Early season cladoceran diversity of atlantic temporary ponds (turloughs)

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Abstract

Turloughs are temporary ponds lying on karstic limestone in western Ireland. They fill and empty with groundwater associated with underground drainage systems, governed by local climatic events. Their biota shows adaptations such as short life span, parthenogenesis and resting stages, but as predation is mild they are also refugia for some arctic or alpine branchiopod crustaceans. We examined early season samples of cladocerans from 28 turloughs in four counties of western Ireland. Here we show that spring samples showed low diversity, suggesting early phase colonization. Chydorus sphaericus *was almost ubiquitous in spring samples, while Daphniidae played an important part. The arctic relict species* Eurycercus glacialis *occurred in about 30% of study sites.*

Keywords: *Turloughs, Temporary ponds, karst,* Chydorus, Eurycercus, Daphnia, *biodiversity, colonization*

Résumé

Diversité printanière des Cladocères dans des mares temporaires atlantiques (turloughs)

Les turloughs sont des mares temporaires du karst calcaire de l'Irlande occidentale. Ils sont alimentés par l'eau phréatique grâce à un système de drainage souterrain et ils sont par conséquent sous l'influence des événements climatiques locaux. Leur faune montre des adaptations à ce régime hydrique telles qu'un cycle de vie court, la parthénogenèse ou la présence d'un stade de résistance. Puisque la prédation y est faible, ces étangs sont aussi un refuge pour des Crustacés Branchiopodes arctiques ou alpins. Au printemps 2002, les Cladocères ont été échantillonnés dans 28 turloughs de quatre comtés de l'Irlande occidentale. La richesse spécifique de ces échantillons printanières apparait faible, ce qui suggère une phase de colonisation précoce. Chydorus sphaericus *était presque omniprésent dans les échantillons; d'autre part les Daphniidae étaient prépondérants. L'espèce relique arctique* Eurycercus glacialis *était présente dans environ 30% des sites étudiés.*

Mots-clés: *Turloughs, mares temporaires, karst,* Chydorus, Eurycercus, Daphnia, *biodiversité, colonisation*

Introduction

Turloughs are sporadically filling ponds or shallow wetlands lying on level beds of lowland karstic limestone (reviewed by Reynolds et al. 1998). These surface expressions of groundwater are a priority habitat under the EU Habitats Directive. A currently accepted definition within the scope of the Water Framework Directive is 'a topographical depression in karst, having intermittent inundation on an annual basis arising mainly from groundwater'. The greatest number and variety of turloughs occur in the western third of Ireland, in areas of relatively frequent and regular rainfall, wherever the karstified Carboniferous limestone approaches the surface. However, turlough-like water bodies have also been described in Wales at Pant-y-llyn (Blackstock et al. 1993), under Mediterranean conditions in Catalunya (Boix et al. 2001), in Slovenia and in eastern Canada (Coté et al. 1990).

Among other comparable studied water bodies are temporary ponds in the UK (Nicolet et al. 2004) and temporary Mediterranean marshlands (Grillas and Roché 1997). However, the duration and seasonality of dry periods in turloughs is more unpredictable than in either of these types, and the Mediterranean wetlands are defined by a suite of characteristic plants which do not occur in Irish turloughs. In addition, the

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karstic groundwater source of filling leads to characteristic high alkalinity and low nutrient status; temperature of incoming water is characteristically low, and the depth (to 10 meters) and extent of filling of turloughs (to hundreds of hectares) often greater.

In most turloughs the water tends to be highly calcareous and oligotrophic; marl is often precipitated leading to high water transparency. While most retain some residual water at dry phase, their temporary nature means that they cannot support large populations of long-lived aquatic predators, notably fishes, and most predatory insects are rare (Reynolds 2004). In addition, their irregular periodicity leads to unpredictable species diversity and abundance. While most usually fill between midwinter and early summer, turloughs respond to local climatic variations and may be empty or full at any time of year. The stresses imposed by periodic drying are offset in some short-lived species by a relaxation of the predation pressures normal in permanent ponds.

Given the importance of temporary pond conditions to the survival of rare or restricted animals and plants (Collinson et al. 1995; Nicolet et al. 2004) conservation interest has been directed to turloughs and there is now a considerable published literature. Most early studies have been descriptive, some vegetational in nature (e.g. Praeger 1932). Hydrographic studies exist for relatively large temporary water bodies in Counties Clare and Galway (Coxon 1987a; Coxon 1987b; Southern Water/Jennings and O'Donovan 1997) and invertebrate populations have been studied over time within a limnological context in a few large turloughs (e.g. Buckley 1993). Regional faunistic studies include surveys of large and small groundwater-fed water bodies in the Burren (Reynolds 1985b), South Galway (Reynolds 1997) and on the Aran islands (Lansbury 1965; Reynolds 1985a). Certain turlough taxa have received attention, often as part of wider biogeographical studies. These include Mollusca (Donaldson et al. 1979; Byrne et al. 1989), Cladocera (Reynolds 1985b, Duigan and Frey 1987; Duigan 1988, 1992; Reynolds and Marnell 1999), Copepoda (Grainger and Holmes 1989), the anostracan *Tanymastix stagnalis* (Young 1975; Grainger 1976, 1991) and aquatic Coleoptera (Bilton 1988; Bilton and Lott 1991; Foster et al. 1992).

The sporadic nature of turlough aquatic fauna suggests the communities are highly unpredictable and variable over time (reviewed in Reynolds 1996). However, rather few studies of the aquatic invertebrate fauna of turloughs have focussed on spatial or temporal variability in assemblages (Reynolds 1996). In particular, early colonisation events and population development have not been studied. The present study examines this through quantitative counts of cladocerans from 28 turloughs for a single sampling period early in the growing season. This is part of a larger investigation of aquatic assemblages of a large number of widely distributed turloughs, heterogeneous in terms of their area, morphology, hydrology, water quality, soils, vegetation and surrounding habitats.

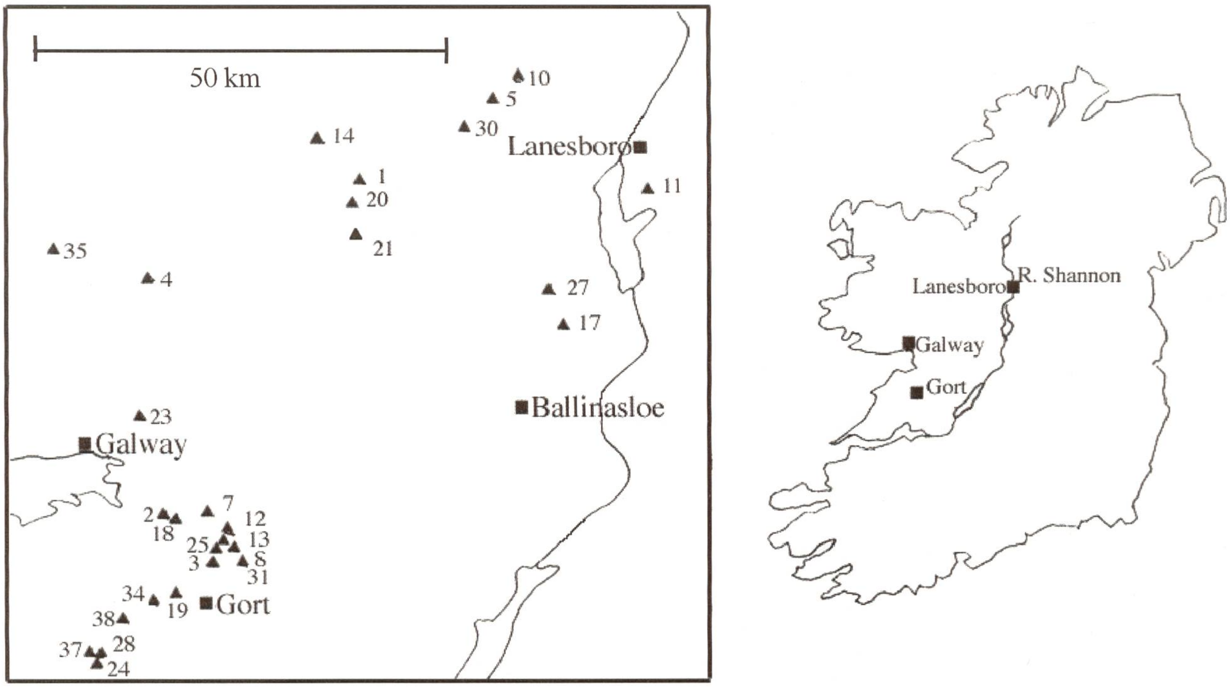

Fig. 1: Map of the studied turloughs in western Ireland.

Fig. 2: Roo West turlough in karst. This SAC has high cladoceran diversity including the arctic relict cladoceran Eurycercus glacialis.

Fig. 3: Turloughmore. This recently flooded turlough in the Burren, Co. Clare, shows hedges extending into the water.

Entomostracans were sampled from the leeward side of each turlough at a depth of approximately 30 cm, and from a range of the habitats present (vegetation, open water, accumulated detritus, flooded hedgerows etc.), using a standard FBA style pond net with a 100 µm mesh net. Entomostracan samples consisted of 10 standard sweeps, each involving sweeping the net forwards along a one meter long path, then back along the same, disturbed path, completed in two seconds. Samples were preserved in 70% alcohol (IMS). In the laboratory any contained plant matter and macroinvertebrates were recorded and then separated from the sample using a coarse sieve. Suspended materials were concentrated with a fine sieve and their settled volume recorded. Water was added to make up to a known volume (usually 50 ml) and a sub-sample of 2.5ml was examined. Unrecognised cladocerans were mounted in lactophenol with lignin pink for identification. All cladocerans were then counted in a grooved counting disc under a binocular dissecting microscope at x200 magnification. If the sub-sample contained 100 or more of the most abundant cladoceran species, the sample was considered complete, otherwise further sub-samples were counted until a number greater than 100 of one species was recorded.

Experimental procedures

28 Turloughs were selected for study from the full geographical and morphological range of turloughs in Ireland (Fig. 1). For the present study these turloughs were sampled at their fullest extent, between 11th and 20th March 2002 in counties Galway (19 turloughs), Roscommon (5), Clare (4), Mayo (1) and Longford (1) (see examples in Fig. 2 and 3). Factors which could potentially influence aquatic populations, such as turlough areal extent, the presence and type of aquatic vegetation and detritus, water clarity/turbidity, poaching and soil type, were determined in the field and supplemented from literature. WTW Multiline probes were used to record water temperature, pH, conductivity and DO during site visits.

Results and discussion

Physical conditions and sample densities

Turloughs were sampled when full in early spring to look for patterns in early-phase cladoceran colonization. The 28 turloughs in Galway, Roscommon, Clare, Mayo and Longford ranged in area from 5 to 177 ha (Table 1). The majority (24) were between 5 and 53 ha (mean 23 ha), while a group of 4 large turloughs ranged from 99 to 177 ha. The 4 eastern (Roscommon and Longford) sites were relatively small (5-13 ha).

Table 1: Investigated turloughs, with SAC status and macroinvertebrate-derived state (A= aquatic, T= terrestrial macroinvertebrates), area (ha) and location (County abbreviations: CE: Clare, GY: Galway, LD: Longford, MO: Mayo, RN: Roscommon.; NGR: National Grid Reference), cladoceran density levels and impacts (drainage, D or nutrient enrichment, E). See text for details.

Status,area (ha)	Name, ID	County NGR	Density, Impact
TA (SAC) 25	Ballinastack 1	GY M647648	2 D
	Ballinderreen 2	GY M400153	2
T (SAC) 29	Ballinduff 3	GY M460080	2
T 99	Belclare 4	GY M378502	1 D, E
AT 53	Brierfield 5	GY M817768	2 D
TA 25	Caranavoodaun 7	GY M453155	2
T 7	Cockstown 8	GY M487104	2 E
A 9	Corbally 10	RN M849801	2 D, E
AT ?	Fortwilliam 11	LD N015633	1 E
AT 22	Cregaclare North 12	GY M482130	2 D, E
A 11	Cregaclare South 13	GY M476116	2
A (SAC) 37	Croaghill 14	GY M594708	2 E
A 15	Feacle 17	RN M908434	2 E
AT (SAC) 5	Frenchpark 18	GY M413149	2
AT (SAC) 25	Garryland 19	GY M415037	2
AT (SAC) 177	Glenamaddy 20	GY M637612	2 E
A 17	Kilkerrin 21	GY M633563	3 D, E
T 29	Kiltullagh 23	GY M367297	1
TA (SAC) 43	Knockaunroe 24	CE R314939	2
A 6	Laban South 25	GY M465102	2 D
A (SAC) 107	Lough Croan 27	GY M888487	2 E
A (SAC) 15	Lough Gealain 28	CE R313947	1 D, E
A 13	Newtown 30	RN M782727	1
AT (SAC) 40	Peterswell 31	GY M499083	1
T (SAC) 28	Roo West 34	GY/CE M396019	2
T (SAC) 120	Shrule 35	MO M258543	1
T ?	Tree turlough 37	CE R306947	1
T 24	Turloughmore 38	CE R347997	1

The low winter rainfall in 2001 is expected to have a similar regional effect on most if not all turloughs. Flooding regime was studied for some south Galway turloughs. These filled in November 2001, but dried out again in December and early January, before levels rose again from mid-January to a maximum in mid-March, when samples were collected. Levels then dropped continuously.

Turlough samples varied greatly in amounts of associated debris. Cladoceran density (abundance estimated per 10 standard sweeps) also varied greatly, ranging from just 2 individuals in Turloughmore, Co. Clare, to over 350000 in Kilkerrin, Co. Galway. Table 1 gives cladoceran densities as 1 (low; mean value 56, range 2-192, n=9), 2 (moderate, mean 7200, range 1290-29960, n=18) and 3 (extreme; 353700, Kilkerrin only). There was no correlation between cladoceran density and turlough area, nor with geographic distribution.

The sporadic nature of turlough aquatic biota has previously been noted, suggesting that the communities are highly unpredictable and variable over time (Reynolds 1996). However, analysis of UK temporary ponds stresses their importance as shelters for scarce or endangered plants and animals (Nicolet et al. 2004) and the same may be true for Irish turloughs. Below we report on early spring cladoceran populations and species richness.

Cladoceran populations

The known flooding pattern of several turloughs, starting in mid-January and sampled in March, suggests that these samples may provide information about turlough colonization and community development. This survey of 28 widely distributed turloughs sampled early in the growing season yielded 15 taxa belonging to 4 families, including 8 Chydoridae and 6 Daphniidae taxa (Table 2). Species richness ranged from 1 to 6 species (mean 3.1) and Simpson's Diversity indices ranged from 1.0 to 2.4.

Chydorus sphaericus was found in all samples except Cockstown. In many it was dominant, with some samples containing only this species. Large chy-

Table 2: Cladocera identified from Spring 2002 samples in 28 Turloughs.

Species:	Frequency (Sample ID)
Bosminidae:	
Bosmina cf. longirostris (O.F.Muller)	1 (28)
Chydoridae:	
Acroperus harpae (Baird)	4 (4, 7, 20, 35)
Alona affinis (Leydig)	7 (3, 7, 10, 14, 20, 34, 38)
Alona quadrangularis (O.F. Muller)	1 (20)
Alonella excisa (Fischer)	4 (17, 18, 21, 35)
Chydorus sphaericus (O.F. Muller)	27 (all except 38)
Eurycercus glacialis Lilljeborg	8 (3, 7, 10, 12, 13, 19, 27, 34)
Eurycercus lamellatus (O.F. Muller)	6 (14, 18, 19, 20, 31, 34)
Graptoleberis testudinaria (Fischer)	1 (20)
Daphniidae:	
Daphnia cf. hyalina var. lacustris	1 (38)
Daphnia longispina (O.F. Muller)	3 (5, 19, 34)
Daphnia magna	1 (8)
Daphnia obtusa	5 (5, 8, 19, 21, 35)
Daphnia cf. pulex	2 (3, 8)
Simocephalus vetulus (O.F. Muller)	8 (7, 8, 10, 13, 27, 34, 35, 38)

dorids of the genus *Eurycercus* occurred in low abundances in several samples. *Eurycercus lamellatus* was recorded in 6 samples and *E. glacialis* in 8. Among small chydorids, *Alona affinis* occurred in 7 samples, *Alonella excisa* and *Acroperus harpae* each occurred in 4 samples. Other species occurred in low abundances and in only one turlough. *Daphnia* were few or absent in most samples, but in two turloughs in South Galway they occurred in extremely high abundance. Garryland contained the species *D. obtusa*, *D. cf. pulex* and *D. longispina*, and Cockstown included *D. obtusa*, *D. cf. pulex* and *D. magna*.

No geographic variation was evident in these samples from 28 widely distributed turloughs sampled early in the growing season. The eastern (Roscommon and Longford) turloughs Corbally, Feacle, Newtown and Fortwilliam, relatively uniform in area, did not form a separate group, having variable cladoceran densities (7 to 29960) and 1 to 4 species, while to the north, Shrule (Mayo) had low density (89) but high species richness (5).

There was also no clear relationship between species lists in neighbouring turloughs. As previously noted, while turloughs are disjunct surface manifestations of continuous groundwater flows, hydrological linkages through the karst appeared to have little to do with the entomostracan and macroinvertebrate communities present in turloughs (Reynolds 1999, 2004).

Turlough size was not correlated with either settled volumes or Cladoceran density. No correlation with density was seen when turloughs were ranked by cladoceran species richness, except at the bottom of the density scale, probably because of the overwhelming abundance of *Chydorus sphaericus* in most samples. Neither the amount of sediment and detritus present in samples, nor plant types, appeared to influence density.

The cladocerans found are generally well known in turlough conditions (reviewed in Reynolds et al. 1998). *Bosmina longirostris, Acroperus harpae, Alona affinis, Alonella excisa, Chydorus sphaericus, Eurycercus lamellatus, Graptoleberis testudinaria* and *Simocephalus vetulus* were recorded in the Clare turloughs Knockaunroe and Lough Gealain (Reynolds 1985b) while *Acroperus harpae* was recorded in Garryland (Reynolds 1999).

Chydorus sphaericus was almost ubiquitous, and often the dominant or even the only species encountered. Duigan (1992) noted that this species complex has the ecological ability to survive in a wide range of permanent and seasonal waters. *C. sphaericus* dominated a third of studied shallow European lakes, generally those with low diversity; proportional abundance of *C. sphaericus* tending to increase with trophic status (De Eyto et al. 2003). *C. sphaericus* can utilise various food sources such as very small algae more successfully than the more littoral, detritus-feeding species such as *A. affinis* (De Eyto and Irvine 2001); it also has a shorter egg development time than *A. affinis*, especially at high pH (De Eyto and Irvine, op. cit.), and so can colonise and exploit new environments quickly.

The arctic relict species *Eurycercus glacialis* occurred in 8 turloughs in Clare, Galway and Roscommon, with moderate associated cladoceran densities of between 1290 and 29960. It was previously only known (again with *C. sphaericus*) from one of the sampled turloughs, Roo West, and several adjacent water bodies in South Galway (Duigan and Frey, 1987; Reynolds and Marnell, 1999), often early in the year. This large cladoceran appears to be a winter form in turloughs, their filling coinciding with low temperatures and minimal predator activity. *E. glacialis* is an indicator of turlough habitat rather than of high water quality, being a relict persisting in turloughs whose hydrology is unimpacted by major drainage. In this, it resembles the large branchiopod *Triops* in southern Europe (see, for example, Boix et al. 2000, 2001).

Daphniidae were a taxonomically rich group on turloughs, represented by 6 taxa, but were few or absent in most samples. The widespread *Simocephalus vetulus* occurred in 8 turloughs, in most cases in the absence of *Daphnia* species. *Daphnia* also occurred in 8 samples but were generally sparse. In the Coole-Newtown turlough complex, however, three species were abundant in Garryland, including the species *D. longispina, D. obtusa* and *D. cf. pulex*, while Cockstown contained over 60% *Daphnia*, and included *D. magna, D. obtusa* and *D. cf. pulex*. In Belgian studies of newly created ponds Daphniidae, particularly *Simocephalus vetulus, Daphnia obtusa* and *D. cf. pulex,* were found to be strong zooplankton competitors (Louette and De Meester 2004).

Other cladocerans found in this survey are generally well-known in turlough conditions (Reynolds 1985, 1999). The maximum number of co-occurring cladoceran species was 6 (in Glenamaddy and Roo West). Where only one species was recorded, it was invariably *Chydorus sphaericus*. The mean number of species was 3.1 per site, but where *Eurycercus glacialis* was present, the mean species richness was 4.0, suggesting that this large species does not compete with smaller forms for food. Simpson's species diversity was quite low for samples; this relates to the overwhelming dominance of *Chydorus sphaericus* in most samples, and the low number of co-occurring species.

Taxonomic richness was lower in this early season study than that seen in some other turlough studies. For example, Reynolds (1985b) found 20 and 18 species respectively in Lough Gealain and Knockaunroe samples over a sampling season, while in the present survey only 1 and 2 species were encountered respectively. It is clear that the methods used to analyse plankton samples will influence the outcome through not always picking up rare species (O Connor et al. 2004). Samples were counted until at least 100 individuals of the most abundant species were recorded. Such counts will inevitably produce lower species richness than scanning a complete sample. Another reason may be seasonality, which cannot be tested in a single, spring sample.

Recent drought or flooding may also influence species richness and density. Evidence of recent flooding from vegetation and associated macroinvertebrate fauna may further explain why many species will not have appeared in significant numbers When turlough samples were classed as 'aquatic' or 'terrestrial' on the basis of included macroinvertebrates (shown as A, AT or T in Table 1), some relationship was seen with cladoceran density. Of the 10 turloughs with densities over 6000, only one (Cockstown, at 6380 per 10 standard sweeps) was classified as 'terrestrial' whereas six of the 10 sparsest turloughs (under 1290) contained only terrestrial macroinvertebrates, bearing out the known recent flooding and increase in water levels. There is an apparent correlation between occurrence of species of *Daphnia*, and T or AT status, suggesting that these species may appear early after flooding. The water entering most turloughs is oligotrophic, except where the system is impacted. Anthropogenic disturbance is also indicated in Table 1. Most turloughs with very sparse cladocerans were considered enriched or disturbed, often with improved grassland on mineral soil and a short flooding period.

The cladocerans found in these early filling stage turlough samples probably represent dispersal of first colonisers from the egg bank (Louette and De Meester 2004). Our species list has much in common with the pioneer colonist species in their study of 25 newly created Belgian new ponds. These workers found 20 zooplankton species to colonise these new ponds within the first 15 months, at an average of 4.2 taxa per pond. The colonizers, representing some 40% of the regional diversity in established ponds, indicated the importance of a local basis for dispersal. As in our studied turloughs, *Chydorus sphaericus* occurred in almost every pond. Daphniids were strong cladoceran competitors, with *Simocephalus vetulus* and *Daphnia obtusa* in 18 and 15 ponds respectively, *Daphnia cf. pulex* in 9 and *Daphnia magna* in 2. *Bosmina longirostris* occurred in 5 experimental ponds, but *Alona affinis* in only one. The speed and effectiveness of colonisation has implications for subsequent cladoceran diversity in oligotrophic waters of turloughs. The initial colonizer has a competitive advantage, but the species need not be the same at subsequent flooding. Where competition is not intense, however, the light levels of vertebrate predation may allow scarce and relict species to survive, such as *Eurycercus glacialis.* The present findings thus support the importance of turloughs for species conservation, but suggest that a classification of turloughs based on their cladoceran fauna is unrealistic, since flooding regime and season will influence the species found at any one time. Classification, if faunal based, must also take into account other aquatic and terrestrial communities, and management impacts, principally drainage and pollution. The degree to which drainage successfully alters the hydrological regime will determine the level of impact on turlough biota. There is concern that impaction may lessen the value of these priority habitats for conservation of rare species.

Conclusion

Turloughs, Irish temporary ponds lying on karstic limestone, fill and empty via underground drainage systems with irregular periodicity. In early-season samples from 28 full turloughs we found variable cladoceran abundance but generally low diversity (mean 3-4 species). The low species richness reflects counting methods, but probably also represents dispersal of first colonisers from the egg bank. *Chydorus sphaericus* was almost ubiquitous in samples, and was sometimes the only species found. Daphniidae were ocasionally important. The rare arctic relict species *Eurycercus glacialis* occurred in about 30% of study sites in spring, more frequently and widely spread than its known summer distribution. Its presence is associated with relatively high cladoceran richness, suggesting that it does not compete with other, smaller colonisers for food.

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