An Updated Taxonomic Account of Limnetic Crustacean Zooplankton in Lake Taal, Philippines

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Limnetic crustacean zooplankton are the preferred prey of the economically important and endemic zooplanktivore Sardinella tawilis (Clupeidae) of Lake Taal. In this paper, we update the species composition, morphology and distribution of limnetic crustacean zooplankton in Lake Taal based on samples collected from 2008 through 2010. A total of nine species belonging to Copepoda (3 spp.) and Cladocera (6 spp.) have been documented including Arctodiaptomus dorsalis, a Neotropical species and Pseudodiaptomus brehmi, which was previously thought to be restricted to Lake Naujan, Mindoro Is. Information on these relatively understudied taxa is an important contribution to the on-going re-assessment of Lake Taal biodiversity in the light of aquaculture and eutrophication impacts, as well as the presence of introduced species.

Key Words: Crustacean Zooplankton, Freshwater, Southeast Asia, Systematics, Tropical caldera lakes,

INTRODUCTION

Studies on Philippine zooplankton were formally started by the description of Trochosphaera aequatorialis in 1872 based on samples collected from a rice field in Mindanao Island in southern Philippines (De Elera 1895; Mamaril Sr. & Fernando 1978; Petersen & Carlos 1984). This was followed by the first accounts of zooplankton species richness during the Wallacea expedition (Brehm 1938; Brehm 1942; Hauer 1941; Kiefer 1930; Kiefer 1939a; Kiefer 1939b; Woltereck et al. 1941). This likewise included surveys of lakes such as Laguna de Bay, Taal, Balinsasayao, Buhi, Calibato, Danao, Lanao, Mainit, and Naujan. Measurements on some basic physico-chemical and morphological characteristics of the aforementioned lakes were also carried out. New species of crustacean zooplankton such as Alona pseudoanodonta Brehm, Diaptomus insulanus Wright and its synonym D. sensibilis Kiefer, D. vexillifer Brehm, Mesocyclops hyalinus Kiefer, Pseudodiaptomus brehmi Kiefer, Tropodiaptomus gigantoviger Brehm, T. prasinus Brehm, and Thermocyclops woltzerecki Kiefer have been described based on the samples collected from the expedition. New records have also been established for many cladoceran species.

The most comprehensive publication on Philippine freshwater zooplankton systematics reported 125 zooplankton species including 49 cladocerans and nine copepods collected from the littoral and limnetic zones of lakes and reservoirs as well as smaller water bodies in the Philippines (Mamaril Sr. & Fernando 1978). This together with two more papers by Mamaril Sr. (1986; 2001) became the most utilized references on Philippine freshwater zooplankton. At present, a website maintained by F. Petersen of Denmark also serves as an invaluable on-line reference for those who want to study Philippine freshwater zooplankton taxonomy (Petersen 2009). Other significant studies on Philippine freshwater zooplankton
were done by Cheng & Clemente (1954); Ueno (1966), Lewis (1979); Lai et al. (1979); Petersen & Carlos (1984); Tuyor & Segers (1999); Tuyor & Baay (2001); WALTER et al. (2006); Aquino et al. (2008); Lazo et al. (2009); and Papa et al. (Papa & Zafaralla 2011; PAPA et al. 2011; Papa et al. 2012). They have either discussed taxonomic revisions, new records or ecological aspects.

Lake Taal (13°55'-14°05'N, 120°55'-121°105'E; Altitude: 2.5 masl) has long caught the attention of scientists for its unique geological origin, geographical location and limnological characteristics. The lake is a 236.9 km² caldera with 90.4 m mean and 198 m maximum depths, respectively. It was formed after a series of volcanic explosions separated the lake from the rest of the South China Sea (Ramos 2002) with a shallow north and a deeper south basin partially separated by an active volcano island in the middle. Since 1975, fish cage aquaculture has proliferated in the north basin which has begun to take its toll on water quality (Aypa et al. 2008). The decline in ecosystem health due to this has prompted renewed interest in assessing the lake’s biodiversity (Tvpl-Pamb 2009). As an important component of freshwater ecosystems, zooplankton diversity needs to be updated to keep up with the recent developments in Systematics. The zooplankton composition of Lake Taal was first studied during the Wallacea expedition (Woltereck et al. 1941) which was later updated by Ueno (1966) and Mamaril Sr. (2001). A report on the limnological status of Lake Taal also presented some data on zooplankton species composition during the late 1980s (Zafaralla et al. 1992; Zafaralla et al. 1989). This paper updates the crustacean zooplankton species richness in Lake Taal using specimens collected during limnetic plankton surveys from 2008 to 2010. We describe key morphological features by examining collected samples using a combination of light and scanning electron microscopy. We also included observations on their abundance and distribution.

MATERIALS AND METHODS

Plankton were collected from six sites in Lake Taal by making replicate vertical tows from a depth of 40 m using an 80 µm mesh size conical plankton net (diameter = 30 cm). Samplings were held monthly in 2008, four times in 2009 (May, June, August, and November) and twice in 2010 (April). Samples were fixed in 5 % formalin with Rose Bengal dye. Density was determined for each species by taking average counts of three 1 mL Sedgwick Rafter sub samples per replicate. Specimens were sorted and dissected on slides with glycerine. These were examined using an Olympus CX21 compound microscope and drawn with the aid of an Olympus U-DA drawing attachment. All measurements were made using a calibrated ocular micrometer and presented in millimetre(s). Representative individuals from the copepod were dehydrated in ethanol series, critical point dried in a BALTEC CPD 030, fixed on SEM aluminum stubs, sputter coated with 5 nm Au/Pd in a BALTEC SCD 030 and viewed in a Philips SEM 505. Pictures were taken with a DISS (Digital Image Scanning System) from Point Electronics. Body and appendage terminology was based on Dussart and Defaye (2001) and Korinek (2002). Specimens (sorted or otherwise) are deposited in the Zooplankton Reference Collection of the University of Santo Tomas.
RESULTS

Class Maxillopoda
Order Cyclopoidea
Family Cyclopidae

*Thermocyclops crassus* (Fischer, 1853)

This is the type species for the genus *Thermocyclops*. Of the more than 50 recognized species under this genus, only *T. crassus* has a cosmopolitan distribution. Though several studies have pointed out the presence of at least two cyclopoid species in Lake Taal, our collections have only yielded this species, at least for the limnetic zone. Female *T. crassus* has a hammer-shaped seminal receptacle with a short and wide sac-like handle. It may be distinguished from the morphologically similar *T. decipiens* by its straight spine in the inner distal segment of the P4 endopod, as well as the presence of hairs instead of spinules on the medial margin of the P4 basipodite (Alekseev 2002; Dussart & Defaye 2001). The female P5 has an apical seta and a setiform spine inserted apically (Fig. 2B). Previous studies on Lake Taal zooplankton have listed *T. crassus* as *T. hyalinus* (Kiefer 1930; Woltereck et al. 1941). At present, *T. crassus* dominated the two other copepod species in Lake Taal and is also common to other sampling localities in the Philippines. Mean lengths of *T. crassus* was 0.49 mm for males and 0.58 mm for females. Specimens of adult, copepodite and nauplii *T. crassus* were observed from samples collected throughout the year.

Order Calanoida
Family Diaptomidae

*Arctodiaptomus dorsalis* (Marsh, 1907)

*A. dorsalis* is the largest copepod species in Lake Taal with average length of 0.97 mm for females and 0.82 mm for males. One key characteristic of female *A. dorsalis* is

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Figure 3. Scanning electron micrographs of selected morphological characters of male (A & B) and female (C & D) *Arctodiaptomus dorsalis*. A) Terminal segment of right antennule B) Exopod of fifth leg (P5) C) Right leg (P5) D) Endopod of P5.
that its P5 has an endopod that is nearly as long as the exopodite 1 (Fig. 3C & D) while for males, the P5 has a lateral spine inserted proximal to the middle of the right of exopodite 2 where the said spine is longer than the exopodite 2 (Fig. 3B).

The Wallacea papers did not mention any calanoid copepods in Lake Taal. The occurrence of a calanoid initially identified as \textit{Tropodiaptomus vicinus} (Zafaralla et al. 1989; Zafaralla 1992 cf Mamaril Sr. 2001) was reported in Lake Taal and later mentioned in Amarasinghe et al. (2008), Vijverberg et al. (2008) and Papa and Zafaralla (2011). However, a more detailed examination of specimens collected from 2008 to 2010 revealed that the diaptomid copepods in Lake Taal were \textit{A. dorsalis} and not \textit{T. vicinus}. This was also mentioned by PAPA et al. (2012) in their report on the invasion of \textit{A. dorsalis} which they found in 18 of 27 lakes throughout the archipelago.

Similar to \textit{T. crassus}, adults, copepodites and nauplii of \textit{A. dorsalis} were also observed all year round in Lake Taal. The adults were not as abundant as those of \textit{T. crassus} as calanoid copepods are known to be less numerous than cyclopoids in eutrophic lakes.

**Family Pseudodiaptomidae**

\textit{Pseudodiaptomus brehmi} Kiefer, 1939

\textit{Pseudodiaptomus} is classified as a highly diversified demersal marine genus in the Indo-Pacific region with 77 species, 14 of which are recorded from coastal environments in the Philippines (Walter et al. 2006). \textit{P. brehmi} was first described by Kiefer in 1939 based on samples collected from Lake Naujan (Mindoro Is., Philippines). At present, \textit{P. brehmi} is listed as a marine species (Walter 2009) and until this study, no record of \textit{P.
brachii in another freshwater environment exists. Petersen has previously classified it as endemic to Lake Naujan (Petersen 2009). Further studies have to be undertaken to ascertain its distribution. Female specimens are characterized by the absence of spines in the first urosome segment (Fig. 4B) while the male P5 has no medial pointed process in its left Re1. Specimens from Lake Taal are rare even for samples collected from deeper locations for almost the entire sampling period except for those collected in April 2010 when they were fairly common.

Class Branchiopoda
Order Cladocera
Family Bosminidae
Bosmina fatalis Burkhhardt 1924

This species is common in lakes and reservoirs in East (including far eastern Russia) and Southeast Asia. In the Philippines, it has been reported from Luzon Is. including La Mesa reservoir and Laguna de Bay and in Mindanao Is. in Lakes Lanao (Mamaril Sr. 1986) and Sebu (Papa unpublished). Bosmina spp., (B. fatalis and B. longirostris) were first reported from Lake Taal in 2001 (Mamaril Sr. 2001). Another study only found B. fatalis in this lake (Vijverberg et al. 2008). Research on the prey preference of S. tawilis from 2004 to 2005 showed that Bosmina spp. features prominently in its diet during the northeast monsoon coinciding with a drop in copepod abundance (Papa et al. 2008). B. fatalis is known for its rounded carapace with a long rostrum with a pair of fixed antennules of variable length and shape curving ventrally. Lake Taal specimens had mean lengths of 0.39 mm. Monthly plankton surveys in 2008 revealed that B. fatalis was second to Ceriodaphnia cornuta in terms of abundance and were present throughout the entire year with highest densities in January.

Family Moinidae
Moina micrura Kurz, 1874

The cosmopolitan Moina micrura is found in a variety of habitats from ponds, rice fields, reservoirs and lakes (Mamaril Sr. 1986). Species from this genus together with those from Diaphanosoma are considered as the replacement of Daphnia in the tropics and are the preyed upon by invertebrate predators (Mamaril Sr. 2001). M. micrura was first reported from Lake Taal in 1938 as M. dubia (Brehm 1938) which is now considered as its junior synonym. Known for having a large head with a well-developed supraocular depression, it can be differentiated from other members of this genus by the absence of hairs on the ventral surface of its head (Korinek 2002). In terms of body size, M. micrura would be the second largest cladoceran genus in the lake at 0.56 mm total length. M. micrura were commonly encountered from the samples collected in Lake Taal though never as abundant as C. cornuta or B. fatalis.

Family Daphniidae
Ceriodaphnia cornuta Sars, 1885

This cladoceran is common to tropical and subtropical regions and is usually found in both the littoral and limnetic areas of lakes but is absent in running waters. The first recorded occurrence of C. cornuta in the Philippines was from the Wallacea papers which included Lake Taal where it was listed as C. rigaudi. It is characterized by its pointed rostrum and small head which sometimes contains a horn-like projection. The carapace is nearly circular and has a deep cervical sinus (Korinek 2002). It is a highly polymorphic species, wherein the hornless and horned forms appear depending on lake productivity and intensive predation by fish, respectively (Zaret 1972). Lake Taal specimens had average lengths of 0.38 mm. The specimens did not possess horns, which may be due to the high productivity of the lake from the excess nutrient inputs from aquaculture as well as natural nutrient sources from the volcanic sediments. Though found in the diets of S. tawilis it is not considered as a preferred prey item in spite of its high densities in the lake (PAPA et al. 2008). It was present in samples collected from all months.

Family Sididae
Diaphanosoma sarsi Richard, 1894

D. sarsi is very common to lakes and reservoirs in tropical regions except in the African continent. Philippine collection localities extend from as far north as Buguey, Cagayan in northern Philippines to Lake Lanao and Surigao City in the southern Philippines. The genus Diaphanosoma includes the largest limnetic cladocerans collected from the Philippines where together with Ceriodaphnia are considered as species replacements of Daphnia in the tropics. It is known for its small head with a sloping dorsal side where the eye occupies the entire head. The ventral margin of its valves also has a duplicature that is rounded at the distal end. The posteroventral margin of its valve has 13-40 small spines which diminish dorsally and has two thin posterior dorsal spines. Collected specimens had average lengths of 0.65 mm. D. sarsi was first reported from Lake Taal during the Wallacea expedition where until 1998, it was thought to have been the only species from this genus to be in this lake. They are usually found in low numbers where they have similar frequencies of occurrence and abundance with D. excisum.

Diaphanosoma excisum Sars, 1885

Korovchinsky (1992) and Korinek (2002) remarked that D. excisum is common in tropical and subtropical regions where they inhabit a wide range of environments from acidic, to turbid, to slightly brackish lakes. In the country,
it has only recorded from a few localities which led to the belief that it is rare in this part of the tropics. Among the major Philippine lakes, *D. excisum* has only been reported from Lake Laguna de Bay (Mamaril Sr. 2001; Mamaril Sr. & Fernando 1978). It is characterized by its large head with a well-developed dorsal part and a moderate to large eye. The ventral margin of the carapace valves has a flap that joins the margin almost at a right-angle. Samples of *D. excisum* collected from the lake had mean lengths of 0.65 mm. Similar to the other two *Diaphanosoma* spp. in Lake Taal, it occurred in low densities in 2008 with highest recorded densities at < 30 ind./l (April).

*Diaphanosoma tropicum* Korovchinsky, 1998

This species has only been recently separated from *D. modigliani*. The revision was done based on samples collected from Sri Lanka, Malaysia, Thailand, China and the Philippines. *D. modigliani* is believed to be endemic to Indonesian lakes Toba and Tempe (Korinek 2002; Korovchinsky 1998). The Philippine specimens were collected from Talisay, Batangas which is situated on the northern shores of Lake Taal. Further examination of samples collected from our survey validated the existence of *D. tropicum* in the lake. It is characterized by its large head with a protruding dorsal part and moderate to large eyes. It may be differentiated from *D. modigliani* by its strongly curved spine on the end of the upper antennal branch, long ventral valve inflexion, large and fewer denticles in the ventro-posterior valve margin, among others (Korovchinsky 1998). It is the largest of the three *Diaphanosoma* spp. in the lake at 0.67 mm mean length. *D. tropicum* were observed to occur in similar densities in the north and south basins of the lake and was least abundant of all the cladoceran species present.

**DISCUSSION**

A total of nine species (six cladocera, three copepoda) of crustacean zooplankton were recorded from Lake Taal (Fig. 1). Seven genera from seven families were represented by the following number of species: Cyclopidae (1); Diaptomidae (1); Pseudodiaptomidae (1); Bosminidae (1); Daphniidae (1); Moinidae (1); Sidae (3). The species composition of zooplankton in Lake Taal has been described as typically tropical, with low diversity for limnetic zooplankton, the absence of large cladocerans such as *Daphnia* and the existence of small-bodied species (Mamaril Sr. 2001). Predation pressure from zooplanktivores such as *Sardinella tawilis* may have led to the present size structure of limnetic zooplankton in the lake (Fernando 2002; Papa et al. 2008). The declining populations of this zooplanktivore in Lake Taal may however trigger a shift in zooplankton community structure. Furthermore, the culture of herbivorous fish such as tilapia in floating fish cages and eutrophication may in the long-term cause changes in the phytoplankton community which will later have an impact on the zooplankton community as well.

This is also the first time that scanning electron micrographs have been used in the Philippines to augment light microscopy in validating micro-characters present in selected species. SEM has been widely used by other scientists to study zooplankton micro-characters, especially minute details or complex three-dimensional structures (Dussart & Defaye 2001) such as appendages, setae and setule patterns, spine and spinule ornamentation etc. Many publications have already began to include scanning electron micrographs with traditional line drawings in the description of novel zooplankton species (Dussart & Defaye 2001; Suarez-Morales & Elias-Gutierrez 2001; Walter et al. 2006). In this study, the use of SEM was useful in validating the presence or absence of certain structures or minute details such as spinule patterns in some appendages that were otherwise more difficult to observe using conventional light microscopy. Some examples are the spinules at the terminal portion of the P5 endopod of *A. dorsalis* (Fig. 3D), the gonophore and spine ornamentation in the last thoracic segment of female *P. brehmi* (Fig. 4A & B). The utilization of SEM in systematic studies of crustacean zooplankton taxa has been very useful in verifying certain structures that were otherwise more difficult to examine in detail using conventional microscopy. Although there are still a few SEM facilities in the country, the availability of cheaper table-top SEMs that require minimal specimen preparation nowadays will probably lead to its wider utilization in verifying taxonomically important micro-characters in zooplankton in the Philippines. Future applications of this technique in identifying zooplankton from other areas will surely lead to a faster and more accurate evaluation of zooplankton biodiversity.

In spite of the cosmopolitan nature of many of the species encountered, our study yielded two interesting species for Lake Taal which may be due to the increased sampling effort put in this study compared to the past surveys and the introduction of non-indigenous species into the lake.

The presence of *Pseudodiaptomus brehmi* in Lake Taal may be considered as one of the few occasions that a Pseudodiaptomus has been recorded in a freshwater environment in the Philippines (Kiefer 1939a; Petersen & Carlos 1984). This is made more significant by the fact that they have not been found in more recent collections from the two other lakes where they have previously been recorded (Laguna de Bay and Lake Naujan). An earlier paper by the senior author has listed *P. brehmi* as a new record for Lake Taal (Papa & Zafaralla 2011). The other
interesting species found in the lake is *Arctodiaptomus dorsalis* (Marsh 1907), a Neotropical invasive species. The presence of *A. dorsalis* confirms the role of aquaculture in the introduction of non-indigenous zooplankton, as the spread of *A. dorsalis* has been linked to the presence of tilapia cage culture (Papa et al. 2012). This may also be the reason behind the introduction and spread of the Neotropical rotifer *Brachionus havanaensis* in many freshwater ecosystems (including Lake Taal) in the Philippines (Papa et al. 2011). Aquaculture in Lake Taal started as a pilot project in 1975 (Aypa et al. 2008), modelled after the success of aquaculture in nearby Lake Laguna de Bay. *A. dorsalis* was first recorded in the Philippines from Laguna de Bay in 1991 (Tuyor & Baay 2001) and since Laguna de Bay serves as the source of tilapia fingerlings that are used to stock other Philippine lakes, it could have easily dispersed *A. dorsalis* to the other lakes as well. Calanoid copepods were first recorded in the lake in August 1989 (unpublished data of Mamaril Sr. 2001). As under-regulated aquaculture practices and the introduction of alien species continue in many lakes in the archipelago, more alterations to the native limnetic zooplankton fauna may occur.

Although this paper only presents the species composition of limnetic zooplankton and does not give a complete picture of the overall biodiversity for zooplankton in Lake Taal as littoral areas were not sampled, it more or less gives a complete account for the limnetic zone based on the 18 sampling trips in six sampling sites that covered both open water and aquaculture areas in a span of two years (2008-2010). The difference in sampling strategies that has to be employed for littoral zooplankton also entails a separate analysis for this group (Matsumara-Tundisi & Tundisi 2005). It is expected that the species richness of zooplankton in Lake Taal will increase after the inclusion of littoral species, and further new records may be established given that it has been 26 years since a comprehensive listing of littoral species (Mamaril Sr. 1986) and 11 years since a review of zooplankton species diversity in Philippine lakes were published (Mamaril Sr. 2001). The littoral zooplankton community is highly diverse, and support species that are not usually found in the pelagic zone (Fernando 2002; Peters & Lodge 2010). Since these species serve as prey for many littoral fishes, including larval fish, it is likewise important to update their species composition. The impact of increasing nutrient levels in the lake can also greatly influence the community structure of the littoral zone. Given the impacts of eutrophication on the pelagic zooplankton community of Lake Taal (Papa et al. 2011), it would be equally important to document its impact on the littoral zooplankton community. It is also high time that a re-evaluation of littoral zooplankton species for Lake Taal (and the entire Philippines) be done in the light of recent alterations on the littoral zones of lakes brought about by human-mediated changes, such as the impact of aquaculture on limnetic zooplankton composition. Other smaller freshwater ecosystems must also be sampled given how deteriorated some lake ecosystems are at present as these places may reveal higher diversity compared to the limnetic zones of tropical lakes.

ACKNOWLEDGMENTS

We would like to thank R. Eckmann and J. Hentschel (University of Konstanz, Germany) for the use of the SEM; T. Chad Walter, H. Dumont, and M. Holynska for verifying our identification of *P. brehmi*, *A. dorsalis* and *T. crassus*, respectively; and Aissa Domingo for the scientific illustrations. The SEMs were taken during the DAAD Research Fellowship of the first author. The samplings were funded by the Fonoti Fund Postgraduate Fellowship of the International Society of Limnology, the Philippine Commission on Higher Education, and the UST Research Center for the Natural and Applied Sciences.

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