: 4.5 S3: 2 S5: 2 S6: 7.5 S13: 1	1	1 except 7 & 12 not timed	Dive collected (1–1.5 per site)
Lake levels / m (above NRWSL)	0.99–1.0	1.38–1.427	1.25–1.278	0.722–0.774	1.388–1.554
Sites (*=monitoring sites)					
1*	10	0	15	14	12
2*	6	1	29	32	9
3*	6	0	10	6	
4	4		23	21	1
5*	33	0	28		
6*	14	5	13	54	many
7a*	0		0	0	
7b*	0			0	
8			2		
9*			13	24	6
10			0		
11*			8	6	4
12				0	
13	23	0			
14	3				
15	0				
16	0				
17	0				
18	8				

On arrival at Llyn Tegid in September 1998 our first unsuccessful searches for *M. glutinosa* were made using various hand-held nets and scoops to sample aquatic vegetation and the upper surface of sediments, but the lake margin substrata are predominantly rocky with little aquatic vegetation and the use of such equipment proved ineffective. Glass-bottomed 'buckets' were also used to search the surface of rocks and sediments for the snail in clear water conditions and although a number of other gastropod species were located no *M. glutinosa* were found. However, examination of the under-surface of large flat rocks by lifting them from the water quickly revealed living *M. glutinosa* and this technique was found to be consistently successful. Hence this was the main search technique adopted throughout the study, although several further unsuccessful attempts were made to use nets in areas of the lake with mud substrata or macrophytic vegetation.

The initial survey in September 1998 examined thirteen sites, which were fairly evenly distributed around the lake (Fig. 3). Further work in June, August and October 1999 re-surveyed eight of the original sites as well as a further six sites to map distributional limits more clearly. Sampling for *M. glutinosa* by wading in the lake margins did not allow the maximum water depths occupied by the snail to be established, so divers surveyed the lake bottom for us at depths from 0.6 to 21 m. The team of four professional divers skilled in marine biological studies carried out this survey in November

Table 2 Numbers of *Myxas glutinosa* recorded at eight monitoring sites at Llyn Tegid, April 2000 to October 2009.

Survey Dates	April 2000	Aug. 2000	Feb. 2001	Sept. 2001	Sept. 2002	Oct 2005	Oct 2009
Approx search time per site (hours):	1	1	1	1 *(algal bloom in lake)*	0.5	0.5	0.5
Lake levels / m (above NRWSL) Sites	1.44–1.47	1.34–1.36	1.075–1.017	1.067–1.187	1.01	1.061–1.129	0.777–0.788
1	0	26	16	1	8	11	5
2	0	10	16	16	7	5	2
3	0	47	14	0	7	10	2
5	0	26	0	12	13	1	16
6	6	36	17	1	6	17	41
7a/7b	0	0	0	0	0	0	0
9	0	1	0	1	11	4	3
11	0	10	20	12	17	3	16

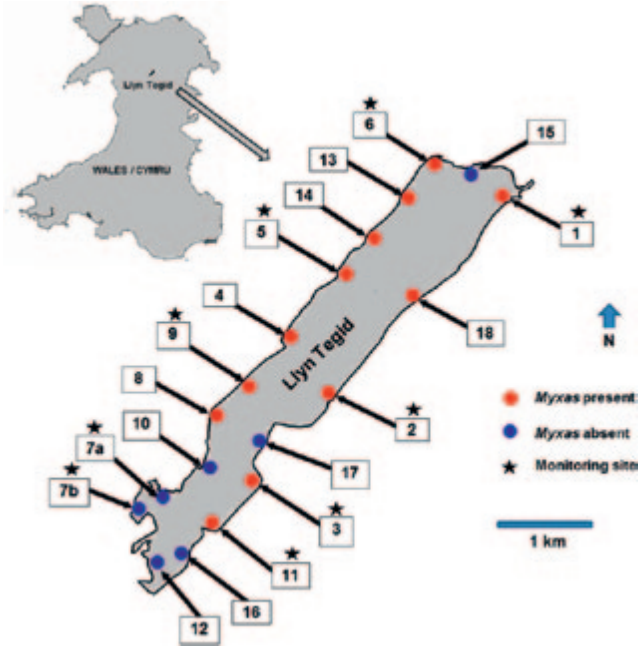

Figure 3 Locations of survey and monitoring sites for *Myxas glutinosa* at Llyn Tegid, Snowdonia National Park.

1999. They dived in pairs at each of six monitoring stations, bringing material ashore that was identified by us. Two dives were undertaken at these sites with each dive taking 30–45 minutes. Details were recorded of substratum and the water depths at which snails were collected.

Monitoring of a group of eight sites covering a representative series of locations around the periphery of the whole lake was continued in April and August 2000, February and September 2001, September 2002, October 2005 and October 2009 (Fig. 3). Survey methods required work in calm weather or only light winds to minimise the difficulties caused by wave action, with lake water levels at a maximum height of 1.35 m above 'lake sill level'. At each survey and monitoring station cobbles and small boulders were lifted from the lake and examined for snails. Preference was given to flat rocks of a manageable size that are not embedded in the substratum. From 1998–2001 a search time of about 60 minutes was used at each of the survey sites, which was reduced to 30 minutes from 2002–2009. This allowed examination of rocks in water depths between approximately 0.1–0.65 m (with an effort made to ensure equal use of time in the different water depths). The monitoring procedures used from autumn 2002 onwards were described as part of the Countryside Council for Wales (now NRW) Common Standards Monitoring programme using the Conservation Objective developed for this snail (Willing, 2004).

Samples of *M. glutinosa* taken at each of the sampling visits were preserved in 70% industrial methylated spirit for later shell measurement and dissection (to measure the length of the praeputium: as defined by Jackiewicz, 1998).

Table 3 Predominant substrata at sites surveyed for *Myxas glutinosa* at Llyn Tegid.

	Predominant substrate (x=minor component, **X**=major component)						
Sites *=monitoring sites	boulders	small boulders	cobbles	small cobbles	gravel	sand	'mud' silt / clay
Substrate particle size ranges (mm)	200–>630		63–200		2.0–63	0.063–2.0	≤ 0.002–0.063
1*			**X**	x			
2*		x	**X**	x			
3*	x	**X**	**X**	x			
4	x	**X**	**X**	x			
5*	x	**X**	**X**	x			
6*		x	**X**	x			
7a*			x	x		**X**	x
7b*			x	x		x	**X**
8		x	x	x	**X**	**X**	x
9*	x	**X**	**X**	x			
10			x	**X**	x	x	
11*			x	x	**X**	x	
12					x	**X**	**X**
13	x		**X**				
14	x		**X**				
15			**X**		**X**		
16				**X**	x	x	
17			**X**	x			
18	**X**		**X**				

Results and Discussion

Mapping undertaken in 1998 and 1999, confirmed by five monitoring visits between 2000 and 2002, demonstrates that populations of *M. glutinosa* occur around *ca* 8.5 km (approximately 75%) of the lake shore at Llyn Tegid (Fig. 3). *M. glutinosa* were not found amongst the gravel and small cobbles that predominate at the extreme northern end of the lake (Site 15), on the shore of Llangower Point on the mid-southern lake shore (Site 17) and at Pont y Lafar (Site 10) on the north shore at the western end of the lake. The snail is also absent from the 'muddy' extreme south-western end of the lake (Sites 7a, 7b, 12, 16).

Data from the diving survey (Table 4) suggest that *M. glutinosa* is an upper-littoral species as, in Llyn Tegid, the littoral zone extends to *ca* 6–10 m depth. The deepest *M. glutinosa* recorded was one on an old boot at 3.5 m (which corresponds to 1.95 m below lake sill level). All other *M. glutinosa* were found on rocks at depths down to 2.65 m (1.26 m below 'lake sill level') strongly suggesting that the snail has a preference in Llyn Tegid for shallow water, although it was not usually found in the uppermost 0–10 cm. The diving survey was undertaken when water levels were *ca* 0.3 m and 0.7 m above the levels of the August and October 1999 surveys respectively. This suggests that *M. glutinosa* populations are confined to a depth range of about 0.6–2.7 m when the lake levels are 'high', but about 0.1–2.1 m at lower levels. No *M. glutinosa* were found by wading and searching at the time of the November 1999 visits, suggesting that they remain in the same zone of the lake and do not rapidly migrate to higher shore levels when the lake level rises. Almost all of the cobble and boulder sized rocks occur at depths of up to 2.5 m and locally 4.0 m (1.02–2.52 m below 'lake sill level'), which corresponds closely to the zone of water movement resulting from wave action. This is the zone where water turbulence probably keeps the rocks free of the fine sediments that *M. glutinosa* appears to avoid at the south-western end of the lake.

The species was found exclusively on the underside of cobbles (usually large cobbles, with

Figure 4 Typical habitat of *Myxas glutinosa* on the shores of Llyn Tegid, at monitoring site 2.

longest axis >15 cm) or boulders, and occasionally other objects including car tyres and old boots. Its consistent avoidance of the upper surface of rocks was also observed during the 1999 diving survey as almost all *M. glutinosa* recovered were on the undersides of rocks, with few on the sides, but none on the upper surface despite the low light levels at water depths >2 m. Why *M. glutinosa* should occur on the underside of cobbles is puzzling as this is not the case at the many sites where it has been found in Ireland. Thus, at 15 sites studied at five Irish lakes, there was only one where *M. glutinosa* (small numbers of immatures) was found on the underside of cobbles or stones (Holyoak, 2004, 2005). Indeed, in Ireland *M. glutinosa* was commonly seen crawling on the upper surface of stones and over mud substrata, or collected by dragging a sieve through submerged vegetation. This raises, an as yet unanswered question, as to why the behaviour of *M. glutinosa* is so different at Llyn Tegid. It seems unlikely that it retreats beneath rocks as a defence against the effects of wave action, since the species occupies the same zone in shallow water along the edge of the lakes in Ireland as it does at Llyn Tegid. It might be related to avoidance of predators hunting by sight, such as fish or birds, but this will remain conjectural until data are obtained on predators of *Myxas*.

The densities of *M. glutinosa* in Llyn Tegid revealed by our surveys were always low. It was unusual to find two or more snails on the same rock lifted from the water. Sixty minutes of searching rarely produced more than 30 snails (maximum 82). Detailed quantification of densities is difficult as rocks suitable for *M. glutinosa* are often unevenly distributed or scarce and some are too heavy to lift. Nevertheless, typical densities at times of maximum abundance are certainly <1 snail m^{-2} and less than a tenth of this at times or places with low densities. Much higher densities were recorded in 2000–2004 at some Irish lakes, with >15 snails m^{-2} (GAH, pers. obs.). The commonest gastropod at Llyn Tegid, *Radix balthica* (Linnaeus), often occurred at higher densities than *M. glutinosa*, with several snails m^{-2} visible on top of stones in shallow water of the lake edge.

The maximum size reached by *M. glutinosa* at Llyn Tegid is smaller than in old collections from English sites and in modern material from Ireland. Shell height of Llyn Tegid specimens rarely exceeded 10 mm, and reproductive maturity was likely at 8 mm shell height judging from length of the praeputium (Fig. 5). In contrast, samples from Irish lakes frequently had shell heights of 12–15 mm and occasionally reached 19.5 mm (GAH, pers. obs.). However, several other gastropod species in Llyn Tegid appear 'dwarfed' when the normal shell height for each species is compared with the ranges cited by Kerney (1999) and Økland (1990), as shown in Table 6.

From September 1998 to September 2002 *M. glutinosa* populations were surveyed at stations around the lake during seven months of the year (Tables 1, 2: February, April, June, August, September, October, November). Data gathered systematically on these visits included the number of individuals found during timed searches, their measured shell height, and (for some specimens collected in 1999) length of praeputium (a convenient measure of size of distal genitalia) in relation to shell height. Taken together this information is consistent with the expectation that *M. glutinosa* in Llyn Tegid has an annual life cycle. In late summer to early autumn there were large numbers of sub-adults (mean shell height 4 mm) at all of the sites supporting the snail in September 1998. Mean shell height only increased slightly between August and October (from 4.0 to 4.8 mm) and there was no significant fall in numbers. The *M. glutinosa* collected by the divers in November 1999 showed a larger

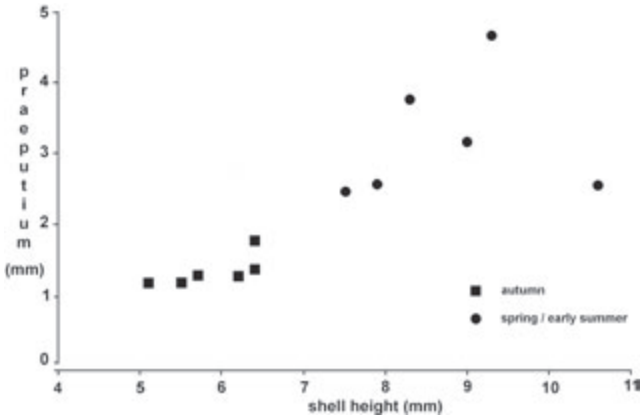

Figure 5 Measurements of samples of *Myxas glutinosa* genitalia (length of praeputium) from specimens collected May-November 1999.

mean shell height (6.0 mm) implying growth had occurred in the six week period since the October visit. When the eight monitoring sites were sampled in February 2001 numbers had fallen at all but one site, but mean shell height had increased from 3.4 mm (in August 2000) to 5.6 mm. During this February visit 33% of the *M. glutinosa* in the measured sample had shell heights >6 mm with 3 specimens exceeding 7 mm. Five of the larger (>6 mm) individuals collected at three separate sites were found with slightly decomposed bodies remaining in the shells, suggesting recent death. Visits to the eight monitoring sites in both April (2000) and June (1999) produced only six snails on each occasion, all but one of these being collected from a single site. These results suggest the adult snails reach maturity in late winter, mostly dying off after reproducing in February or March. In the period April to June only a few adult snails remain and the young *M. glutinosa* are very difficult to find, presumably because of their tiny size. By August, partly grown snails have become relatively easy to locate; these grow throughout the autumn, whilst the population declines presumably due to predation and other factors.

Boycott (1936) noted that almost all aquatic pulmonates are annuals living 9–15 months or less and that *M. glutinosa* has a synchronised life-cycle, with adults breeding early in the summer

Table 4 Data from the diving surveys to study *Myxas glutinosa* at Llyn Tegid, 27th November 1999 (sites 1, 2, 6) and 28th November 1999 (4, 9, 11).

Site No.	1	2	4	6	9	11
lake-level above sill height/m	1.55	1.55	1.39	1.55	1.39	1.39
maximum depth searched/m below water surface on survey day ( )=below NRW sill level /m	3.9 (2.35)	21.0 (19.45)	12.0 (10.61)	3.5 (1.95)	6.0 (4.61)	11.0 (9.61)
occurrence of cobble/ boulder sized rocks ( )=below NRW sill level/m	max 1.7 (0.15), sand below	max 3.0 (1.45), mud below	max 7.0 (5.61), soft silt below	max 2.4 (0.85), mud below	max 1.5–2.0 (0.11–0.61), mud below	max 4.0 (2.61), leaf litter and mud below
Myxas Dive total per site:	10	9	1	numerous > 1 m^{-2}	6	4
deepest *Myxas* found at/m ( )=below NRW sill level/m:	1.5 (+0.05)	3.5 (1.95)	2.65 (1.26)	2.4 (0.85)	1.9 (0.51)	2.3 (0.91)
Myxas depth data/m ( )=below NRW sill level/m:	10 at 0.8–1.5 (+0.75–+0.05)	7 at 1.3–2.0 (+0.25–0.45), 2 at 3.5 (1.95)	2.65 (1.26)	plenty at <1 (+0.55), 7 at 1–2 m (+0.55–0.45), 2 at 2–4 (0.45–2.45) (deepest 2.4 m)	4 at 1.4 (0.01), 1 at 1.8 (0.41), 1 at 1.9 (0.51)	singles at 2.1 (0.71), 2.2 (0.81), 2 at 2.3 (0.91)

Table 5 Measurements of shell height of *Myxas glutinosa* from Llyn Tegid (1998–2009).

Date:	Mean height of shell (mm)	*n*	S.D.	S.E.
Sept. 1998	5.4	48	0.7	0.2
June 1999	8.8	6	1.21	1.2
Aug. 1999	4.0	119	0.9	0.16
Oct. 1999	4.8	56	1.1	0.3
Nov. 1999	6.0	21	0.8	0.37
April 2000	5.1	6	1.17	1.23
Aug. 2000	3.4	82	0.76	0.17
Feb. 2001	5.6	39	0.79	0.26
Sept. 2001	4.1	23	0.68	0.29
Sept. 2002	4.6	70	0.73	0.17
Oct. 2005	5.3	51	1.0	0.14
Oct. 2009	5.3	85	0.83	0.09

and then dying. Whilst this synchronised reproduction apparently occurs in the Llyn Tegid populations, breeding there occurred much earlier in the year (February and March) so that by August partly grown snails were fairly easy to find. In Ireland a less precisely synchronised breeding cycle seems to occur, with adult *M. glutinosa* found from May to August (numerous localities) and immatures in October (three localities) (Holyoak, 2004, 2005). In 2004 populations of *M. glutinosa* were discovered in both Lough Ree and Lough Corrib, Ireland (Holyoak, 2005) where it was possible to collect samples from various locations on several days in June and July. It was found that the species was abundant and widespread, so that samples could be collected and measured. The results were surprisingly variable, with shell height <3->15 mm, which may also imply a prolonged breeding season, rather than a closely synchronised cycle. In comparison, in a study of *M. glutinosa* at lakes in the Åland Islands, Finland, Carlsson (2001) suggested that reproduction probably occurred from late spring to early summer with juveniles emerging in late August in one year and mid-September in another year. However, he also suggested that, since individuals were observed breeding at the end of October, and shell heights varied widely within samples, either staggered breeding could occur or, as in Poland (Feliksiak, 1938), *M. glutinosa* could have two generations per year.

Table 6 Comparative shell height measurements (mm) for three gastropod species found in Llyn Tegid; * represents mean adult size.

	Llyn Tegid	Kerney (1999) (for U.K.)	Økland (1990) (for Norway)
Myxas glutinosa	5.1–10.6 *6.5	12–15	8–13
Radix balthica (Linnaeus 1758)	*7	12–28	10–30
Physa fontinalis (Linnaeus 1758)	*5.5	8–12	5–11

Boycott (1936) noted that *Radix balthica* in captivity could 'get through' two generations in a summer and was known to spawn as late as November at Malham Cove, whilst *Galba truncatula* (O.F. Müller) was known to normally have two or three generations in a summer in natural habitats. Macan (1973) showed that whilst *R. balthica* generally breeds in late spring and early summer and then dies, the off-spring may then, in favourable conditions, breed in the autumn of the same year as observed in Hodson's Tarn in 1971. It is likely that in Llyn Tegid *M. glutinosa* could occasionally produce two generations in a season (as in Poland) when suitable conditions occur or that they may have a prolonged breeding season where conditions are suitable (as at Lough Ree, Ireland, in 2004). Thus the synchronous life-cycle we recorded in the Llyn Tegid population of *M. glutinosa* may be a response to 'severe' conditions there resulting from the soft-water and relatively low nutrient levels. *M. glutinosa* is primarily a hard-water species elsewhere and the low calcium levels in the lake (estimated at 2 ppm: Kerney, 1999) combined with low nutrient levels may account for its small body size together with that of the few other gastropods species living with it in the lake (Willing & Holyoak, 1998).

CONSERVATION OF *MYXAS GLUTINOSA* AT LLYN TEGID

The apparent restriction of *M. glutinosa* to the shallow margins of Llyn Tegid (upper 2.0–3.0 m depending upon water levels) has implications

for the conservation of the snail. If the water level were to fall or be artificially lowered by 2.0–3.0 m then most of the suitable habitat occupied by *M. glutinosa* would be exposed, so risking mass mortality of its population. It is not possible to predict the effects of different rates of lake level fall because the rates at which the species can move down within a falling littoral zone are unknown. Results from the diving survey show that at many locations in the lake, suitable *M. glutinosa* habitat does not extend far below the uppermost 3 m of the littoral zone and so there may be limited areas to which it could migrate. However, if lake levels fell slowly, turbulent water in shallow shore areas might clear fine sediments that currently blanket rocks in the lower littoral zone, providing suitable areas for it to colonise. As noted above, *M. glutinosa* had not migrated to higher shore levels when the lake was surveyed in November 1999, following a lake level rise of *ca* 1 m since the October 1999 visit. Also in October 2009 (Willing, 2010) monitoring surveys were undertaken at particularly low lake levels (falling to 0.777 m – levels only previously seen in October 1999) and although monitoring was undertaken in water depths ranging from 0.05–0.6 m, the majority of the *M. glutinosa* recorded in 2009 were taken in <10 cm water depth at the very margins of the lake. At site 6 an additional 5 minutes of searching (after the 30 min. monitoring search) recovered a further 16 *M. glutinosa* all in <10 cm water depth. The low water levels appeared to have 'concentrated' the population into a narrow band in shallow water. In the week following the two-day monitoring period lake levels fell by a further 8 cm, implying that unless the *M. glutinosa* moved downwards ahead of the receding shoreline, many would have been left exposed and died. More study is needed, but these observations suggest that *M. glutinosa* migrates slowly in response to changing lake levels; possibly the algae on which it grazes are only available on substrata that have been continuously immersed in quite shallow water.

The extreme fluctuation of lake levels that began at Llyn Tegid in 1955, with the construction of a barrage across the outflow from the lake, was followed by a period when *M. glutinosa* seemed to disappear (Hynes & Yadav, 1985). The former Environment Agency does not possess details of the speed or extent of lake level falls for this period (A. Arrowsmith of NRW Bala, pers. comm.). It is possible that falls in lake level reduced populations of *M. glutinosa*, so that it was not recorded again until 1998. This can only be speculation as it is uncertain that the survey methods used in 1960, 1964 and 1989 would have revealed the presence of the species, especially if searching occurred when lake levels were high or in months when the snails are small and difficult to find. It is unfortunate that in 1989 Hope Jones and Yeo focussed their searching exclusively on the south-western end of the lake, which the 1998–2009 surveys showed does not support *M. glutinosa*. It is therefore unclear if its populations were affected by engineering works at the lake outlet in 1955 or the subsequent manipulations of water-level. Nevertheless, any future plans to alter the lake levels should take full account of the predictable risk to *M. glutinosa* populations in the lake.

Cyanobacterial ('blue-green algae') and algal 'blooms' were first observed in 1995 and have been a recurrent feature of Llyn Tegid in recent years (Duigan *et al.,* 2007). Studies of algal (diatom) remains obtained from the lake sediments (Bennion, 2004) suggest that Llyn Tegid had lower nutrient levels in the past and that enrichment may have increased from about 1985 (chiefly due to agricultural, forestry and tourist-development inputs). The physical characteristics of Llyn Tegid make it naturally prone to cyanobacterial blooms in the event of raised nutrient levels (Happey-Wood, 2003). Burgess *et al.* (2006) noted that both dissolved phosphorus and nitrate concentrations in Llyn Tegid are high for an oligotrophic-mesotrophic lake, due to diffuse inputs from the mainly non-agricultural catchment.

When populations of the snail were monitored in September 2001 the whole lake was affected by a cyanobacterial 'bloom' which lasted several weeks. Total numbers of snails recorded then were lower than in 1998–2001, with only 43 being recorded from the eight monitoring stations that in August 2000 had produced 156 individuals. It was therefore feared that this sign of nutrient (nitrate, phosphate, or both) enrichment might have reduced the *M. glutinosa* populations in the lake, especially since water pollution due to nutrient enrichment has been cited as one of the likely causes of the extinction of the species over much of the British Isles (Bratton, 1999). However, monitoring of the same eight sites a year later produced a total of 138 snails, with

some *M. glutinosa* present at all of the monitoring stations previously supporting the snail. Hence it seems likely that the low numbers recorded in 2001 were, at least partly, a consequence of poor visibility hampering searches (suitable stones being hard to locate in the murky water) rather than indicative of any lasting harm to *M. glutinosa* population levels. Algal blooms were present at some survey sites (particularly 1, 3, 6 and 11) in 2009 and had been present in the lake during and for several weeks prior to the survey. It has been noted that problematic blue-green algal blooms accumulate on the down-wind shore of the lake near to Bala, when periods of calm warm weather are followed by westerly winds (Duigan *et al.,* 2007). Site 6 is situated in this area of the lake that is most severely affected by algal blooms. Despite being subject to these high levels of algae and cyanobacteria, monitoring at site 6 supported the largest numbers of *M. glutinosa* recorded during the 2009 survey (41 found in 30 minutes). In summary, it would seem that the algal/cyanobacterial blooms in Llyn Tegid have not caused a detectable reduction of *M. glutinosa* populations in the lake.

These observations seem to be at odds with the losses of *M. glutinosa* elsewhere in Britain and Europe (e.g. Whitfield *et al.,* 1998; Kerney, 1999; Mouthon & Vimpére, 2014) where the dramatic decline of the species has been associated with nutrient enrichment, the suspected underlying cause of the algal blooms in Llyn Tegid. *M. glutinosa* certainly seems to be able to survive occasional episodes in the lake with elevated levels of suspended algae. It should be remembered, however, that the algae are blown and therefore concentrated, towards the north-eastern end of the lake. High levels are only occasionally present there and do not indicate that this part of the lake has higher nutrient levels than those elsewhere. Hence, further increases in nutrients in the lake could have a negative impact on *M. glutinosa* and it would be unwarranted to believe that these findings suggest that the species is unaffected, or that it might not in the future suffer declines in Llyn Tegid if further nutrient enrichment occurs.

Our data from population studies carried out over eleven years show little if any overall change in status of *M. glutinosa* at the monitored sites, provided comparisons are made for similar seasons (in relation to the annual cycle of reproduction and abundance of the species) and data are gathered using appropriate searching methodology when water levels in the lake are not too high. Consequently, when judged against the Conservation Objective for *M. glutinosa* for Llyn Tegid the snail was judged to have a favourable conservation status in the lake in the monitoring periods between 2002 and 2009 (Willing, 2004, 2006, 2010).

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