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# Has zooplankton 24 hour vertical distribution pattern in Lough Derg (Ireland) been changed over the period of ~90 years?

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**Abstract**

The vertical distribution of zooplankton was examined in Lough Derg, Ireland. Zooplankton was collected at one location every 2 m from the surface to the bottom during 24 hours at four-hour intervals. Zooplankton was identified to the species level and its density was calculated for each taxon, depth and hour. We recorded 9 rotifer, 3 copepod, and 4 cladoceran species. The highest total zooplankton density (rotifers, copepods, cladocerans, mysids and zebra mussel larvae) was recorded at 3 a.m. Rotifers preferred mainly a depth from 0 to 8 m, while copepods and cladocerans were observed within the whole water column during a 24 hour observation. It was a different pattern of diurnal migration than that Southern and Gardiner (1932) received, though they didn't study rotifers. Probably food concentration and/or predators, or other environmental factors could influence the diel vertical migration of zooplankton from Loug Derg.

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## INTRODUCTION

Heterogeneous distributions of zooplankton originate from various processes, some of which can be attributed to swimming of the animals (Folt, Burns 1999), diel vertical and horizontal migrations (Stich, Lampert 1981; Kvam, Kleiven 1995), and active swimming along horizontal and vertical gradients of temperature, food concentration, predation (Kvam, Kleiven 1995; Lampert et al. 2003), and the abundance of other species (Dumont 1972).

In addition, zooplankton species typically exhibit daily, rhythmic changes in their vertical distribution. In general, zooplankton tend to move upwards during the hours of darkness and downwards as daylight approaches (Southern, Gardiner 1932; Hutchinson 1967).

Lough Derg was chosen to study a 24 hour cycle of zooplankton migration. In the early 1920s, Southern and Gardiner (1932) examined diurnal migrations of crustaceans in Lough Derg and found that species were not homogenous in their pattern of diurnal migration. Since Southern and Gardiner's (1932) study, the lake environment has changed. In subsequent decades, an increase in the abundance of planktonic algae (especially blue-green algae) has been observed, an invasive species – the zebra mussel *Dreissena polymorpha* appeared, and there has been a decrease in the abundance of an important economic fish species – the eel (*Anguilla anguilla*). Further increases in the levels of algal development have been observed in recent years, giving rise to concern about angling and other tourism along the lake shore (McCarthy et al. 1998).

The aim of this study was to re-examine the abundance and species composition of zooplankton across different water layers over a 24 hour period and compare present patterns in zooplankton vertical distribution with those described by Southern and Gardiner (1932).

## Materials And Methods

Lough Derg (52°49'-53°06' N, 8°09'-8°31' W), the lower of the two larger lakes on the River Shannon is a well mixed, non-freezing, meso- to eutrophic, monomictic lake. Thermocline formation in summer is usually short-lived. Table 1 presents some characteristic features of Lough Derg. Much of the lake lies on carboniferous limestone with the exception of the narrow southern section, which is underlain by Silurian strata. The lower reaches of Lough Derg are largely enclosed by hills, the Slieve Aughty Mountains to the west and the Arra Mountains to the east, while to the north the upper reaches of Lough Derg are surrounded by a relatively flat agricultural landscape (Fig. 1).

**Table1**

The characteristic features of Lough Derg.

| Features | Values |
|---|---|
| Mean depth (m) | 7.6 |
| Max depth (m) | 34 |
| Annual water level fluctuation (m) | 0.3 |
| Residence time (year) | 0.2 |
| Catchment area ($km^2$) | 10.280 |
| Shoreline (km) | 179 |

Bowman (2000) reported some physical and chemical features of the lake during 1998 and 1999: the temperature range from 4.8°C (January) to 17.5°C (August); Secchi disc - 1.0 – 3.5 m; pH - 7.94 – 8.34; chlorophyll – 1 – 12 (μg $dm^{-3}$); $N\text{-}NO_2 + N\text{-}NO_3$ - 500 – 1200 (μg $dm^{-3}$); $P\text{–}PO_4$ - 10 – 50 (μg $dm^{-3}$).

Phytoplankton is characterized by diatoms and cyanobacteria. In winter - *Aphanizomenon flos-aquae*, *Oscillatoria* spp., *Stephanodiscus astraea*; in spring - *S. astraea*, *Tabellaria* spp., *Melosira italica*, *Asterionella formosa*; in summer - *Oscillatoria* spp., *Tabellaria* spp., *Melosira granulata*; in autumn - *Oscillatoria* spp., *Tabellaria* spp., *M. granulata* (Bowman 1985, 2000; Bowman et al. 1993). The fish are represented by the following species: *Salmo salar*, *S. trutta*, *Perca fluviatilis*, *Tinca tinca*, *Esox lucius*, *Abramis brama*, *Scardinius erythrophthalmus*, *Anguilla anguilla* (economically important), *Coregonus pollans*, *Rutilus rutilus*. Also an invasive bivalve species, *Dreissena polymorpha*, has been observed in the lake since 1997 (McCarthy et al. 1998).

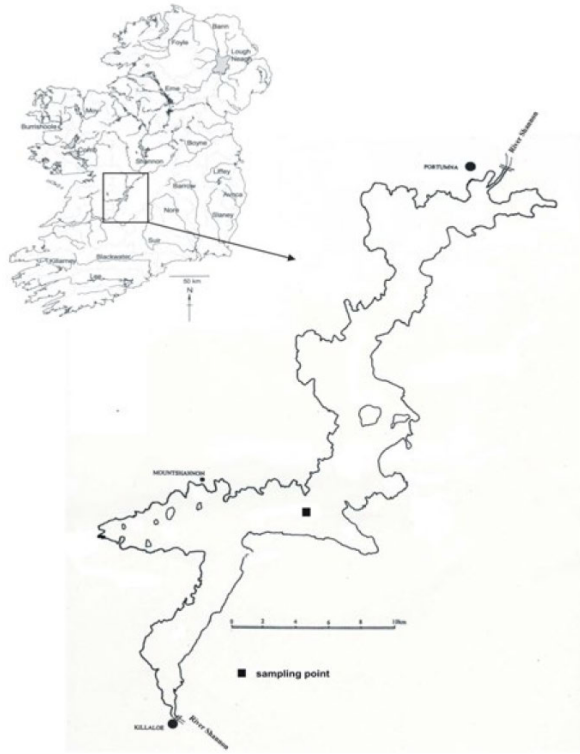


**Fig. 1.** Location of Lough Derg (Ireland).

Samples were taken from the central site at the deepest part of Lough Derg, on 26-27 of August 2003, at four-hour intervals (7 p.m., 11 p.m., 3 a.m., 7 a.m., 11 a.m., 3 p.m.), every two meters (from 0 m to 18 m) (Fig. 1). Samples for zooplankton taxonomic identification and quantitative analyses were collected using a 5-l Ruttner sampler. Ten-liter zooplankton samples (two replicate 5 l samples) were concentrated with a 50 μm plankton net in the field and immediately treated with 4% formalin. For identification and counting of zooplankton species, 5 replicate sub-samples were analyzed microscopically (×100 or ×200) in the Kolkwitz chamber of 0.4 mm height and 22 mm diameter. Taxonomic analyses of zooplankton (rotifer, copepod and cladoceran taxa) were conducted using the following keys: Dussart (1967, 1969); Flößner (1972, 2000); Ejsmont-Karabin et al. (2004); Rybak and Błędzki (2005); Voight and Koste (1978a,b). Quantitative samples were prepared by filtering 10 $l^{-1}$ of water and reducing the sample volume to 0.05 $l^{-1}$. Zooplankters were counted in 0.5 $ml^{-1}$ Kolkwitz chambers. Mean density per $l^{-1}$ was estimated on the basis of five chamber counts.

When collecting the water samples for zooplankton community identification, on-site measurements of water temperature (ºC), pH and conductivity (µS cm$^{-3}$) were also measured using a multi-parameter YSI meter.

## Results And Discussion

During the 24 hour cycle, values of physico-chemical parameters of lake water were similar from surface to bottom, and a thermocline was not present. The temperature ranged between 19.01°C (at 11 a.m.) to 19.25°C (at 7 p.m.), pH was stable at 8.78, and conductivity was 370 µS cm$^{-3}$. Similar temperatures, higher pH values and conductivity were recorded in the study of Southern and Gardiner (1926a,b). The lake's high alkalinity is derived from the underlying carboniferous limestone bedrock and run-off from the surrounding Midlands limestone plain.

The ecological importance of migratory behavior of plankton has been the subject of much research and discussion (e.g. Southern, Gardiner 1926a,b; Hutchinson 1967; Dumont et al. 1985). Hutchinson (1967) showed that the maximum zooplankton concentration usually occurs near the surface at night (nocturnal ascent) and at various depths during daytime (diurnal descent). But this is a general point of view and it is likely that many environmental factors could change this "pattern". Southern and Gardiner (1926a,b) in their studies on zooplankton in Lough Derg showed that species were not identical in their reactions to whatever stimuli that provoke the responses of species named "diurnal migration".

During our 24 hour study in Lough Derg, 17 species of zooplankton were found: 9 rotifers, 3 copepods, and 4 cladocerans. Some of them, such as *Keratella cochlearis* and *Polyarthra vulgaris*, are common in the European lakes. One species *Mysis relicta* is typical for water bodies in northern Europe (Appendix 1).

The highest values of total zooplankton density (rotifers, copepods, cladocerans, mysids and zebra mussel larvae) were observed in the water column between 0 and 8 m at 3 a.m. (780 – 1180 ind. l$^{-1}$). Zooplankton densities below 100 ind. l$^{-1}$ were observed at 11 a.m. (except at 12 m) and 3 p.m. (except 0 – 4 m). During the early (7 a.m.) and late morning (11 a.m.) the highest densities of zooplankton were observed from 10 m to the bottom but, by the early afternoon (3 p.m.) at 0 to 4 m (Fig. 2). Water-column zooplankton densities were the highest from the surface to 8 m in the late afternoon (7 p.m.), from the surface to 4 m in the evening (11 p.m.), and from the surface to 8 m at 3 a.m. In general, these observations of total zooplankton density support Hutchinson's hypothesis (1967) that the maximum zooplankton concentration occurs near the surface at night and at various depths during the day.

Rotifers as a group preferred a depth from 0 to 8 m, except at 11 p.m. when they were also observed at the surface (150 ind. l$^{-1}$) and at the deeper part of the water layer at 18 m (80 ind. l$^{-1}$). The highest value of rotifer density (167 ind. l$^{-1}$) was recorded at 3 a.m. at 6 m. A high percentage of rotifers, above 60% of the total zooplankton density, was recorded at 11 p.m. at 8 m, 12 m, 18 m and at 3 a.m. at 6 m and 18 m (Fig. 3). The most abundant rotifer species were *Keratella cochlearis* and *Polyarthra vulgaris*. Both were observed in the whole water column at night, but during the day they were found in different water layers with low abundance (Table 2). George and Fernando (1970) found that these species can exhibit nocturnal upward migration in the summer season and migrate in the reverse direction in winter. Furthermore, Karabin and Ejsmont-Karabin (2005) suggest that the main factor that triggers off the vertical migrations of Rotifera is food resource. However, the presence of predators namely their kairomones may induce vertical migrations (Loose, Dawidowicz 1994)

**Appendix 1**

List of zooplankton species in Lough Derg.

| |
|---|
| **Rotatoria** |
| *Ascomorpha saltans* Bartsch 1870 |
| *Conochilus unicornis* Rousselet, 1892 |
| *Kellicotia longispina* (Kellicott, 1879) |
| *Keratella cochlearis* (Gosse, 1879) |
| *Keratella cochlearis* f. *tecta* (Lauterborn, 1900) |
| *Keratella quadrata* (Müller, 1786) |
| *Polyarthra vulgaris* Carlin, 1943 |
| *Synchaeta oblonga* Ehrenberg, 1831 |
| *Trichocerca similis* (Wierzejski, 1893) |
| **Copepoda** |
| *Cyclops strenuus* (Fischer, 1851) |
| *Eucyclops macrurus* (Sars, 1863) |
| *Eudiaptomus gracilis* (Sars, 1863) |
| **Cladocera** |
| *Bythotrephes longimanus* Leydig, 1860 |
| *Daphnia galeata* Sars,1864 |
| *Daphnia hyalina* Leydig, 1860 |
| *Leptodora kindtii* (Focke, 1844) |
| **Mysidacea** |
| *Mysis relicta* Loven, 1869 |
| |
| + larvae of *Dreissena polymorpha* (Pallas, 1771) |

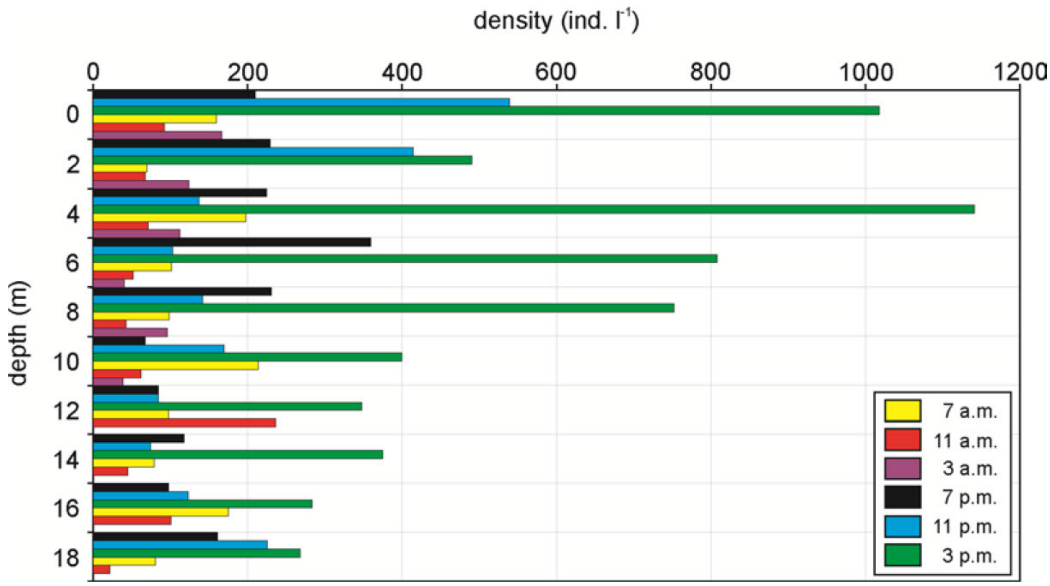


**Fig. 2.** Total density (ind. $l^{-1}$) of zooplankton in a water column of the Lough Derg during the 24 hour study.

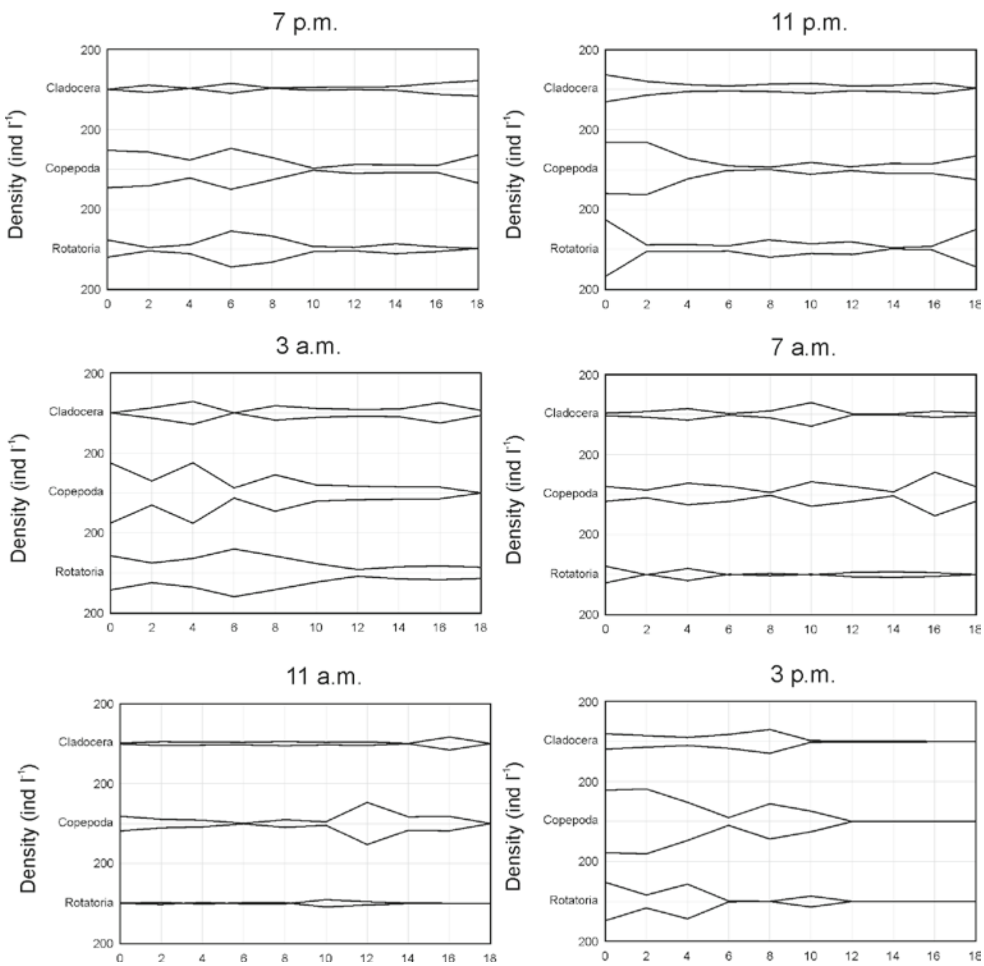


**Fig. 3.** Density of rotifers, copepods and cladocerans in a water column of the Lough Derg during the 24 hour study.

**Table 2**

Density (ind. $l^{-1}$) of most abundant species of rotifer and crustacean community during 24 hour cycle in Lough Derg.

| Hours | Meters | Rotifera | | Copepoda | | | Cladocera | | Others |
|---|---|---|---|---|---|---|---|---|---|
| | | *Keratella cochlearis* | *Polyarthra vulgaris* | nauplii | copepodite | *Eudiaptomus gracilis* | *Daphnia galeata* | *Daphnia hyalina* | larvae - *Dreissena polymorpha* |
| 7 p.m. | 0 | 43 | | 43 | | 51 | | | 72 |
| | 2 | 6 | | 45 | 22 | 17 | 17 | | 122 |
| | 4 | 5 | 19 | 42 | | 5 | | | 154 |
| | 6 | 42 | 12 | 79 | 12 | 12 | 24 | | 140 |
| | 8 | 56 | 6 | 45 | | 11 | | | 106 |
| | 10 | 7 | 3 | 3 | | | 7 | | 47 |
| | 12 | 7 | | 10 | | 11 | 3 | 3 | 49 |
| | 14 | 10 | 5 | 19 | | | | 10 | 63 |
| | 16 | | 6 | 5 | | 11 | | 27 | 43 |
| | 18 | | | 30 | 20 | 20 | | 30 | 50 |
| 11 p.m. | 0 | 101 | 20 | 40 | | 74 | | 61 | 202 |
| | 2 | 17 | | 68 | 6 | 52 | 17 | 17 | 232 |
| | 4 | 14 | 3 | 24 | | 30 | | 17 | 48 |
| | 6 | 14 | | 4 | | 8 | | 7 | 67 |
| | 8 | 31 | 4 | | | 4 | 4 | 13 | 79 |
| | 10 | 13 | 5 | 16 | 5 | 8 | | 21 | 91 |
| | 12 | 18 | 10 | 3 | | 5 | | 8 | 34 |
| | 14 | | 4 | 4 | | 18 | | 4 | 32 |
| | 16 | 9 | | 24 | | | | 19 | 57 |
| | 18 | 42 | 14 | 56 | | | | | 84 |
| 3 a.m. | 0 | 83 | 33 | 182 | | 42 | | | 670 |
| | 2 | 58 | 17 | 58 | | 33 | | 25 | 291 |
| | 4 | 45 | 60 | 165 | 15 | 30 | | 45 | 750 |
| | 6 | 28 | 125 | | 14 | 28 | | | 599 |
| | 8 | 62 | 49 | 99 | 12 | 12 | 25 | | 456 |
| | 10 | 35 | 26 | 35 | 17 | | | 26 | 243 |
| | 12 | 27 | | 27 | 9 | 18 | | 9 | 257 |
| | 14 | 37 | | 18 | 9 | 18 | | 9 | 283 |
| | 16 | 16 | 24 | 16 | 8 | 16 | 8 | 48 | 129 |
| | 18 | 34 | | | | | | 17 | 206 |
| 7 a.m. | 0 | 32 | 9 | 27 | | 10 | | 9 | 73 |
| | 2 | | | 4 | | 13 | 17 | 4 | 30 |
| | 4 | 13 | 13 | 13 | 7 | 20 | | 20 | 91 |
| | 6 | | | 33 | | 7 | | 7 | 53 |
| | 8 | | 5 | 9 | | | | 19 | 65 |
| | 10 | | | 33 | 7 | 20 | | 60 | 93 |
| | 12 | | 6 | 18 | 6 | 12 | | 6 | 48 |
| | 14 | 5 | 5 | | 5 | 10 | | 5 | 46 |
| | 16 | | 6 | 66 | 12 | 24 | | 12 | 54 |
| | 18 | | | 20 | 7 | 16 | | 7 | 30 |
| 11 a.m. | 0 | 5 | | 29 | | 10 | | 5 | 44 |
| | 2 | | | 19 | | 10 | | 10 | 29 |
| | 4 | | 10 | 10 | 7 | 6 | | 7 | 27 |
| | 6 | | | | | 7 | | 7 | 37 |
| | 8 | 2 | | 14 | 2 | 4 | | 6 | 14 |
| | 10 | 9 | 9 | | | 14 | | 5 | 23 |
| | 12 | 11 | 6 | 50 | 28 | 28 | | 6 | 106 |
| | 14 | | 4 | 15 | 4 | 18 | | | |
| | 16 | | 7 | 27 | | 7 | | 27 | 27 |
| | 18 | | 4 | 4 | | 4 | | | 9 |
| 3 p.m. | 0 | 16 | 5 | 26 | | 16 | | 10 | 88 |
| | 2 | | 7 | 17 | 10 | 17 | | 7 | 63 |
| | 4 | 13 | 4 | 4 | 4 | 17 | | 4 | 58 |
| | 6 | | 2 | 2 | 3 | 4 | | 6 | 23 |
| | 8 | | | 10 | | 13 | | 14 | 55 |
| | 10 | 4 | 3 | 14 | | 3 | | | 14 |

Copepods reached their highest density (200 ind. $l^{-1}$) at 3 a.m. twice, at 0 m and 4 m. This group preferred the depths from 0 to 8 m at 7 p.m., 11 p.m., 3 a.m. and 3 p.m., but deeper water layers from 12 m to the bottom at 7 a.m. and 11 a.m. A high percentage of copepods (>80% of the total zooplankton density) was observed several times in the morning at 7 a.m. and 11 a.m. (Fig. 3). Immature stages of all copepods (nauplii and copepodites) and *Eudiaptomus gracilis* were most abundant. High numbers of all copepods nauplii and *E. gracilis* were recorded throughout the whole water column while copepodites of all copepods were found at specific water layers (Table 2). This differs from the patterns of *E. gracilis* migration observed by Southern and Gardiner (1932). They observed *E. gracilis* adult and immature stages with the maximum concentration in the surface layers (0 – 5 m) during the night and at 10 – 20 m during the day. In another Irish lake (Gouganebarra), Gardiner (1957) observed the same pattern of *Diaptomus laticeps* diurnal migration with maximum concentrations at 0 – 5 m during night time (3 a.m.) and at 20 – 25 m during daytime (2 p.m.).

Cladoceran density was never above 100 ind. $l^{-1}$. The highest densities of cladocerans were observed during the night in different water layers: 11 p.m. at 0 m (68 ind. $l^{-1}$), 3 a.m. at 4 m (75 ind. $l^{-1}$) and 16 m (64 ind. $l^{-1}$); and during the early morning at 7 a.m. at 10 m (60 ind. $l^{-1}$). In general cladocerans preferred surface water layers during the night but deeper water layers during the day. A high percentage of cladocerans, 40–55% of the total density of zooplankton, was recorded at 2 m (7 a.m.), 6 m (11 a.m. and 3 p.m.), between 8 – 10 m (7 a.m.) and once in a deeper layer at 16 m (11 p.m.) (Fig. 3).

*Daphnia hyalina* was the most abundant species and was observed within the whole water column except at 7 p.m. when it was found only below 12 m (Table 2). Southern and Gardiner (1932) reported a contrasting pattern of migration for *D. longispina*, a large *Daphnia* species similar to *D. hyalina*. During the morning (6 a.m.) they found high concentrations of *D. longispina* in deeper water layers, but by midday *Daphnia* concentrations were the highest in the upper 5 m of the water column and were almost absent below the 10 m level. In addition, Gardiner (1957) found different results for *D. longispina* abundance in Gouganebarra Lake: this species remained at 0 – 15 m throughout a 24 hour period. Ziarek et al. (2011) observed that individual *Daphnia* behavior shows extreme flexibility as a response to external and internal factors (food, light, individual size of daphnids, the presence of kairomones, the occurrence of toxic elements), but the most important factor influencing the biology of *Daphnia* is the temperature.

In the present study, *D. polymorpha* larvae were observed in large numbers throughout the whole water column over the 24 hour period examined. The maximum concentration (750 ind. $l^{-1}$) was observed at 3 a.m. at 4 m depth. High concentrations of *D. polymorpha* larvae (40 to 50% of the total zooplankton community) were commonly observed in Lough Derg during summer months (Pociecha, unpublished data).

The results of our field survey reveal the highly dynamic character and variability of zooplankton behavior. In general, zooplankton vertical migration in Lough Derg was supportive of Hutchinson's (1967) hypothesis. Hutchinson (1967) distinguished three types of vertical migration patterns: nocturnal migration, twilight migration and reverse migration.

We can't distinguished one type of migration for one group in the examined zooplankton groups of Lough Derg. For copepods we can describe nocturnal migration (between 7 p.m. to 3 a.m.) and reverse migration (at 3 p.m.). Cladocerans and rotifers have not any of the typical discussed patterns (Fig. 3). The occurrence of these patterns could have been caused by temperature and light gradients, predator avoidance or presence of invasive species.

The vertical distribution of limnetic zooplankton species in Lough Derg may be related to the absence of a thermocline as a borderline for zooplankton species (Lampert 2005). Temperature is often observed to be the most important factor governing the zooplankton vertical distribution (Dawidowicz, Loose 1992; Cooke et al. 2008). Zooplankton distribution in Lough Derg is probably not connected with homogenous physico-chemical variables but with other environmental factors. Light, temperature and biotic interactions, such as predation, interspecific competition, food availability and feeding habits can influence and modify migration patterns (Gliwicz, Pijanowska 1988; Lampert 1989; Mavuti 1992; Loose, Dawidowicz 1994; Sakwińska, Dawidowicz 2005; Haupt et al. 2009; Cohen, Forward 2009; Wojtal-Frankiewicz et al. 2010). Dumont et al. (1985) stressed that in the absence of strong forcing factors, such as visual predation and light damage, it would be advantageous for zooplankton not to migrate downwards during the day, allowing zooplankters to feed continuously on the phytoplankton.

Summing up, we did not observe any evidence for a pattern of zooplankton vertical distribution in Lough Derg. Southern and Gardiner (1932) in their studies on the diel vertical migration of crustaceans in Lough Derg didn't obtain a homogenous pattern of DVM, about ~90 years later we stated that crustaceans were observed in the whole water column during day and night. Rotifers preferred mainly a depth from 0 to 8 m but we could not compare this result with the studies of Southern and Gardiner because they investigated only crustaceans. Probably light, food and/or predators, or other environmental factors (especially the concentration of a chemical trigger – the substance kairomone) influence the zooplankton density, but this needs to be confirmed in the future studies. In the future studies we would also like to focus on the pattern of vertical distribution and diel migration of zooplankton in relation to:

1) seasons (spring, summer, autumn and winter),
2) gradients of light and temperature,
3) biotic factors: food availability and predation,
4) influence of the invasive species zebra mussel *Dreissena polymorpha*.

Liu et al. 2006 wrote that DVM is only a tip of an iceberg from the perspective of the whole picture of zooplankton behaviors , though it appears to be the most marvelous spectacle during the lifetime of the performers. DVM is notable for its diel rhythm, magnitude of migration and ontogenetic variances (Mclaren 1963; Uye et al. 1990; Zaret, Suffern 1976), but all these remarkable features do not mean to decouple the mechanisms underlying DVM from the behavioral strategies directing the "everyday concerns" of an individual animal. In other words, one mechanism, if it is reasonable for interpreting the general behaviors, will be recommendable for the understanding of DVM, and vice versa. Zooplankters seemingly do not need to develop a different logic to deal with the same problem: how to survive as long as possible.

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