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Contact CEH NORA team at
nora@ceh.ac.uk

ANALYSIS OF LOCH LOMOND PRESERVED CRUSTACEAN ZOOPLANKTON SAMPLES, 2001-2007

Report to Scottish Environment Protection Agency [SEPA reference: R70102PUR]

Iain Gunn

Centre for Ecology and Hydrology Edinburgh,
Bush Estate, Penicuik
Midlothian EH26 OQB, Scotland, UK
Telephone: 0131 445 4343; Fax: 0131 445 3943
e-mail: idmg@ceh.ac.uk
Web: www.ceh.ac.uk

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1. INTRODUCTION

From 1994-2007, as part of the Environmental Change Network (ECN), freshwater crustacean zooplankton samples were collected from Loch Lomond, at approximately monthly frequencies, by the Scottish Environment Protection Agency (SEPA),

The key project objectives of the research project are as follows:

- to process and analyse up to a maximum of 209 preserved freshwater crustacean zooplankton samples collected from Loch Lomond from 1994-2007
- to interpret the resultant data in the context of other long-term data held for Loch Lomond

The Centre for Ecology & Hydrology (CEH) were contracted by SEPA to analyse a sub-set of 60 these Loch Lomond preserved crustacean zooplankton samples, before the end of March 2008. CEH were unable to commit to analysing any more samples within the proposed timeframe of the project. The remainder of the samples are/or will be analysed by another contractor or contractors.

2. METHODOLOGY

A sub-set of 60 freshwater crustacean zooplankton samples collected from Loch Lomond during 2001-2007 were delivered to CEH Edinburgh for analysis (Table 1). These open water crustacean zooplankton samples were collected and concentrated with a plankton net (mesh size 140 µm, 30 cm diameter and 80 cm long), which was hauled to the water's surface from a depth of 5 m (i.e. a vertical net tow) from the three sample sites situated along a north-south gradient: Cailness (northern (Tarbet) basin); Ross Point (Luss (mid) basin); and Creinch (southern (Fault) basin). All samples were preserved in formaldehyde.

In the laboratory the crustacean zooplankton samples were placed in a glass vessel and made up to a final volume of 250 ml with distilled water. Each sample was thoroughly mixed, to distribute the animals randomly, and then sub-sampled with a Stempel pipette (volume 5 ml). The animals present in each sub-sample were identified (Dussart and Defaye 1995; Einsle 1996; Flößner and Kraus, 1986; Harding and Smith 1974; Lieder 1983; Scourfield and Harding 1966) and counted under a low power binocular microscope. For copepod species, nauplii were counted in addition to adults and copepodites (I-V). The level of identification of the preserved freshwater crustacean zooplankton taxa was taken to species level wherever possible. No specimen was identified beyond the level justified by its condition of preservation or stage of maturity as recommended in the appropriate key. In most cases, three sub-samples were examined although in a few cases, where crustacean zooplankton numbers were particularly low, an additional fourth sub-sample was also checked. The sub-sample counts were converted to numbers of individuals per litre by using appropriate multiplication factors.

As the population of *Daphnia* was thought likely to be the principal phytoplankton-grazing cladoceran in Loch Lomond, additional size analysis was carried out on this species in an effort to help analyse population changes and relate them with other long-term data, particularly the phytoplankton, held by SEPA. For each sample, where *Daphnia* was recorded, up to a maximum of 25 individuals were measured from the top of the head crest to the end of caudal spine. Each *Daphnia* individual was allocated to one of four different size classes:

Size Class	**Length of *Daphnia***
1	< 1 mm
2	> 1 mm <1.4 mm
3	> 1.4 mm <2.00 mm
4	> 2.00 mm

In addition, each of these *Daphnia* was also examined for egg counts and evidence of a head crest with a point or 'helmet'. Where a helmet was present, measurements were taken of the size of helmet by measuring the distance from the middle of the eye to top of the crest.

Table 1. Details of collected zooplankton samples delivered to CEH for analysis

Sample Date		**Sample location**	
20.08.2001	Cailness	Creinch	
27.04.2005	No sample	Creinch	
04.07.2005	Cailness	Creinch	
17.08.2005	Cailness	Creinch	
03.08.2005	Cailness	Creinch	
13.05.2005	Cailness	Creinch	
26.10.2005	Cailness	Creinch	
07.02.2006	Cailness	Creinch	
12.07.2006	Cailness	Creinch	
27.07.2006	Cailness	Creinch	
02.08.2006	Cailness	Creinch	
15.08.2006	Cailness	Creinch	
07.09.2006	Cailness	Creinch	
17.10.2006	Cailness	Creinch	
08.11.2006	Cailness	Creinch	
21.03.2007	Cailness	Creinch	Ross Point
17.04.2007	Cailness	Creinch	Ross Point
09.05.2007	Cailness	Creinch	Ross Point
23.05.2007	Cailness	Creinch	Ross Point
20.06.2007	No sample	No sample	Ross Point
18.07.2007	Cailness	Creinch	Ross Point
27.09.2007	Cailness	Creinch	Ross Point
18.10.2007	Cailness	Creinch	Ross Point
30.10.2007	Cailness	Creinch	Ross Point
15.11.2007	Cailness	Creinch	Ross Point
11.12.2007	Cailness	Creinch	Ross Point

CEH were also asked to produce a list of digital images of common and rare freshwater crustacean zooplankton taxa derived from its collection of Loch Lomond samples.

3. RESULTS

All the data from this study are compiled in electronic format in an accompanying Microsoft Office Excel 2003 spreadsheet: LomondcrustaceanzooplanktonCEHanalysis2001-2007.xls

Species list

Nine crustacean zooplankton species were found in the 60 Loch Lomond samples analysed by CEH (Table 2). The nomenclature used is the most recent and widely accepted in Britain and follows that laid down in the latest revision of the "*Coded checklist of animals occurring in fresh water in the British Isles*" (see http://www.ceh.ac.uk/subsites/eic/ddc/furselist/index.htm).

Table 2. Crustacean zooplankton species recorded from Loch Lomond during 2001-2007 in 60 samples analysed by CEH

Cladocera (Branchiopoda)

Anompoda

Bosminidae

Bosmina longispina Leydig (= *Bosmina coregoni* var. *obstusirostris* (Sars))

Daphniidae

Daphnia galeata Sars (= *D. hyalina* var*. galeata* Sars)

Ctenopoda

Holopedidae

Holopedium gibberum Zaddach

Haplopoda

Leptodoridae

Leptodora kindti (Focke)

Onychopoda

Cercopagidae

Bythotrephes longimanus Leydig
Polyphemus pediculus Linneaus

Copepoda

Calanoida

Diaptomidae

Eudiaptomus gracilis (Sars)

Cyclopoida

Cyclopidae

Cyclops abyssorum Sars (= *Cyclops strenuous abyssorum* Sars)
Mesocyclops leukarti (Claus)

In a few samples, larvae of the phantom midge *Chaoborus flavicans* were also recorded.

See Appendix 1 for a gallery of digital images derived from the Loch Lomond samples of all the nine freshwater crustacean zooplankton taxa listed in Table 2.

Abundance

The abundances of the main crustacean zooplankton species are shown graphically in Figures 1-3 for 2005-2007. The principal taxa at all three sites and years were the calanoid copepod, *Eudiaptomus gracilis*, the cyclopoid copepods *Mesocyclops leukarti* and *Cyclops abyssorum* and the cladocerans *Daphnia galeata* and *Bosmina longispina*.

The general seasonal features of the population dynamics of the crustacean zooplankton taxa over the period 2005-2007, based on the samples CEH examined, can be summarised as follows:

(a) *Eudiaptomus gracilis* was the commonest crustacean zooplankton species in Loch Lomond. It was consistently recorded throughout the year at all three sample sites. Population densities of adults and copepodites reached a peak in May although this trend was not so evident at the Creinch sample site. The *Eudiatomus* population reached a maximum peak of 25.9 ind.l^{-1} at Cailness on the 23rd May 2007.

(b) *Mesocyclops leukarti*, after *Eudiatomus*, was the commonest crustacean zooplankton species found in the Loch Lomomd samples examined. It was consistently recorded throughout the year but, unlike *Eudiaptomus* and *Cyclops*, population densisties of adults and copepopdites tended to reach a peak in the autumn months. The *Mesocyclops* population reached a maximum peak of 18.19 ind.l^{-1} at Creinch on the 7th September 2006.

(c) *Cyclops abyssorum* was less abundant and was more sporadically recorded compared to *Eudiaptomus* and *Mesocyclops.* However, like *Eudiaptomus*, the population densities of *Cyclops* adults and copepodites peaked in May. The *Cyclops* population reached a maximum peak of 4.7 ind.l^{-1} at Cailness on the 9th May 2007. Extremely low numbers of over-wintering *Cyclops* were recorded.

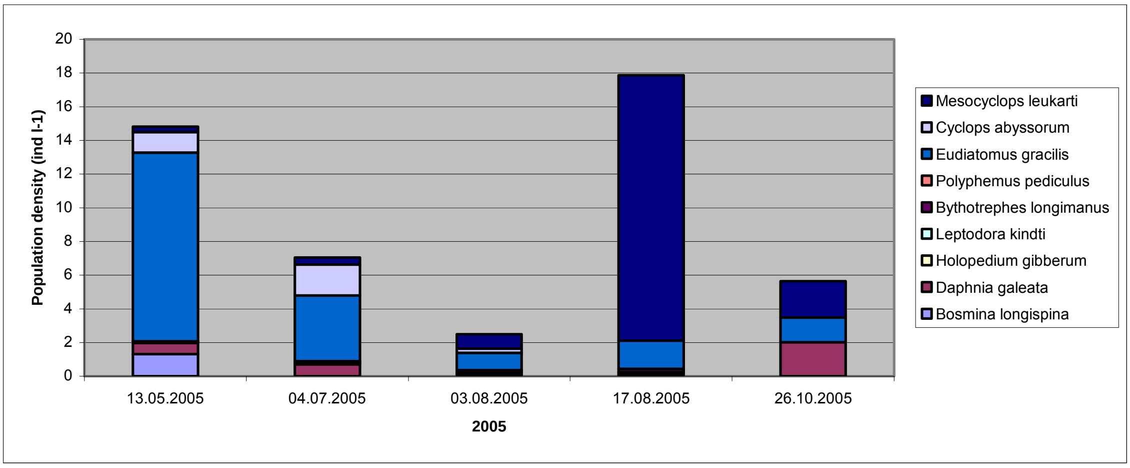
(d) *Daphnia galeata* population densities were genereally very low (<1 ind.l^{-1}) throughout the year at the three sample sites. However, there were increases in numbers recorded in the following periods: August (3.71 ind.l^{-1}) and October 2005 (2.82 ind.l^{-1}) at Creinch; September 2006 at both Cailness and Creinch (17.25 ind.l^{-1} and 5.36 ind.l^{-1}, respectively); May to July 2007 at all three sites – the *Daphnia* population reaching a maximum peak of 6.91 ind. l^{-1} at Creinch.

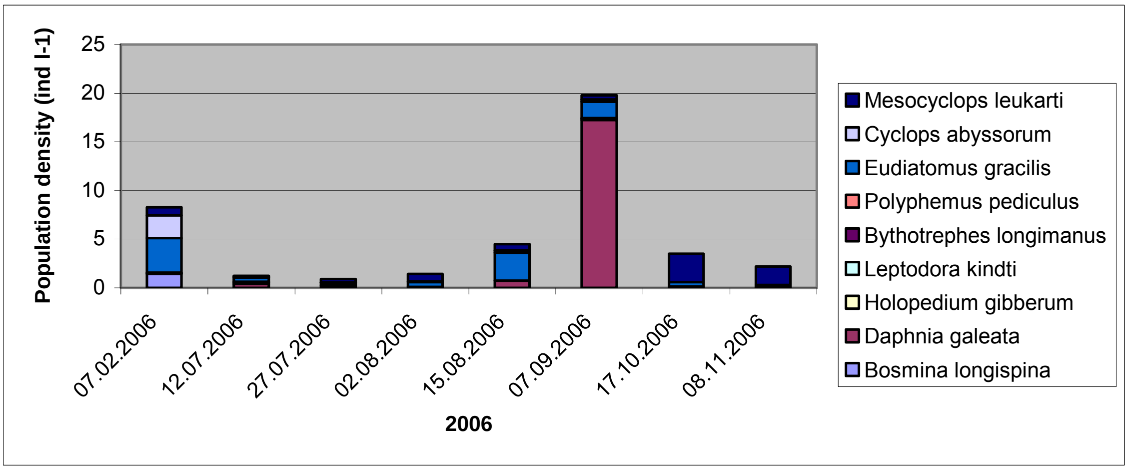
(e) *Bosmina longispina* population densities peaked in May. The *Bosmina* population reached a maximum peak of 5.03 ind.l^{-1} at Creinch in May 2005. *Bosmina* was absent in the plankton during the summer months before re-appearing in very low numbers in the autumn samples.

(f) The other four recorded species, *Holopedium gibberum* and the three predatory cladocerans *Bythotrephes longimanus*, *Leptodora kindti* and *Polyphemus pediculus,* were all found in extremely low numbers (<0.40 ind. l^{-1}) at all three sample sites. *Holopedium gibberum* was only recorded once at Creinch in May 2007.

Data for the single sample date in 2001 (20th August) at Cailness and Creinch sample sites have not been graphed. At both these sites *Eudiaptomus gracilis* (12.55 and 10.11 ind.l-1) and *Mesocyclops leukarti* (7.61 and 15.6 ind.l-1) were the dominant crustacean zooplankton taxa.

Figure 1. Population densities of crustacean zooplankton at Cailness, Loch Lomond 2005-2007





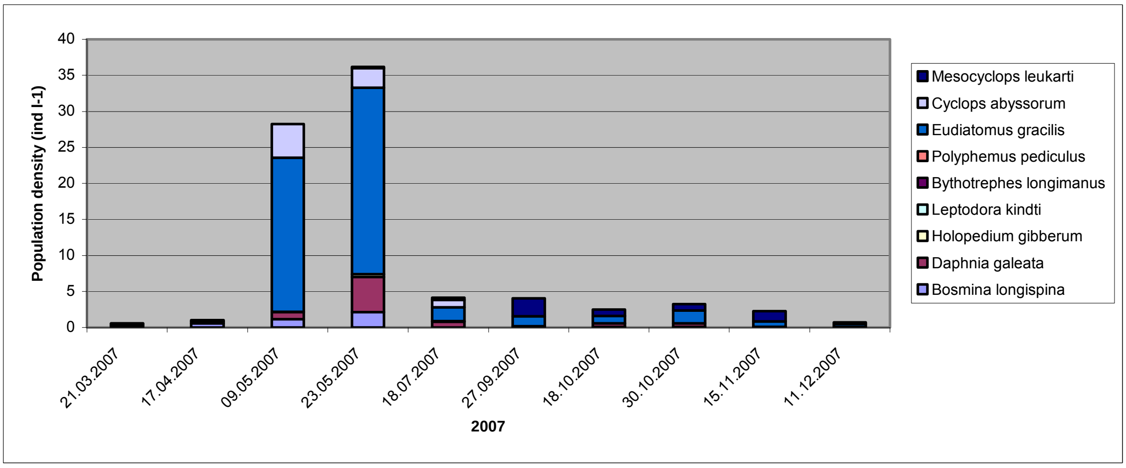
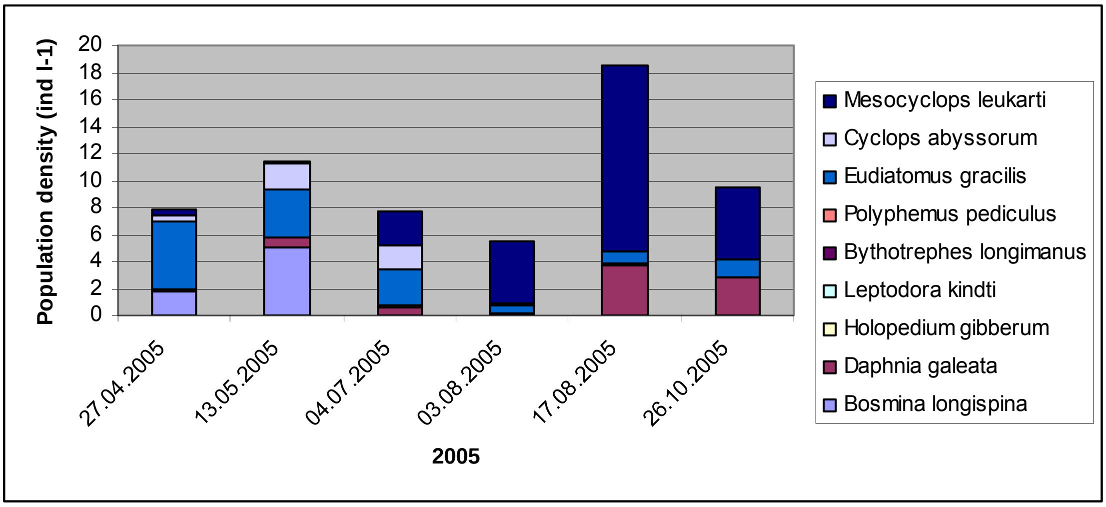
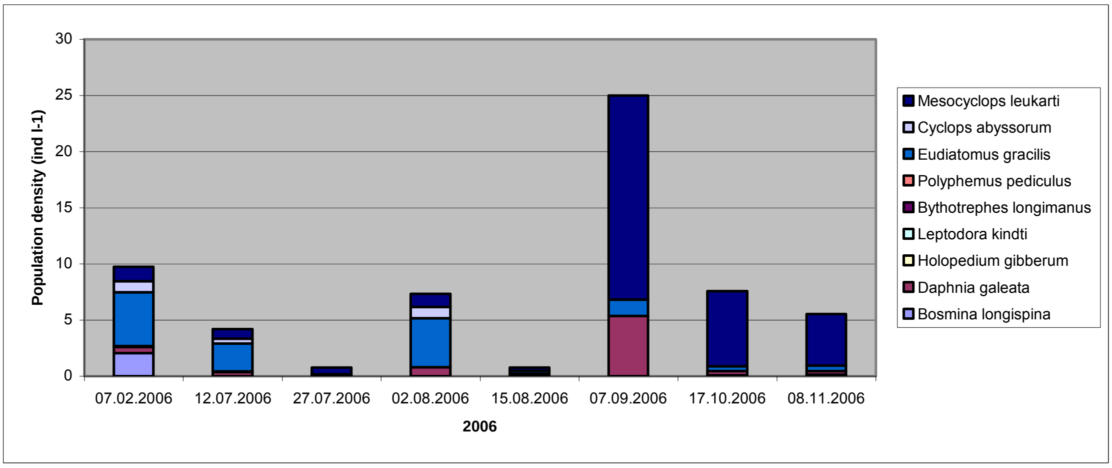


Figure 2. Population densities of crustacean zooplankton at Creinch, Loch Lomond 2005-2007





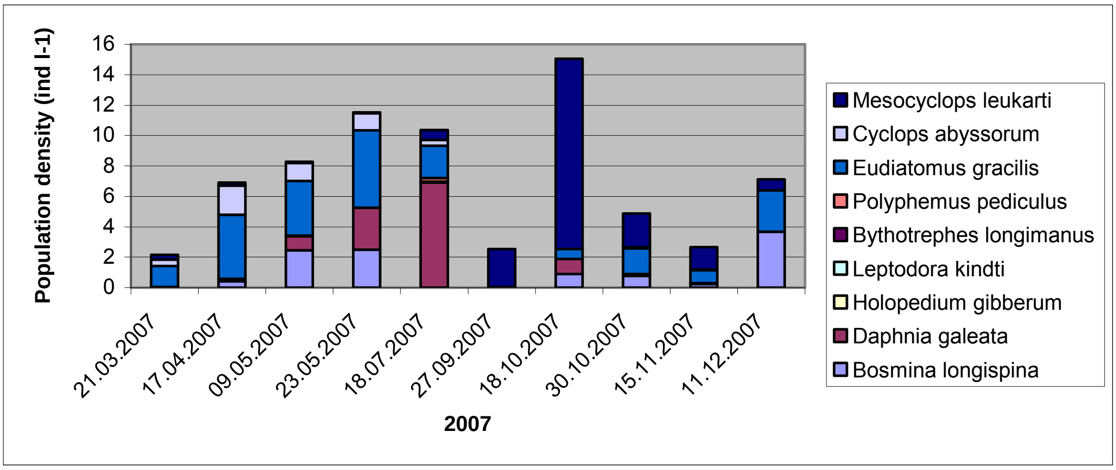
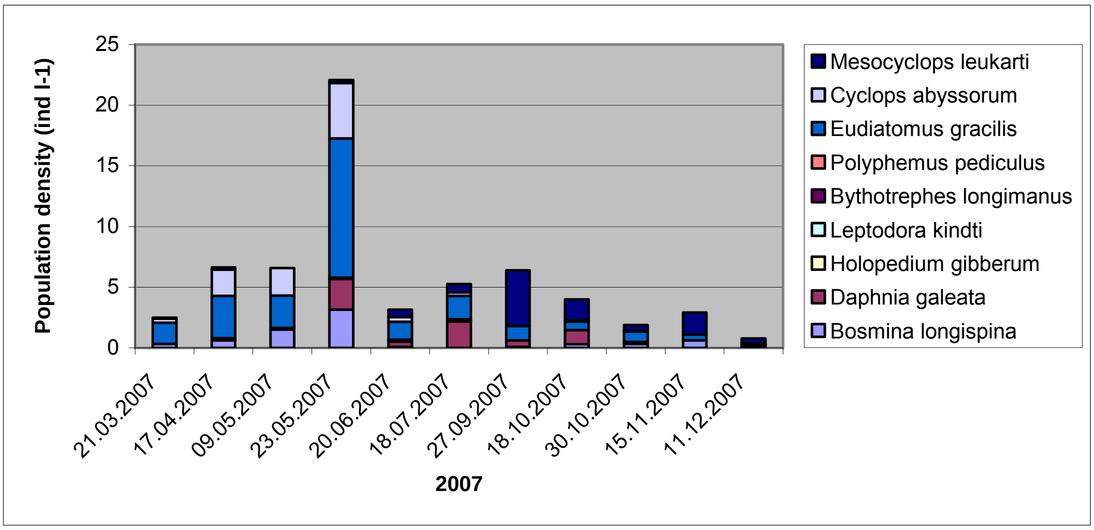


Figure 3. Population densities of crustacean zooplankton at Ross Point, Loch Lomond 2007



Size analysis

All the data from the *Daphnia* size analysis part of the study are detailed in an accompanying spreadsheet: LomondcrustaceanzooplanktonCEHanalysis2001-2007.xls. These data have yet to be analysed in detail. One comment, in hindsight, is that perhaps it would have been better and easier to measure *Daphnia* body length by measuring from top of head to base of the caudal spine rather than end of spine as as been done in other studies of *Daphnia* population dynamics, e.g. George and Edwards (1974).

The majority of the *Daphnia* individuals tended to develop helmets over the summer months (from late May onwards) but this became much less prevalent over the winter months. Cyclomorphosis in *Daphnia* populations has been primarily related to changes in temperature and water turbulence but such growth may also be induced by organic substances released by fish predators (Wetzel, 2001). In Loch Lomond, powan, *Coregonus laveratus*, are known to feed heavily on zooplankton from late spring to late autumn (Pomeroy, 1994).

Daphnia individuals were also examined for egg counts but in general both eggs and neonates had been shed after collection and preservation in formaldehyde and thus it wasn’t possible to make any sort of reliable assessment of egg numbers and hence make any sensible estimates of seasonal variations in egg production. However, it was clear from those individuals where there was evidence of reproduction that it was limited to *Daphnia* within size classes 3 or 4. No animals below 1.40 mm carried eggs.

4. DISCUSSION

The crustacean zooplankton community of Loch Lomond, based on the 60 samples analysed by CEH, contains nine species (Table 2). This is consistent with previous studies (Pomeroy, 1994). Among Scotland's large lochs the Loch Lomond crustacean zooplankton community is considered to be unique in containing *Mesocyclops leukarti* (Maitland, Smith and Dennis, 1981). Over the period of this study, 2001-2007, the filter-feeding calanoid copepod, *Eudiaptomus gracilis*, was the most numerous species in the Loch Lomond crustacean zooplankton community throughout much of the year. The cyclopoid copepods *Mesocyclops leukarti* and *Cyclops abyssorum* were commonly occurring, particularly in the autumn and spring, respectively. The cladocerans *Daphnia galeata* and *Bosmina longispina* were the main phytoplankton-grazing species.

Krokowski (2007) reported that there was a north-south trophic gradient in Loch Lomond, with the highest in-loch nutrient concentrations occurring in the mesotrophic southern basin which correspondingly had higher phytoplankton biomass and abundances compared to the more oligotrophic northern basin. However, there were no obvious differences in the crustacean zooplankton community in terms of species composition or abundance, between the oligotrophic northern basin and the more enriched southern basin apart from *Holopedium gibberum* being much more frequently recorded at Cailness compared to Creinch. *Hoplopedium gibberum* is noted for its strong preference for oligotrophic lakes and for waters with low calcium content (Fryer, 1991; Scourfield and Harding, 1966) so perhaps its distribution is an indication of the relatively nutrient poor conditions of the northern basin. May and O'Hare (2005) also noted that species composition of the rotifer community of Loch Lomond varied little between the northern and southern basins although rotifer abundance did, apparently, reflect the trophic gradient along the length of the loch.

Krokowski (2007) also noted that the increased abundance of diatom taxa indicative of nutrient enriched conditions suggested an increase in the trophic state of Loch Lomond. In Loch Leven, increased densities of phytoplankton grazers, such as *Daphnia*, can play a very significant role in improving water quality by reducing chlorophyll level and improving water clarity (Ferguson, et al, 2007). In Loch Lomond the phytoplankton community is characterised by a small spring peak of diatoms followed by a larger autumnal peak due to cyanobacteria, green algae and desmids (Krokowski, 2007). The desmid-diatom community is a potentially good food source for zooplankton grazers. However, the limited complementary data from Krokowski's and the present study, for example, the period between May 2005 and August 2005, indicates that *Daphnia* populations were relatively low corresponding to when phytoplankton abundance was high in Loch Lomond suggesting that in this period, at least, zooplankton predation was not a major factor in affecting phytoplankton growth and abundance. As Krokowski (2007) points out phytoplankton abundance in Loch Lomond is probably mainly associated with increased water temperatures and nutrient availability.

There seems no reason to change the current sampling regime as it gives a good temporal and spatial coverage for the crustacean zooplankton community in Loch Lomond. In terms of preservation techniques, using formaldehyde worked well in terms of keeping the crustacean zooplankton samples in good condition for identification purposes although it was less effective in retaining eggs/neonates and egg sacs attached to individual adult *Daphnia* and copepods, respectively. These had been generally shed in the samples.

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APPENDIX 1 – DIGITAL IMAGES OF CRUSTACEAN ZOOPLANKTON SPECIES DERIVED FROM LOCH LOMOND SAMPLES:

1. *Polyphemus pediculus*
2. *Mesocyclops leukarti*
3. *Mesocyclops leukarti*
4. *Leptodora kindti* - head region
5. *Holopedium gibberum* - head region
6. *Eudiatopmus gracilis*
7. *Daphnia galeata*
8. *Cyclops abyssorum*
9. *Bythotrephes longimanus* – head region
10. *Bosmina longspina*

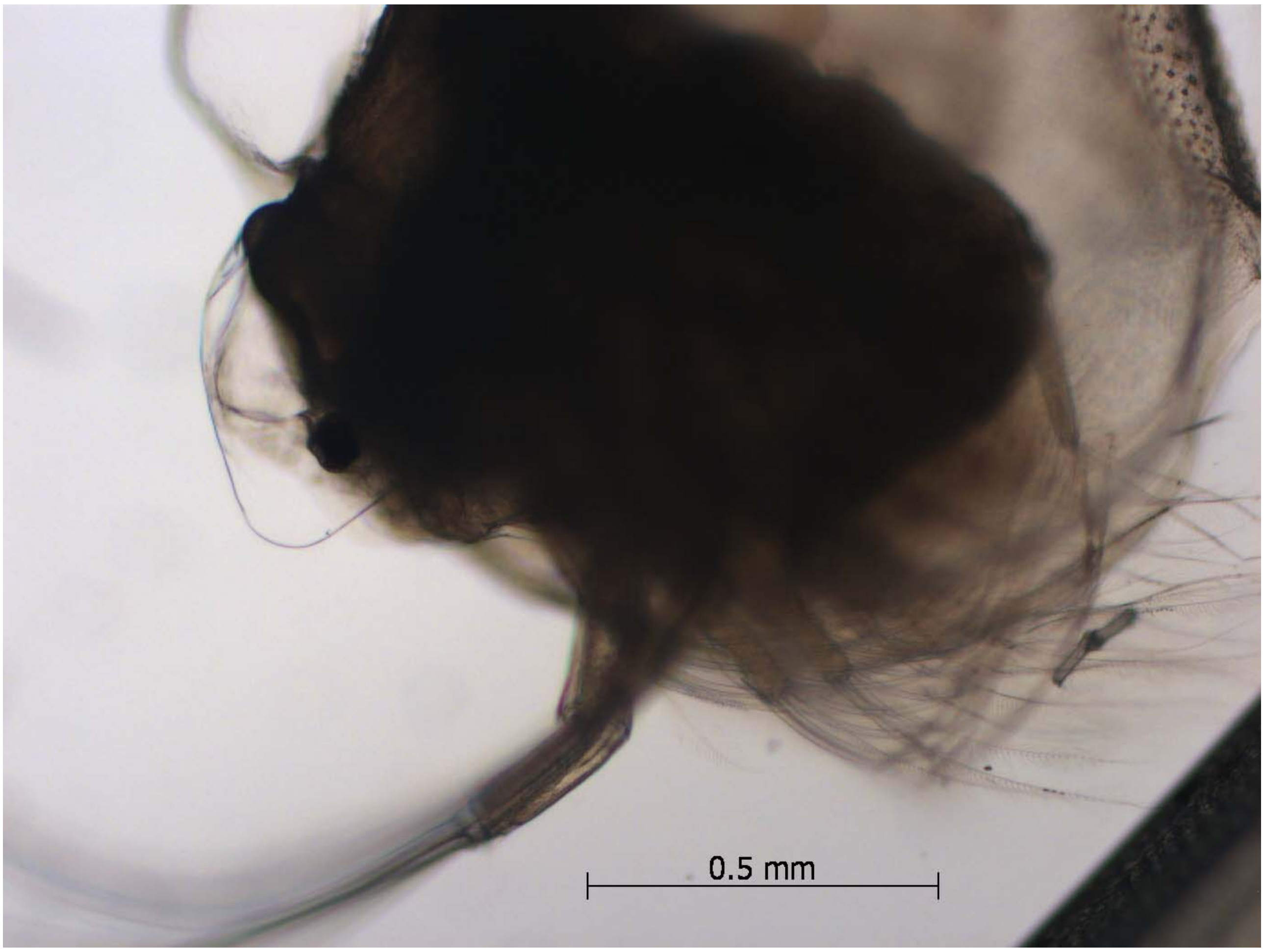
1. *Polphemus pediculus* Linneaus

2. ***Mesocyclops leukarti*** **(Claus)**

3. *Mesocyclops leukarti* (Claus)

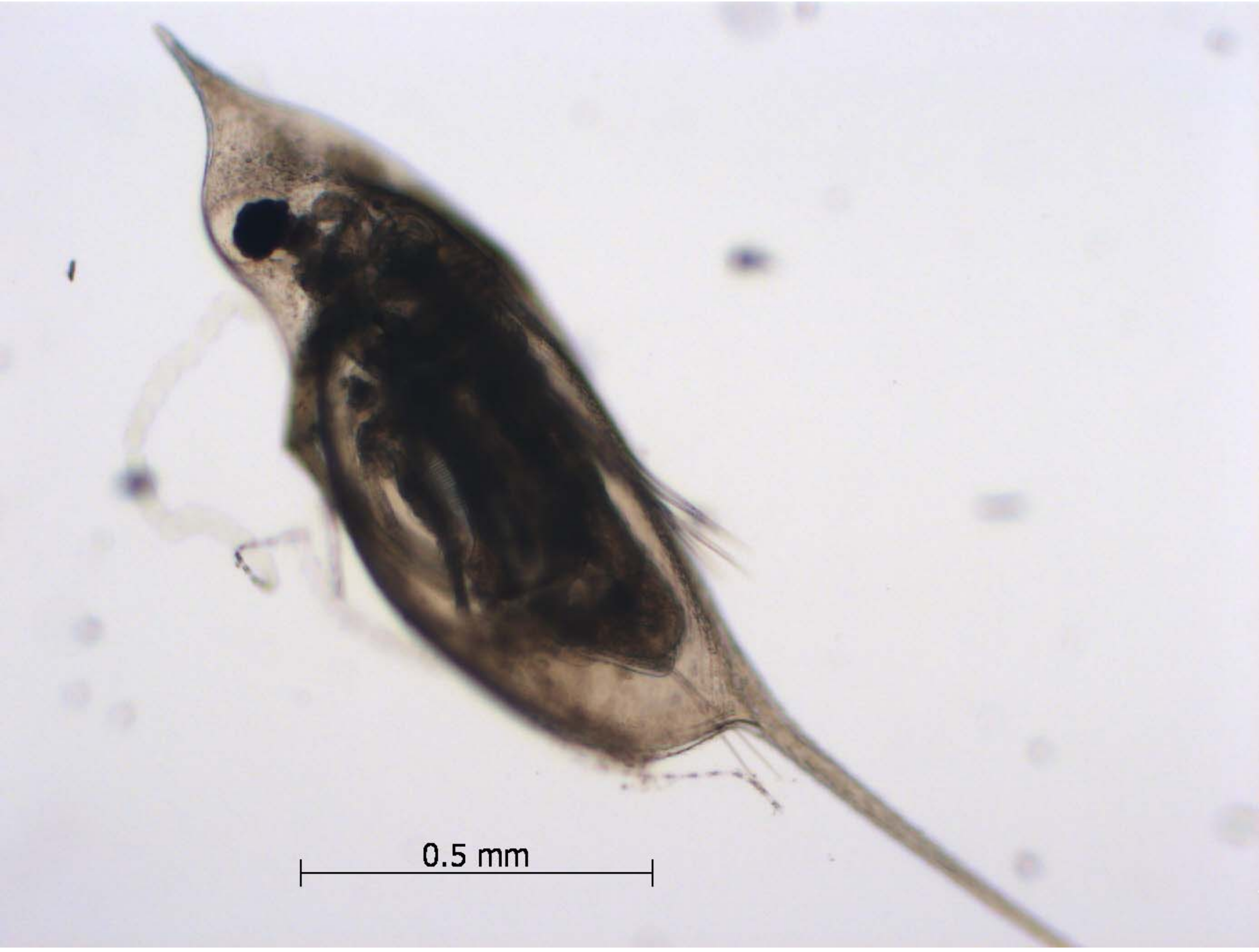
4. *Leptodora kindti* (Focke) – head region

5. *Holopedium gibberum* Zaddach – head region

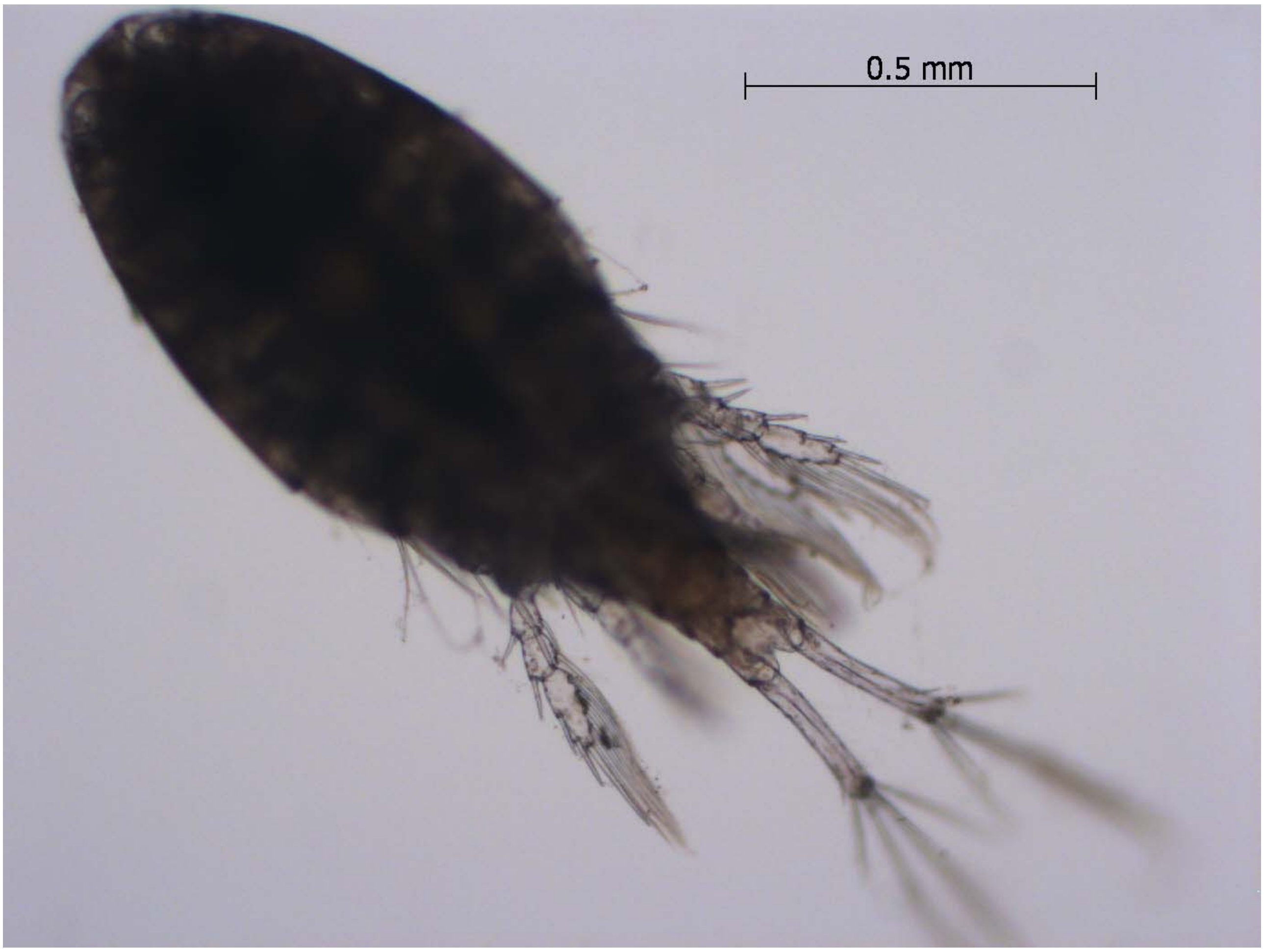


6. *Eudiaptomus gracilis* (Sars)

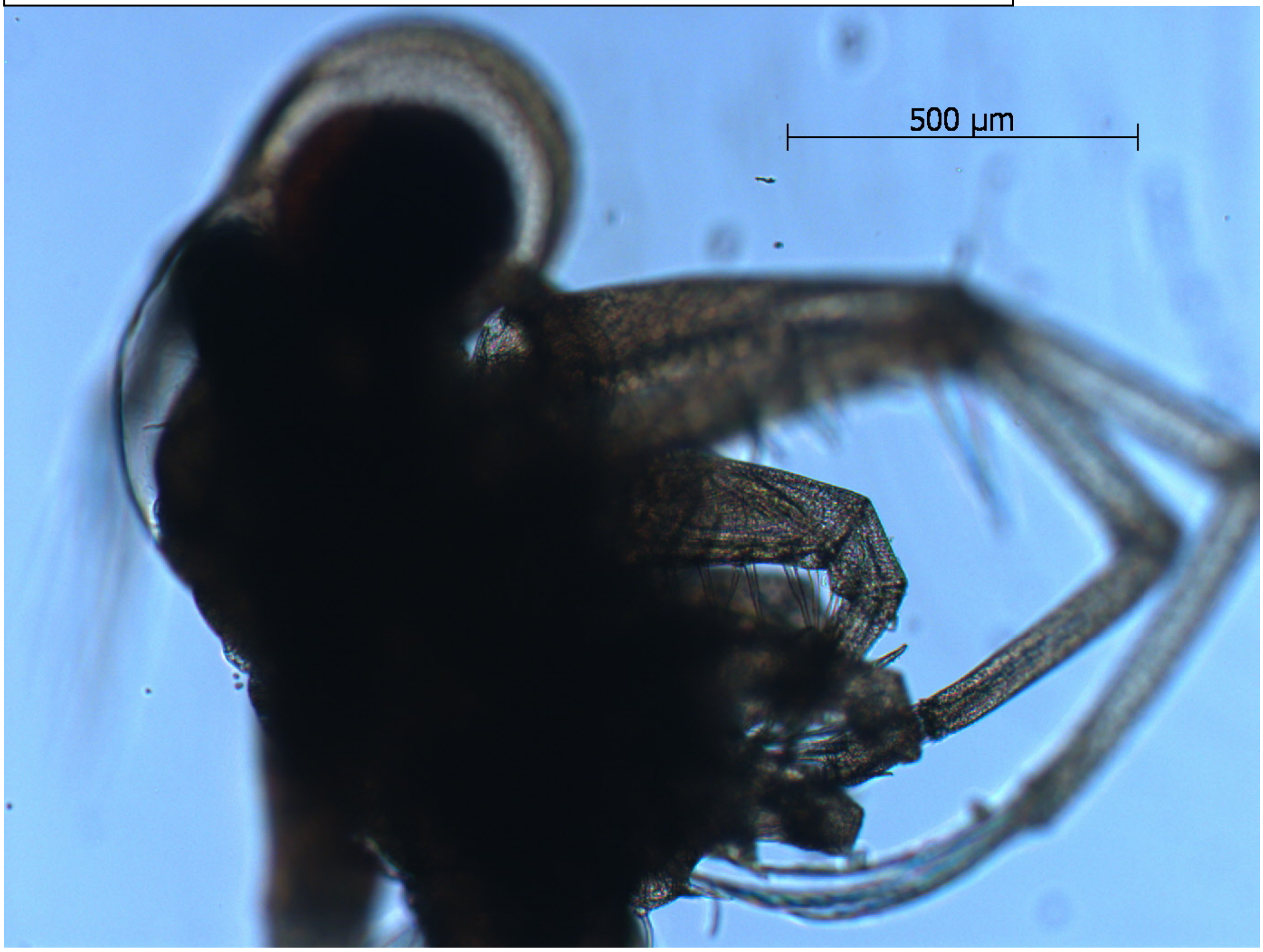
7. *Daphnia galeata* Sars



8. *Cyclops abyssorum* Sars



9. *Bythotrephes longimanus* Leydig – head region



10. *Bosmina longispina* Leydig