

First record of the invasive *Arctodiaptomus dorsalis* (Marsh, 1907) (Copepoda:Calanoida:Diaptomidae) in Lake Lanao (Mindanao Island, Philippines)

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Arctodiaptomus dorsalis, originally described to be distributed within the Americas, has been documented to occupy a significant number of freshwater lakes in the Philippines. This paper reports the first record of *A. dorsalis* in Lake Lanao, an ancient lake located in the island of Mindanao. Based on its very high abundance, and positive correlation between the total body length of females with lake dissolved nitrates, phosphates and chlorophyll a concentration, *A. dorsalis* has clearly established itself in the lake ecosystem and has benefitted in the steady increase in the lake's nutrient load. Lake Lanao's endemic *Tropodiaptomus gigantoviger* may be considered as another calanoid species to be displaced by *A. dorsalis* given that a thorough examination of plankton samples collected from Lake Lanao have not yielded individuals of *T. gigantoviger*.

Keywords: Invasive species, Copepods, Tropical Limnology, Non-Indigenous Zooplankton

INTRODUCTION

One of the ancient lakes on Earth [1], Lake Lanao (8°00'N, 123°50'E) is an oligotrophic, freshwater lake [2] located on the northwest region of Mindanao. With a recorded maximum depth of 112 m and an area of 35,600 ha, it is one of the deepest and largest lakes in the country [3]. The

lake and its surrounding watershed have been declared as a National Park and Reserve [2], and a priority area for conservation and research [4]. Lake Lanao has been the focus of studies by William Lewis, publishing data on its abiotic properties [5] and its zooplankton community [6], which was noted to be dominated by *Chaoborus* larvae. It is inhabited by at least 18 endemic cyprinid fish species [3] and *Tropodiaptomus gigantoviger*, an endemic calanoid copepod [6].

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Members of the genus *Tropodiptomus* have also been documented to be present in Laguna de Bay [7], Lake Buhi and Lake Taal [7–8] but have not been recorded from these sites in more recent studies [9]. Another endemic calanoid species, *Filipinodiptomus insulanus*, which was originally recorded from Laguna de Bay [10], Lake Danao in Leyte [11], and Lake Paoay [12] has suffered the same disappearance as that of *Tropodiptomus*. The absence of these endemic species in more current literature has been tied to the observation of *Arctodiptomus dorsalis* in lakes previously inhabited by *Tropodiptomus* and *F. insulanus* [9].

A species originally described with a range extending from the southern United States to Central America and northern South America, *A. dorsalis* was first reported in Philippine waters in 1991 (M. Directo, unpublished report to International Zooplankton Course, Ghent University, 1993). Its occurrence in Laguna de Bay, Lake Mainit, and Lake Sebu was reported in 2001 [11] and its invasion of 18 lakes in the country was published in 2012 [9]. After more than two decades, it has spread to other inland waters of the country, a situation that may eventually lead to the establishment of *A. dorsalis* in other parts of Asia [9]. Though more recent papers think this is highly unlikely [19], the threat of invasion of microscopic organisms has always been very difficult to monitor and therefore necessitates a more vigilant approach by concerned scientists and government agencies.

This paper presents the first record of *A. dorsalis* in Lake Lanao and offers an insight on how this invasive species may have taken over the lake and its probable effect on the endemic *T. gigantoviger*.

EXPERIMENTAL

Samples were collected from opposite sides of the lake (Fig. 1). Four transects were established in Marawi City in the north and three in Bayang, Lanao del Sur in the south. Collection points were set up within each transect, originating from the shoreline.

Sampling was done once a month during the inter-monsoon (May) and southwest monsoon (August to September) seasons of 2013 by vertical towing of 80 μm conical plankton net; with a mouth diameter of 234 cm. Samples were then preserved in 5% formalin. Water samples were also obtained for the determination of selected physico-chemical factors such as dissolved phosphate, nitrates, and Chlorophyll a. Water samples were brought to the MSU-IIT Chemistry Department for analyses. Other physico-chemical parameters such as water temperature, depth, and transparency were measured on site using a mercury thermometer and Secchi disk. The pH and dissolved oxygen values were determined using portable pH and D.O. meters, respectively.

Collected plankton samples were then filtered through 20 μm mesh sieves, and stained with Rose Bengal dissolved in 5% formalin in the

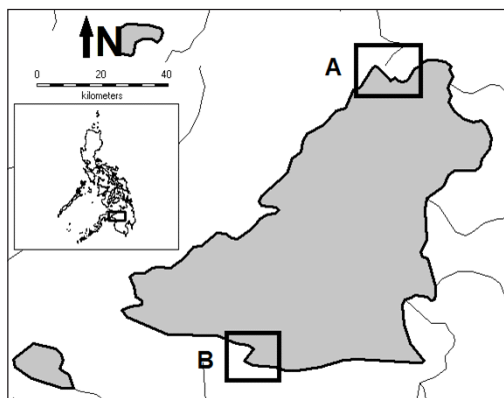


Figure 1. Map of Lake Lanao indicating the sampling sites. A – Marawi City, B – Bayang

laboratory. Samples were divided into two equal halves. One was used for identification, sorting and measuring while the other half was used for density determination [9]. The first halves of the samples were used to measure the density of the samples using a Sedgewick Rafter counting chamber. Three trials were done on each sample per month and per site. Life stages counted were the Nauplii stage, Copepodite, Adult Male, and Female. Density determination was calculated using the following equation:

$$D = TC/\pi r^2 h$$

where D is density, TC is total count, *r* is the radius of the plankton net and *h* is the distance of the tow. Of the sorted specimens, micrographs were taken and analyzed using ImageJ 1.48 (Freeware downloaded from <http://imagej.nih.gov/ij/>) to take morphometric data of adult females which were correlated against measurements of Secchi disk transparency (SDT), dissolved phosphates (DP) and nitrites (DN), and Chlorophyll a (Chla) using PAleontological STatistics (PAST) Version 3.02 (Freeware downloaded from <http://folk.uio.no/ohammer/past/>).

RESULTS AND DISCUSSION

Arctodiaptomus dorsalis was collected from all seven transects during the inter-monsoon and southwest monsoon seasons. Juveniles form the majority of the samples (Fig. 2), suggesting that reproduction is continuous [13]. As an *r*-strategist, *A. dorsalis* is capable of producing a large number of fast developing eggs, with juveniles developing quickly as well when food is not a limiting factor [14].

Statistical analyses of correlation of total length (TL) of adult females yielded a negative correlation with SDT, but positive relationships with DP, DN and Chla (Table 1). Increase in egg production has been positively correlated to an increase in TL in *Eudiaptomus dreischi* [15],

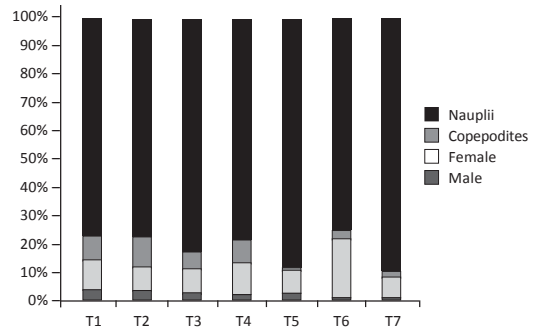


Figure 2. Relative abundance of *A. dorsalis* collected during the study from the all the seven transects

Table 1. Pearson-*r* and *P* values for correlation of female *A. dorsalis* total length (TL) with SDT, DP, DN and Chla

	<i>r</i>	<i>P</i>
Secchi Disc Transparency	-0.61756	0.13949
Dissolved Phosphorous	0.28962	0.52869
Dissolved Nitrates	0.50482	0.24788
Chlorophyll a	0.41878	0.34972

Pseudocalanus [16], and *Eurytemora affinis* [17], as well as an increase in Chla [16, 17]. These factors could provide a probable explanation on the reproductive success of *A. dorsalis* in Lake Lanao as the lake is known to have increased nutrient levels through the years due to increasing eutrophication. Throughout the sampling period, it was evident that microalgal blooms were present in the sampling sites.

The clear dominance of *A. dorsalis* over other calanoids in lakes where it has established itself [9] may have already occurred in Lake Lanao where the endemic *T. gigantoviger* was previously recorded [7, 8, 18]. If this was the case, *T. gigantoviger* will be next in the list of Philippine calanoid species to be replaced by *A. dorsalis*, together with *T. vicinus*, *Pseudodiaptomus brehmi*, *P. nostradamus*, and *Filipinodiaptomus insulanus* [9]. According to Havens & Beaver [19], *A. dorsalis* has a

tendency to fill niches vacated by other zooplankton species, especially if eutrophication and predation are taken into consideration.

The exact reason behind how *A. dorsalis* came to the Philippines is still unknown but there is a probable correlation with the spread of aquaculture, particularly, of introduced species [14]. This correlation is yet to be established in the Philippines, hence, further research should be done in the future.

In the Americas, *A. dorsalis* was documented to be expanding its range, relating *A. dorsalis*' spread to aquaculture and eutrophication [14]. Lake Lanao, with its increased anthropogenic activities, introduction of exotic species and increased concentration of organic waste [20], now has characteristics that are favorable for the establishment of *A. dorsalis*. These factors may also have led to a decrease in zooplankton diversity [20], lessening predation pressure by cyclopoids on *A. dorsalis* [21]. And with the proliferation of *A. dorsalis*, there is an increased competition for prey items with cyclopoids. Therefore, as cyclopoid populations decrease due to the lessening of their food items by calanoids, the latter increase in number because of lessening predation by cyclopoids, and the cycle goes on, giving calanoids a clear advantage.

This record of *A. dorsalis* in another Philippine lake shows the extent of invasion by this calanoid, particularly in the island of Mindanao. Increased aquaculture, eutrophication, introduction of exotic species are probable causes for the proliferation of *A. dorsalis* but further studies should be conducted to confirm this correlation. As it is, there seems to be "pockets" of invasion by *A. dorsalis* in the Philippines, which seem to be related to the degree of aquaculture intensity in the country with Laguna de Bay (southern Tagalog region), Lake Buhi (Bicol) and Lake Sebu (western

Mindanao) being centers of the invasion [9]. Other zooplankton should also be considered and how this invasion has impacted the community diversity and dynamics of the lake. The status of Lake Lanao itself should also be prioritized for future research efforts. As one of the major lakes in the country, the lake ecosystem's impact on biodiversity is as significant as its importance to the people of Lanao.

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