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The Vertical Dynamics of Larval Chironomids on Artificial Substrates in Lake Lido (Bogor, Indonesia)

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Abstrak: Kelimpahan dan komposisi komuniti larva kironomid di atas substrat buatan telah dikaji di Tasik Lido, Bogor, Jawa Barat, Indonesia. Tasik ini kaya secara organik kerana aktiviti penternakan ikan. Tujuh puluh dua substrat buatan telah diatur pada tiga kedalaman (2.0, 3.5 dan 5.0 m) di dua lokasi: satu lokasi kultur sangkar dan satu lokasi kultur bukan sangkar (kawalan). Larva kironomid telah dikumpul pada 7, 14, 28 dan 56 hari selepas substrat buatan diaturkan. Pada masa yang sama, beberapa parameter fizikal dan kimia air juga telah diukur. Tiga subfamili kironomid iaitu Chironominae, Tanypodinae dan Orthocladiinae telah dijumpai di kedua-dua lokasi. Di lokasi kultur sangkar, kedua-dua kepelbagaian dan jumlah kelimpahan lebih tinggi secara signifikan pada kedalaman 2.0 dan 3.5 m berbanding kedalaman 5.0 m; walau bagaimanapun keadaan ini tidak sama di lokasi kultur bukan sangkar. Berdasarkan data terkumpul daripada semua kedalaman, ujian Mann-Whitney U telah menunjukkan bahawa lokasi kultur bukan sangkar mempunyai kepelbagaian dan jumlah kelimpahan yang lebih signifikan daripada lokasi kultur sangkar. Oksigen terlarut dan kekeruhan menunjukkan pebezaan signifikan antara kedalaman 2.0 m dan 2 kedalaman yang lain di lokasi kultur sangkar, manakala tiada satu parameter persekitaran pun menunjukkan perbezaan signifikan antara ketiga-tiga kedalaman di lokasi kultur bukan sangkar. Perbandingan parameter persekitaran pada kedalaman yang sama di kedua-dua lokasi menunjukkan perbezaan yang signifikan untuk kekeruhan, pH dan oksigen terlarut. Analisis Spearman rank di lokasi kultur sangkar telah menunjukkan bahawa kelimpahan dan oksigen terlarut berkorelasi secara positif, manakala kelimpahan dan kekeruhan berkorelasi secara negatif. Walau bagaimanapun, hanya pH yang berkorelasi secara negatif dengan kelimpahan di lokasi kultur bukan sangkar.

Kata kunci: Larva Kironomid, Kedalaman Air, Tasik Diperkayakan Secara Organik

Abstract: The composition and abundance of chironomid larval communities was studied on artificial substrates in Lido Lake, located in Bogor, West Java, Indonesia. The lake is organically enriched as a result of fish farming activity. Seventy two artificial substrates were deployed at three depths (2.0, 3.5 and 5.0 m) at two sites: a cage culture site and a non-cage culture site (control). Larval chironomid larvae were collected 7, 14, 28 and 56 days after the artificial substrates were deployed. In addition, selected physical and chemical parameters of the water were simultaneously measured. Three chironomid subfamilies, the Chironominae, Tanypodinae and Orthocladiinae, were found at both sites. At the cage culture site, both diversity and total abundance were significantly higher at the 2.0 and 3.5 m depths than at the 5.0 m depth, but this was not the case at the non-cage culture site. Based on pooling of the data from all depths, a Mann-Whitney U test showed that the non-cage culture site had a significantly higher diversity and total abundance than the cage culture site. Dissolved oxygen (DO) and turbidity showed significant differences between the 2.0 m depth and the 2 greater depths at the cage culture site, whereas none

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of the environmental parameters showed significant differences among the three depths at the non-cage culture site. A comparison of the environmental parameters at the same depth at the two sites showed significant differences in turbidity, pH and DO. A Spearman rank correlation analysis at the cage culture site showed that abundance and DO were positively correlated, whereas abundance and turbidity were negatively correlated. However, only pH was negatively correlated with abundance at the non-cage culture site.

Keywords: Chironomid Larvae, Water Depth, Organically Enriched Lake

INTRODUCTION

During the larval stage, chironomids (non-biting midges) can be found in running to stagnant freshwater ecosystems as well as in saline waters (Bidwell & Gorrie 2006; Epler 2001; Bervoets *et al*. 1995). Chironomids may also be terrestrial (Delettre 2005, 2000, 1995; Frouz 1999). In aquatic environments, chironomid larvae can be found within tubes made from debris assembled with their saliva or in burrows in soft mud substrates. Chironomid larvae feed on detritus as detrivores, on algae as grazers and even on other animals as predators (Pinder 1986; McCafferty 1981; Pennak 1978).

Chironomid larvae play an important role in aquatic food chains (Zilli *et al*. 2008; Frouz *et al*. 2003). Their abundant populations are significant in aquatic food chains because larval chironomids can be a food source for larger invertebrates (Pinder 1986), fish (Kamler *et al*. 2008; Kakareko 2002; Lobinske *et al*. 2002; Batzer 1998; Pinder 1986), amphibians (Dutra & Callisto 2005) and reptiles (Novelli *et al*. 2008). Chironomid larvae generally live in organically rich waters (Arimoro *et al*. 2007), and the composition, diversity and abundance of chironomid larvae are affected by environmental conditions (Rosa *et al*. 2011; Arslan *et al*. 2010; Özkan & Çamur-Elipek 2007; Hirabayashi *et al*. 2003; Ward 1992). Organic pollution and organic enrichment affect the structure and abundance of chironomid assemblages (Cartier *et al*. 2010; Simião-Ferreira *et al*. 2009; Marques *et al*. 1999). Cortelezzi *et al*. (2011) found anatomical deformities in chironomid larvae, a sublethal effect furnishing an early warning of chemically caused environmental degradation.

Substrates are important for chironomid larvae as habitat and shelter (Halpern *et al*. 2002; Pennak 1978). The substrate type and depth can influence the abundance and composition of chironomid larvae (Fu *et al*. 2012; Luoto 2012; Nyman *et al*. 2005; Mousavi 2002; Learner *et al*. 1989). Artificial substrates can be colonised by chironomid larvae and can thus facilitate observations of larval succession (Taylor & Kovats 1995). Artificial substrates may also facilitate the collection of chironomid larvae from specific depths.

In Indonesia, only a few studies of Chironomidae have been conducted recently, *e.g.,* Kikuchi and Sasa (1990). The aim of the current study was to reveal the composition and abundance of larval chironomid communities on artificial substrates at three different water depths in an organically enriched site and in a non-organically enriched site. The research tested the hypothesis that organic enrichment would affect the diversity and abundance of larval

chironomids. The study highlighted the environmental factors affecting the distribution of the chironomids in terms of depth and organic enrichment.

MATERIALS AND METHODS

Study Area

The study was conducted in Lido Lake, a natural lake located at 106° 48' 26" – 106° 48' 50" E, 6° 44' 30" – 6° 44' 58" S, in Bogor, West Java Province, Indonesia. The sources of the lake's water are ground water, a small stream southwest of the lake and runoff from the area surrounding the lake. Lido Lake is approximately 506 m above mean sea level (MSL). The lake is 767 m long and 429 m wide at its widest point, with maximum and average depths of 18 and 9.71 m, respectively. It covers a total surface area of 198750 m^2 and has a storage capacity of 1930028.76 m^3 of water. Hotel and paddy field activities in the surrounding area might influence the lake via runoff.

Fish are cultured in net cages near the outlet of the lake. The fish are given artificial food (pellets). As a result, the surrounding water is enriched with organic matter from uneaten pellets and fish faeces. Samples were taken from artificial substrates deployed at two sites: a cage culture site with a water depth of 7 m and a non-cage culture site near the inlet of the lake with a water depth of 6 m (Fig. 1).

Artificial Substrate Arrangement

The artificial substrates were constructed of mosquito netting (1 mm mesh) attached to a 30 x 30 cm wire frame. Three replicates were placed at each depth. At each site, artificial substrates were deployed at water depths of 2.0, 3.5 and 5.0 m. Each arrangement of artificial substrates was then provided with buoys and fastened to the buoys to secure its position (Fig. 2). Seventy two artificial substrates were deployed at each depth at the two sampling sites to allow sampling four times in sequence. The substrates were deployed at the same time to allow colonisation by chironomid larvae.

Sampling Procedures

Chironomid larvae were sampled from June 2009 to August 2009. Samples of chironomid larvae were collected 7, 14, 28 and 56 days after the 72 artificial substrates were deployed. Substrates were collected from each depth at scheduled intervals, i.e., 3 replicate substrates were collected after 7 days of deployment, another 3 replicates were collected after 14 days of deployment, and the same pattern was followed until the end of the experiment at 56 days. Chironomid larvae were collected by brushing each 30 x 30 cm artificial substrate with a paintbrush with half of the bristles trimmed. The samples were fixed in 10% formalin and labelled. Rose Bengal solution (CV Mulia Jaya, Bogor, Indonesia) was added to stain the samples. Chironomid larvae were sorted from the debris using a stereo microscope (Olympus SZ6045TR, PT Fajar Mas Murni, Jakarta). Each chironomid larva was then soaked in 10% KOH (CV Mulia Jaya, Bogor, Indonesia) and mounted in CMCP-10 (Polyscience Inc., Washington,

USA). The collected larvae were identified to the genus level with the help of standard identification manuals (Epler 2001). Several environmental parameters were also measured simultaneously with larval chironomid sampling at the three sampling depths: turbidity, temperature, total suspended solid (TSS), total dissolved solid (TDS), pH, dissolved oxygen (DO) and biochemical oxygen demand (BOD). These parameters were determined in accordance with standard methods (Eaton *et al*. 1995).

Data Analysis

Two types of nonparametric tests were applied. Differences in the abundance and diversity and in selected environmental parameters as a function of depth and sampling site were tested with a Mann-Whitney U test. A Spearman rank correlation test was performed to identify environmental parameters that were correlated with the abundance of larval chironomids at the two sampling sites. The correlation analysis did not consider depth variation (Fowler & Cohen 1990).

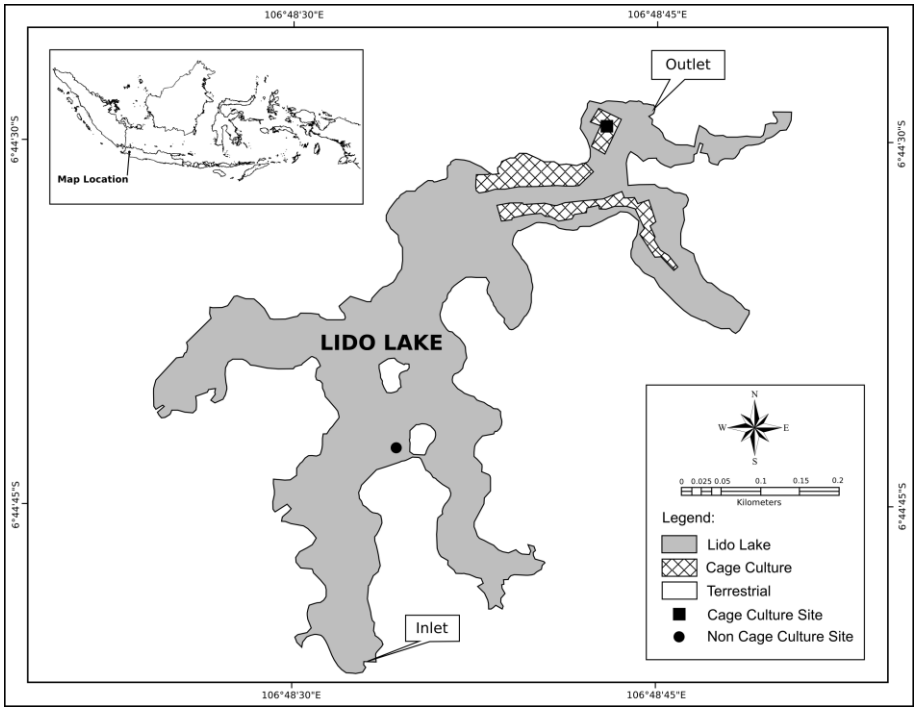

Figure 1: Research location at Lido Lake, West Java Province, Indonesia. Black square and circle indicate the two sites at which artificial substrates were deployed.

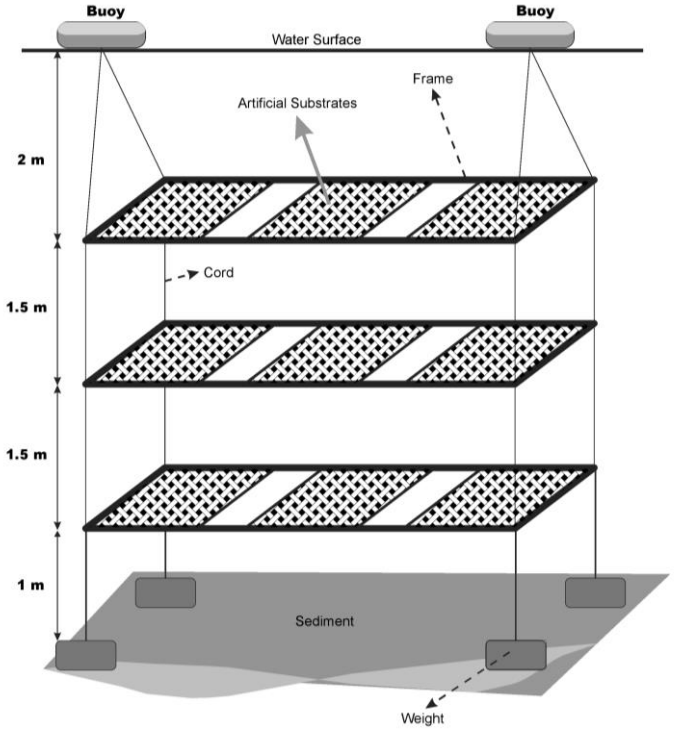

Figure 2: Arrangement of artificial substrates at each site for larval chironomid collection.

RESULTS

The chironomid larvae found at the cage culture site consisted of two subfamilies, Chironominae (six genera: *Chironomus*, *Dicrotendipes*, *Kiefferulus*, *Polypedilum*, *Paratanytarsus* and *Rheotanytarsus*) and Tanypodinae (three genera: *Ablabesmyia*, *Pentaneura* and *Procladius*). The chironomid larvae found at the non-cage culture site consisted of three subfamilies, Chironominae (eight genera: *Chironomus*, *Dicrotendipes*, *Kiefferulus*, *Paratanytarsus*, *Polypedilum*, *Pseudochironomus*, *Micropsectra* and *Rheotanytarsus*), Tanypodinae (three genera: *Ablabesmyia*, *Pentaneura* and *Procladius*) and Orthocladiinae (one genus: *Nanocladius*).

In general, fewer genera were found at the cage culture site than at the non-cage culture site. Only 9 genera were found at the cage culture site, whereas 12 genera were found at the non-cage culture site. The number of genera found was related to the depth of the substrate. At the cage culture site, 8, 6 and 4 genera were found at the 2.0, 3.5 and 5.0 m sampling depths, respectively, whereas 9, 7 and 10 genera were found at the 2.0, 3.5 and 5.0 m sampling depths, respectively, at the non-cage culture site (see Table 1). At the culture site, the diversity of larval chironomids at the 2.0 m depth was significantly higher

than the diversity at the 3.5 and 5.0 m depths (see Table 2 and Fig. 3). However, the diversity did not differ between the 3.5 and 5.0 m depths at the culture site. At the non-cage culture site, the diversity did not differ significantly among the three depths. When all depths were pooled, a Mann-Whitney U test showed that the diversity at the non-cage culture site was significantly higher than that at the cage culture site ($p<0.05$; 2-tailed test).

Dicrotendipes and *Kiefferulus* appeared to be the dominant species at 2.0 and 3.5 m at both sites. *Pseudochironomus*, *Micropsectra* and *Nanocladius* occurred only at the non-cage culture site. In addition, several genera, e.g., *Pseudochironomus, Micropsectra*, *Procladius* and *Nanocladius,* occurred only at greater depths. As in the case of diversity, the mean total abundance at 2 m was significantly greater than that at 3.5 and 5.0 m at the cage culture site, but the total abundance of larval chironomids at 3.5 m did not differ significantly from that at 5.0 m. At the non-cage culture site, the mean total abundance at 2.0, 3.5 and 5.0 m did not differ significantly (see Table 2), although the mean total abundance was greater after 14, 28 and 56 days (Fig. 4). A comparison between the two sites based on pooled data with a Mann-Whitney U test showed that the mean total abundance at the non-cage culture site was significantly greater than that at the cage culture site ($p<0.05$; 2-tailed test).

The values of several environmental parameters decreased with depth (Table 3). Such decreases were especially marked for DO and BOD. Turbidity, TSS and TDS tended to increase slightly with depth. Temperature and pH showed slight variations. A Mann-Whitney U test (Table 2) showed that turbidity and DO at 2.0 m were significantly greater than at 3.5 and 5.0 m at the cage culture site. Only DO differed significantly between 3.5 and 5.0 m. No environmental parameters differed significantly among the three depths at the non-cage culture site.

A between-site comparison of the environmental parameters at the same depth could indicate the effect of cage culture on the larval chironomid habitat. BOD at the cage culture site was greater than that at the non-cage culture site (Table 3) but this difference was not statistically significant. The cage culture activities appeared to influence turbidity at 2.0 and 5.0 m, pH at the 3 depths and DO at 3.5 and 5.0 m.

A Spearman rank correlation analysis of the relationship between the total abundance and environmental parameters showed a positive correlation between abundance and DO at the cage culture site ($p<0.01$, $r = +0.719$), whereas abundance and turbidity were negatively correlated ($p<0.01$, $r = –0.846$). At the non-cage culture site, only pH was negatively correlated with abundance ($p<0.05$, $r = –0.699$).

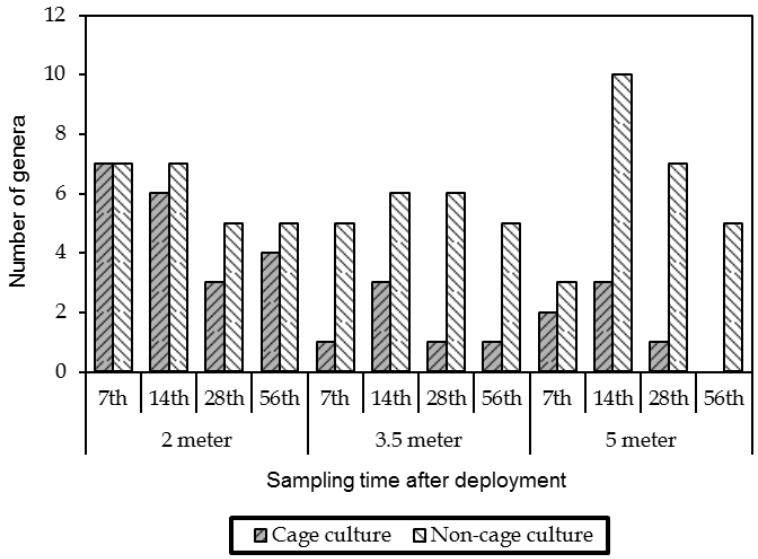

Figure 3: Diversity of larval chironomids at the two sampling sites at each sampling time.

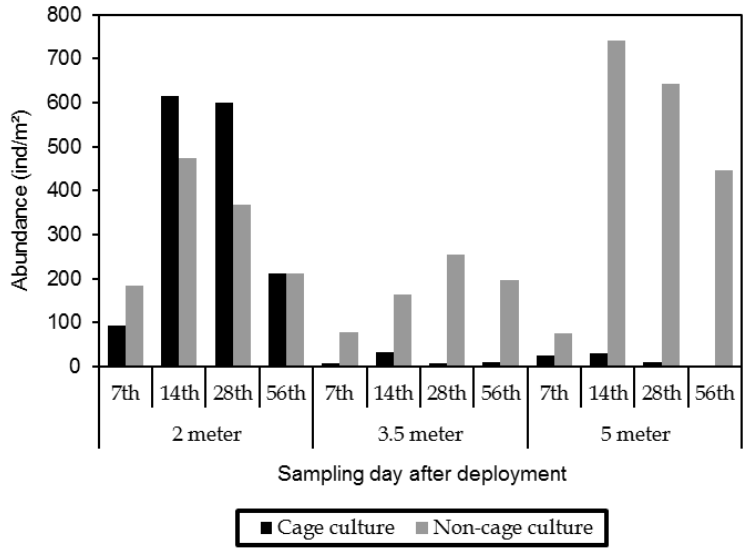

Figure 4: Mean total abundance (individuals per m^2) of larval chironomids at the two sampling sites at each sampling time.

Table 1: Chironomid larvae found at the study sites and their mean abundance (individuals per m^2).

Species	Cage culture site												Non-cage culture site											
	Depth 2.0 m				Depth 3.5 m				Depth 5.0 m				Depth 2.0 m				Depth 3.5 m				Depth 5.0 m			
	7^{th} day	14^{th} day	28^{th} day	56^{th} day	7^{th} day	14^{th} day	28^{th} day	56^{th} day	7^{th} day	14^{th} day	28^{th} day	56^{th} day	7^{th} day	14^{th} day	28^{th} day	56^{th} day	7^{th} day	14^{th} day	28^{th} day	56^{th} day	7^{th} day	14^{th} day	28^{th} day	56^{th} day
Subfamily Chironominae																								
Chironomus	4	15	–	–	7	–	–	–	19	4	11	–	7	41	–	–	11	41	4	7	41	304	4	7
Dicrotendipes	11	300	285	137	–	4	–	–	–	–	–	–	15	78	230	119	7	4	133	122	–	4	22	15
Kiefferulus	22	219	281	48	–	22	–	11	–	22	–	–	48	26	63	48	37	15	78	41	19	244	544	407
Polypedilum	19	–	33	22	–	–	4	–	–	–	–	–	59	281	52	19	–	63	26	22	–	15	7	7
Paratanytarsus	–	7	–	–	–	–	–	–	–	–	–	–	–	–	19	–	–	30	7	–	–	–	–	–
Rheotanytarsus	4	–	–	–	–	–	4	–	–	–	–	–	–	4	4	–	–	–	–	–	–	–	–	–
Pseudochironomus	–	–	–	–	–	–	–	–	–	–	–	–	11	–	–	–	–	–	–	–	–	4	–	–
Micropsectra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	115	22	11
Subfamily Tanypodinae																								
Ablabesmyia	19	19	–	–	–	–	–	–	–	–	–	–	22	7	–	7	4	–	–	–	–	26	41	–
Pentaneura	15	56	–	4	–	7	–	–	7	–	–	–	22	37	–	19	19	11	7	4	15	7	–	–
Procladius	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	11	4	–
Subfamily Orthocladiinae																								
Nanocladius	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11	–	–
Total	94	616	599	211	7	33	8	11	26	30	11	0	184	430	368	212	78	164	255	196	75	741	644	447

Table 2: Statistical test results for the differences in environmental parameters and larval chironomid abundance and diversity between depths in the same site and between sites at the same depth (Mann-Whitney U test). The significance level of the test was set at $p<0.05$.

Comparison	Larval chironomid abundance	Diversity	Turbidity	TSS	TDS	pH	DO	BOD
Cage culture site								
2.0 m vs. 3.5 m	*, p=0.021	*, p=0.026	*, p=0.021	*, p=0.038	ns, p=0.772	ns, p=0.248	*, p=0.021	ns, p=0.773
2.0 m vs. 5.0 m	*, p=0.021	*, p=0.029	*, p=0.021	ns, p=0.442	ns, p=1.000	ns, p=0.248	*, p=0.021	ns, p=0.564
3.5 m vs. 5.0 m	ns, p=0.885	ns, p=1.000	ns, p=0.468	ns, p=0.110	ns, p=0.663	ns, p=0.773	*, p=0.029	ns, p=0.564
Non-cage culture site								
2.0 m vs. 3.5 m	ns, p=0.149	ns, p=0.553	ns, p=0.773	ns, p=0.773	ns, p=0.773	ns, p=0.773	ns, p=0.386	ns, p=0.248
2.0 m vs. 5.0 m	ns, p=0.286	ns, p=1.000	ns, p=0.191	ns, p=0.058	ns, p=0.564	ns, p=0.386	ns, p=0.386	ns, p=0.191
3.5 m vs. 5.0 m	ns, p=0.248	ns, p=0.766	ns, p=0.248	ns, p=0.081	ns, p=0.564	ns, p=0.386	ns, p=0.386	ns, p=0.773
Cage culture site vs. Non-cage culture site								
2.0 m	ns, p=0.773	ns, p=0.372	*, p=0.021	ns, p=0.757	ns, p=0.772	*, p=0.043	ns, p=0.059	ns, p=0.309
3.5 m	*, p=0.021	*, p=0.017	ns, p=0.149	ns, p=0.309	ns, p=0.386	*, p=0.021	*, p=0.029	ns, p=0.468
5.0 m	*, p=0.021	*, p=0.029	*, p=0.043	*, p=0.042	ns, p=1.000	*, p=0.043	*, p=0.021	ns, p=0.767

Note: * = significantly different; ns = not significantly different

Table 3: Mean value and range (in brackets) of environmental parameters at each depth at sampling sites.

Parameter	Cage culture site			Non-cage culture site		
	Depth (m)					
	2.0	3.5	5.0	2.0	3.5	5.0
Turbidity (nephelometric turbidity unit, NTU)	2.0 (1.5–2.7)	4.5 (2.9–7.4)	4.4 (3.1–5.1)	6.5 3.0–13.0	8.9 (3.7–16.0)	14.5 (5.0–28.0)
Temperature (°C)	26.6 (26.3–27.9)	26.4 (25.1–27.6)	25.8 (24.8–27.4)	26.9 (25.6–27.9)	26.4 (25.6–27.1)	26.0 (25.3–26.8)
TSS (mg/l)	9 (8–12)	19 (10–34)	9 (4–18)	11 (2–22)	12 (4–24)	45 (12–116)
TDS (mg/l)	170.5 (130–244)	150.5 (108–172)	148.0 (104–174)	144.0 (98–176)	137.0 (104–164)	151.0 (110–186)
pH	6.75 (6.45–7.06)	6.42 (6.20–6.69)	6.50 (6.16–6.80)	7.18 (6.97–7.30)	7.15 (6.93–7.32)	7.05 (6.76–7.43)
DO (mg/l)	4.510 (2.74–6.31)	2.150 (1.69–2.73)	0.879 (0.00–1.69)	6.960 (4.85–8.47)	6.020 (2.73–7.9)	5.870 (5.04–6.96)
BOD (mg/l)	2.47 (1.27–4.99)	1.45 (0.49–3.09)	1.66 (0.25–3.20)	1.86 (0.75–3.97)	1.36 (0.37–3.98)	1.02 (0.00–2.90)

DISCUSSION

Chironomid larvae are common, abundant and important organisms in benthic communities (Seminara & Bazzanti 1988). They are a dominant group of insects, representing more than 50% of the density of the macrobenthos (Verneaux & Aleya 1998). Dipterans are also known to represent pioneer taxa, with many chironomid larvae (78% of all species) recorded during early succession in the aquatic macroinvertebrate communities of a newly created shallow lake in a wetland area (Cañedo-Argüelles & Rieradevall 2011). Only 3 of 11 subfamilies found worldwide (Epler 2001; Armitage *et al*. 1994) were found in the current study. These three subfamilies commonly occur in lentic ecosystems and in aquatic environments affected by fish farms (see Dascălu *et al*. 2009; Takahashi *et al*. 2008).

Chironomus, *Dicrotendipes*, *Kiefferulus* and *Polypedilum* were the most abundant genera found in this study. In the fish farm area of the Izvoru Muntelui-Bicaz Reservoir, *Procladius* sp., *Polypedilum nubeculosum* and *Micropsectra* sp. were the most abundant species of chironomid larvae (Freimuth & Bass 1994). In addition, *Chironomus*, *Goeldichironomus* and *Polypedilum* were commonly found at high densities in environments with highly organic sediments (Leal *et al*. 2004; Callisto *et al*. 2001; Callisto & Esteves 1998; Freimuth & Bass 1994), whereas many other chironomid genera were not recorded (Callisto *et al*. 2001). In the current study, a greater abundance of larval chironomids was found at the non-cage culture site, where organic material was less abundant. This difference in abundance may be related to the values of the other environmental parameters.

Several studies have shown that physical and chemical factors strongly influence the composition and abundance of chironomids (Botts 1997; Callisto 1997; Kikuchi & Sasa 1990; Oliver 1971). The diversity and abundance of the larval chironomids at the cage culture site tended to decrease with depth. However, the opposite trends occurred at the non-cage culture site, where the greatest number of genera and greatest abundance were found at 5.0 m. Water

depth has been shown to be an important regulator of the distribution of aquatic insects and to be negatively correlated with larval chironomid abundance (Zhang *et al*. 2012, 2011a; Smiljkov & Slavevska-Stamenkovic 2006; Nyman *et al*. 2005; Mousavi 2002; Porinchu *et al*. 2002; Quinlan *et al*. 1998; Olander *et al*. 1997; Learner *et al*. 1989). The sites selected for the current study were chosen to contrast a site with organically rich waters (the cage culture site) with a site with waters that were (relatively) organically poor (the non-cage culture site). The cage culture site was enriched with organic matter from uneaten food pellets and fish faeces. It was also located relatively near the outlet of the lake, where all organic matter entering the lake (via the inlet or runoff) could be concentrated; therefore, it could have a relatively higher organic content than the non-cage culture site at the inlet. This difference was verified by the finding that the BOD at the cage culture site was greater than that at the non-cage culture site, although the difference in BOD values was not statistically significant (see Tables 2 and 3). Several studies of larval chironomids have shown that organic matter (in the form of dissolved organic carbon, total organic carbon or particulate organic carbon) does not have a substantial influence on the distribution of the larvae (Porinchu *et al*. 2002; Larocque *et al*. 2001; Olander *et al*. 1997; Walker *et al*. 1991). In Swiss lakes, however, a relationship could be demonstrated between dissolved organic carbon and the distribution of larval chironomids, although the dissolved organic carbon alone did not explain a high proportion of the variance in the species data (Lotter *et al*. 1997). Larocque *et al*. (2006) and Bigler *et al*. (2006) have found that the greatest proportion of the variance in chironomid assemblages was explained by the dissolved organic carbon content of the lake water.

It was shown above that water depth may influence the distribution of chironomid larvae, and a previous study has found that the larvae can live at depths of 3 and 5 m (Eggermont *et al*. 2008) or even at greater depths (Luoto 2012). In the current study, the chironomid larvae at the cage culture site were significantly more abundant at a depth of 2.0 m than at 3.5 and 5 m. The abundance of chironomid larvae at 3.5 and 5 m at the non-cage culture site was significantly greater than that at the cage culture site.

As shown above, the cage culture site was impacted by fish farming and had greater average values of BOD, turbidity and TSS at certain depths but lower values of DO at 3.5 and 5.0 m. Moreover, the larval chironomid abundance and diversity at the cage culture site was significantly lower than that at the non-cage culture site. The occurrence of low species richness in organically polluted waters has been reported by Filik-İşcen *et al*. (2008).

Fish farming in an aquatic ecosystem creates problems caused by waste in the water column and in the vicinity of the net cages and by organic particles that are deposited on the sediment under the net cages. The waste and organic particles are present because the cultured fish consume large amounts of food and introduce large amounts of waste outside the net cages. The waste takes the form of uneaten food and faeces (Degefu *et al*. 2011; Pawar *et al*. 2001; Wu 1995; Bergheim *et al*. 1991; Growen *et al*. 1991). In addition, organically enriched conditions result in bacterial decomposition and in respiration by phytoplankton. Moreover, the fish in the cages consume DO and produce an oxygen deficiency

in the environment of the fish farm (Degefu *et al*. 2011; Beveridge 2004). Additionally, the uneaten pellets may increase the total amount of suspended solids. As a result, the turbidity would also increase (Degefu *et al*. 2011; Zang *et al*. 2011b). Low levels of DO in aquatic environments as a result of fish farming waste have also been noted by several authors (Degefu *et al*. 2011; Zang *et al*. 2011b; Zachritz *et al*. 2008) thus, DO appears to be the factor responsible for the distribution pattern of chironomid larvae in the study area. A few studies have shown that chironomid larvae occur in environments with low oxygen concentrations (e.g., Callisto *et al*. 2002) due to the ability of the larvae to switch to anaerobic metabolism under these nearly anoxic conditions (Nagell & Landahl 1978; Augenfeld & Neess 1961). However, many more studies have shown that chironomid larvae prefer high oxygen concentrations. The larvae will reach their optimum abundance under such conditions (Özkan *et al*. 2010; Takahashi *et al*. 2008; Santos & Henry 2001). The preference of chironomid larvae for high oxygen concentrations is indicated by their biological ability to increase the oxygen concentration by pumping water, creating irrigation if the DO level is low (Roskosch *et al*. 2012; Gingras *et al*. 2007; Leuchs 1986; Walshe 1950).

Interestingly, the correlation analyses also showed that the abundance of chironomid larvae was positively correlated with DO at the cage culture site, whereas the correlation between larval abundance and turbidity was negative. These findings underscore the impact of fish farming on larval chironomids. At the non-cage culture site, only pH was negatively correlated with larval abundance. The higher pH value at the non-cage culture site might be related to the higher level of DO produced by the photosynthetic activity of the phytoplankton. Because this activity would cause the absorption of CO_2, it might increase the pH value. At the cage culture site, the activity of phytoplankton might be lower due to the higher turbidity.

The present study shows that the cage culture in the study area affected the values of certain environmental parameters, i.e., caused increased organic matter (BOD), turbidity and TSS and decreased DO. Accordingly, the degradation of the environment caused by the cage culture would influence the diversity and abundance of larval chironomids.

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