ARTICLE

New records of an Invasive Calanoid Copepod, *Arctodiaptomus dorsalis* (Marsh, 1907) in freshwater ecosystems in the Bicol Peninsula (Luzon Is., Philippines)

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Abstract—*Arctodiaptomus dorsalis* is a Neotropical freshwater calanoid species that is now widely distributed throughout the Philippines because of its ability to adapt well to eutrophic environments and aquaculture. A previous survey already confirmed the presence of *A. dorsalis* in three lakes in the Bicol peninsula. The primary goal of this study was to determine the extent of the occurrence of *A. dorsalis* in Bicol given its ability to displace native calanoid species. Samples were collected from 34 freshwater bodies throughout the Bicol Peninsula spanning the provinces of Camarines Norte, Camarines Sur, Sorsogon and Albay. Our results show that *A. dorsalis* is now recorded from five freshwater ecosystems in Bicol that are linked either through natural connections, aquaculture, or water system constructions. This includes man-made structures such as Lago del Rey and the Camarines Sur Water Sports Complex, and natural freshwater ecosystems such as Lake Buhi, Lake Danao and the Bicol River. Except for Lake Buhi, the other four sampling sites are new locality records for *A. dorsalis*. Translocation of fishes and passive dispersal through natural or man-made channels aided the dispersal of *A. dorsalis* in these areas. Though only 14% of the total sampling sites were positive for *A. dorsalis*, it occurred in the larger water bodies (natural and man-made lakes and large rivers) in the region including one, Lake Buhi, that previously contained native calanoid species such as *Tropodiaptomus vicinus*. Our results confirm the absence of *Tropodiaptomus vicinus* from Lake Buhi and the dominance of *A. dorsalis* in the pelagic plankton community of freshwater ecosystems. It would seem that *A. dorsalis* invasions in this area are more successful in inter-connected larger freshwater ecosystems.

Keywords—Zooplankton, copepods, non-indigenous zooplankton, biological invasion, tropical lakes

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INTRODUCTION

Arctodiaptomus dorsalis (Marsh, 1907) is a Neotropical calanoid copepod that may be differentiated from other common diaptomid calanoid copepods by the dorsal projections on the posterior thorax of adult females, where its name was derived from (Bruno et al. 2005). *A. dorsalis* is commonly found in perennial ponds, freshwater bodies, impoundments and even in subterranean waters. Aside from many cenotes (sinkhole lakes) in the Yucatan Peninsula (Morales et al. 1996), it was also found in a phreatic groundwater in a cave in Cuba (Bowman 1979) and in the Split Sink cave system in Florida (Bruno et al. 2005). The only record of *A. dorsalis* in a temporary habitat is in a seasonal flood plain pond in Missouri (Reid 2007). It was suggested that *A. dorsalis* is unable to survive under conditions of low food concentrations (Elmore 1983) despite its wide chemistry range (Cole 1961). The species has high tolerance to algal toxins as well as to high levels of eutrophication (Cole 1966). This species is believed to be highly invasive and is capable of displacing native, endemic species in water bodies where it is introduced (Reid 2007, Papa et al. 2012a). Several of its characteristics contribute to its ability to proliferate quickly. Like most diaptomids, *A. dorsalis* is a selective phytoplankton grazer; it usually prefers consuming diatoms but also occasionally consume cyanobacteria and chlorophytes. Its presence in temporary water bodies suggests that *A. dorsalis* is capable of producing resting eggs (Williams-Howze 1997). Another important factor related to its proliferation is its ability to produce a large number of small, fast-developing eggs under normal food conditions. *A. dorsalis'* nauplii and copepodites also develop faster compared to other diaptomids (Reid 2007). This shows that the species is functionally diverse and will be able to compete with native species and thrive in a wide range of inland waters where it may be accidentally introduced.

Studies on Philippine calanoids have been done since the 1920s and subsequently recorded a good number of species in the tropics (Kiefer 1928, Brehm 1930, Kiefer 1930). The Wallacea-Tressler Expedition is one of the most extensive early studies on Philippine freshwater calanoid copepods (Woltereck et al. 1941, Brehm 1942). That study led to the documentation of freshwater zooplankton (Copepoda, Cladocera and Rotifera) in Philippine lakes such as Laguna de Bay, Lake Taal, Lake Naujan, Lake Lanao and Lake Buhi. It included the discovery of novel endemic species such as *Filipinodiaptomus* (*Diaptomus*) *insulanus*, *Diaptomus vexillifer*, *Pseudodiaptomus brehmi* and *Tropodiaptomus gigantoviger* (Mamaril Sr. 2001). Four decades later in the 1970s, A. C. Mamaril conducted what is considered the most extensive survey of freshwater zooplankton, where he was able to add more locality records for many of the previously documented calanoid species (Mamaril Sr. and Fernando 1978, Lai et al. 1979, Mamaril Sr. 1986). During these early pioneering studies, most calanoid copepods that had been recorded from the Philippines only included species occurring in their natural distribution range. It was only in the paper of Tuyor and Baay (2001) where a non-indigenous zooplankton (NIZ) species was first recorded from the Philippines. They wrote the first published account of *Arctodiaptomus dorsalis* in the Philippines (and, in fact, the tropics), where it was identified from Laguna de Bay (Luzon Is.) and Lakes Mainit and Sebu (Mindanao Is.). However, the first record of *A. dorsalis* in the Philippines was in 1991 from Laguna de Bay. A group of Filipino scientists who underwent training on zooplankton identification in Belgium were able to identify *A. dorsalis* from Laguna de Bay plankton samples with the help of their facilitators (M. Directo, unpublished report, 1993). Unfortunately, no one sounded the alarm that the presence of this NIZ species may have an impact on the native zooplankton fauna of the Philippines, either by displacing previously existing calanoid copepods, or the alteration of the zooplankton community structure of lakes where no calanoid copepods had been present.

It was believed that *A. dorsalis* was introduced into Philippine waters through the dumping of drinking water reserves of transcontinental ships coming from North America. Dispersion of *A. dorsalis* was then aided by intensive aquaculture practices that saw the transfer of juvenile aquaculture species such as *Oreochromis niloticus* from major aquaculture centers such as Laguna de Bay to other lakes. The subsequent eutrophication of many Philippine lakes through irresponsible aquaculture practices (Beveridge 1984) then turned many Philippine lakes into favorable environments for the survival of *A. dorsalis*. Recent research on *A. dorsalis* showed that it was found in 18 out of 27 lakes surveyed (Papa et al. 2012a). The impact of this invasion is hard to estimate and predict, but knowledge of the abundances and distribution of NIZ species will be critical in controlling their spread (Krylov and Panov 1998, Strayer et al. 2006, May 2007). Neglect of this may result in their spreading further into other water systems all over the Philippines and cause a decline in calanoid diversity in local freshwater ecosystems.

The Bicol region is found in the southernmost part of Luzon Island with a total land area of 18,054.3 km divided into six provinces (Albay, Camarines Sur, Camarines Norte, Catanduanes, Masbate and Sorsogon). Three major lakes (Lake Buhi, Lake Bato and Lake Baao) and at least 28 other major and minor freshwater bodies are scattered across the peninsula. As the previous study by Papa et al. (2012a) pointed to the occurrence of *A. dorsalis* in three major lakes in the Bicol region, it is important to determine the extent of the invasion in this area, as well as collect samples in areas that have not yet been included in past zooplankton surveys. Since the *A. dorsalis* distribution in the Philippines appears to be clustered in areas with intense aquaculture practices in the region, we expect to find more areas in the Bicol region where *A. dorsalis* occurs, given that Lakes Buhi and Bato are heavily utilized for aquaculture.

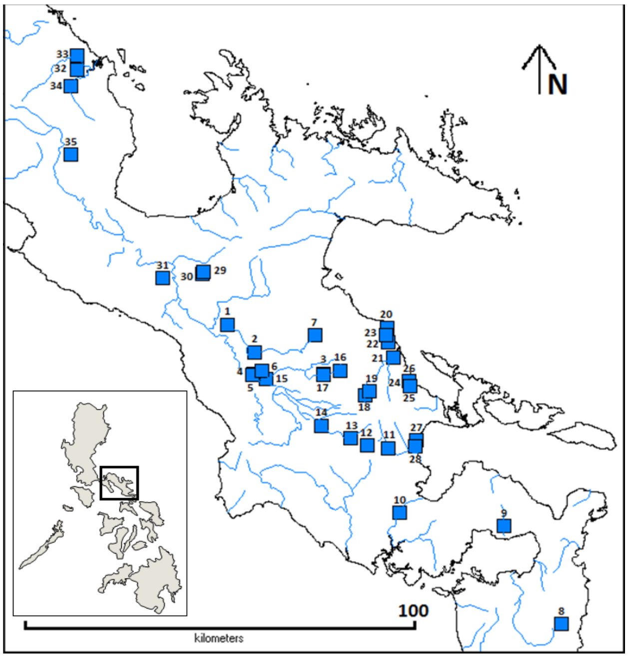

Figure 1. Map of the freshwater bodies within the Bicol Peninsula

MATERIALS AND METHODS

Sampling sites and zooplankton collection

The sampling sites include 36 freshwater ecosystems within the Bicol Peninsula (Figure 1 and Table 1). Sites were surveyed from May 17, 2013 to May 22, 2013. A transect perpendicular to the shoreline towards the middle of the lake/ river/pond basin was established. Sampling points were then assigned based on GPS coordinates. In cases of rivers, streams and other lotic water bodies, several points in equal distances across the length of the river served as sampling points. In lakes, samples were taken in the limnetic and littoral samples. Both oblique and vertical tows were used as method of haul. Plankton sampling was done by towing 50, 80 and 100 µm mesh-size plankton nets from several transects perpendicular to the lake shore (Papa and Holynska 2013). Samples were fixed with 70% EtOH and stored in the University of Santo Tomas – Zooplankton Reference Collection (UST-ZRC) separately. An Xplorer GLX water quality studies meter was used to measure surface temperature, dissolved oxygen (DO), pH and conductivity in situ during field sampling.

Materials examined

Zooplankton samples were sorted, dissected, and identified using an Olympus CX21 Compound microscope and a Swift Stereomicroscope at the University of Santo Tomas (Manila, Philippines). Samples were segregated based on their specific life stages, and densities were obtained using counts from four 1-ml Sedgewick-Rafter subsamples (Wetzel and Likens 1991).

Data analyses

Identification was aided by means of taxonomic keys, illustrations and descriptions by Mamaril Sr. and Fernando (1978), Mamaril Sr. (2001), Dussart and Defaye (2001) and Petersen (2009). Slides were deposited in the UST-ZRC with accession numbers 0069, 0070 and 0072-0078. The distribution of *A. dorsalis* was mapped using DIVA-GIS Software Version 7.5. To determine the relationship between densities, environmental variables and samplings sites, densities between sampling sites and physico-chemical parameters were log transformed and subjected to Canonical Correspondence via PAST (Paleontological Statistics) version 2.17.

RESULTS AND DISCUSSION

Arctodiaptomus dorsalis was found in five out of 34 freshwater ecosystems in the Bicol Peninsula located in the neighboring provinces of Camarines Sur and Albay. Figure 2 shows the five sampling locations where *A. dorsalis* was present (Bicol River, Lake Danao, Lake Buhi, the Camarines Sur Water Sports Complex (CWC) and Lago del Ray). Findings in all sampling sites except Lake Buhi are new records of *A. dorsalis*. Examination of the relative density values shows that *A. dorsalis* is the dominant zooplankton (79.61%) in Lago del Ray (Figure 3). The variations in the densities of *A. dorsalis* male adults and copepodites across sampling sites were strongly related to temperature, while the densities of the female adults were more related to the amount of dissolved oxygen in the water (Figure 4). Generally, as temperature increases, growth, sexual maturation and reproduction of zooplankton also increase. The freshwater bodies that have been sampled have high temperatures, since collection were done during the summer period. It showed richness in zooplankton diversity with *A. dorsalis* as the most abundant. Meanwhile samples have also confirmed the existence of all the life stages of *A. dorsalis*, which includes nauplii, copepodites, and female and male adult species present in the water. The eutrophic nature of the natural and man-made lakes sampled in the study may have provided a favorable environment for *A. dorsalis* to survive.

TABLE 1. Freshwater bodies sampled for zooplankton in this study.

USTZRC Ref. No.	Freshwater Bodies	North-South Coordinates	East-West Coordinates	Municipality
0306-0307	1. Lake Baao	13^0 28' 8.0384"	123^0 18' 36"	Baao, Cam. Sur
0308-0311	2. San Miguel Bridge	13^0 24' 6.8"	123^0 22' 28.9"	Nabua, Cam. Sur
0311-0312	3. Lake Bato (1)	13^0 20' 51.6"	123^0 22' 11.6"	Bato, Cam. Sur
0313	4. Lake Bato (2)	13^0 20' 53.6"	123^0 22' 12.2"	Bato, Cam. Sur
0314	5. Lake Bato (3)	13^0 20' 52.6"	123^0 22' 13.6"	Bato, Cam. Sur
0315	6. Masuli pond	13^0 21' 25.1"	123^0 23' 33.1"	Masuli, Cam. Sur
0316-0323	7. Lake Buhi	13^0 26' 37.6"	123^0 31 .7'	Buhi, Cam. Sur
0324-0331	8. Lake Bulusan	12^0 45' 4.2"	124^0 5' 40.5"	Sorsogon City, Sorsogon
0332-0339	9. Sorsogon Dam (Cawayan Bridge)	12^0 59' 11.4"	123^0 57' 29.8"	Sorsogon City, Sorsogon
0340-0342	10. Tapiao Bridge	13^0 01' 5.1"	123^0 42' 54.1"	Sorsogon City, Sorsogon
0343	11. Camalig Bridge	13^0 10' 21.2	123^0 40' 55.2"	Camalig, Albay
0344-0347	12. Libod Bridge	13^0 10' 46.7	123^0 38' 14.7"	Libod, Albay
0348	13. Guinobatan Bridge	13^0 11' 43.5	123^0 35' 54.7"	Guinobatan, Albay
0349	14. Brgy. Tastas	13^0 13' 34.7	123^0 31' 53"	Ligao City, Albay
0350-0352	15. Brgy. Agos	13^0 20' 16.5	123^0 24' 2.3"	Ligao City, Albay
0353-0361	16. Lake Danao	13^0 21' 29.1	123^0 34' 25.6"	Polangui, Albay
0362-0363	17. Brgy. Anopol	13^0 20' 58.6	123^0 32' 8.3"	Polangui, Albay
0364-0366	18. Isolated Pool	13^0 17' 54.2	123^0 38' 3.41"	Tiwi, Albay
0367	19. Isolated Pond	13^0 18' 29.4	123^0 38' 32.8"	Tiwi, Albay
0368	20. Malinao	13^0 27' 39.5	123^0 41' 6.5"	Malinao, Albay
0369-0371	21. Malinao Dam	13^0 23' 25.1	123^0 41' 56.2"	Malinao, Albay
0372-0373	22. Malinao Irrigation	13^0 25' 37.5	123^0 41' 16.8"	Malinao, Albay
0374-0375	23. Mestizo Bridge	13^0 26' 36.66	123^0 41.3'	Tiwi, Albay
0376-0377	24. Malilipot	13^0 20' 1.8	123^0 44' 8.8"	Tabaco, Albay
0378	25. San Isidro Bridge	13^0 20' 2.4	123^0 44' 9.8"	Tabaco, Albay
0379-0380	26. Malilipot Bridge	13^0 19' 16	123^0 44' 22.5"	Tabaco, Albay
0381-0382	27. Arimbay Bridge	13^0 11' 27.4	123^0 45' 16"	Bigaa, Legaspi City
0383	28. Rawis Bridge	13^0 10' 35"	123^0 45' 7.9"	Rawis, Albay
0404-0405	29. CWC	13^0 35' 25"	123^0 15' 9.11"	Pili, Cam. Sur
0402-0403	30. Lago del Ray	13^0 35' 40"	123^0 15' 20"	Pili, Cam. Sur
0397-0401	31. Bicol River (Stream Order #4)	13^0 34' 45.3"	123^0 9' 36.5"	Milaor, Cam. Sur
0394-0396	32. Tulay na Bato	14^0 4' 47.3"	122^0 57' 29.2"	Daet, Cam. Norte
0390-0393	33. Daet River	14^0 6' 48.4"	122^0 57' 27.2"	Daet, Cam. Norte
0388-0389	34. Pagsangahan Bridge	14^0 2' 28.8"	122^0 56' 34.4"	Basug,Cam. Norte
0386-0387	35. Sooc Dam	13^0 52' 31.1"	122^0 56' 34.9"	Sipocot, Cam. Sur
0384-0385	36. Yabo Bridge	13^0 52' 3.0"	122^0 56' 54.8"	Sipocot, Cam. Sur

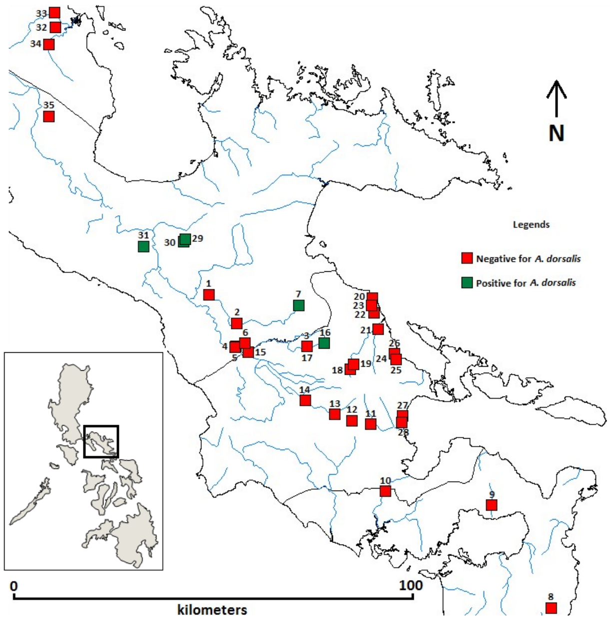

Figure 2. Distribution map of *Arctodiaptomus dorsalis* in the Bicol Peninsula.

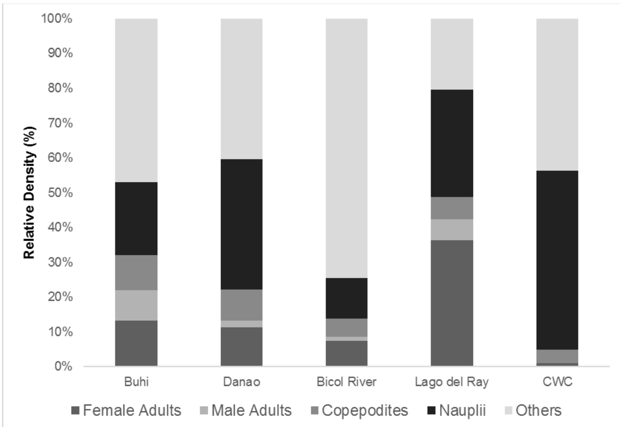

Figure 3. Relative densities of *A. dorsalis* from five freshwater ecosystems in Bicol Region.

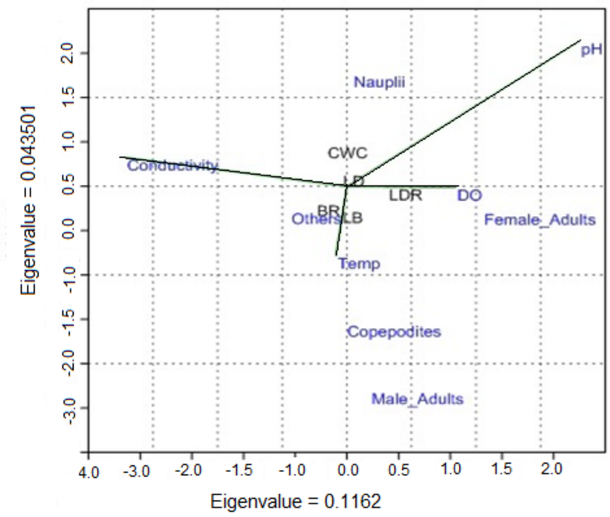

Figure 4. Association of Physico-Chemical Parameters to the abundance of the different life stages of *A. dorsalis.*

This study confirms the presence of *A. dorsalis* in Lake Buhi as was previously reported by Papa et al. (2012a). Furthermore, *A. dorsalis* was found in Bicol River which is connected to Lake Buhi. However, in contrast to the previous study, no *A. dorsalis* specimens were found from Lakes Bato and Baao. This may be due to an algal bloom (in Lake Bato) and low water level (in Lake Baao) (Irigoien et al. 2005). This might indicate that extremely unfavorable environmental conditions may force *A. dorsalis* populations to decline or disappear altogether. However, the reported ability of *A. dorsalis* to produce resting eggs may help it to re-establish viable populations once conditions become more favorable (Havel et al. 2000, Reid 2007). The samples collected for this study were collected in May, 2013 during the hot dry season, while the samples collected for the study of Papa et al. (2012a) were collected in November, 2011 during the cool dry season when algal blooms are less frequent and lake water levels are higher due to the just concluded southwest monsoon at the time.

The discovery of *A. dorsalis* in Lake Danao, a sanctuary for *Mistichthys luzonensis*, may serve as evidence that aquaculture has helped in the dispersion of this invasive copepod. The translocation of this endemic fish species from Lake Buhi (Soliman 1991) may be one of the main factors that led to the establishment of *A. dorsalis* in that lake. Furthermore, *A. dorsalis* was also identified from the CWC and Lago del Ray, which are newly-constructed man-made lakes used for aqua sports in the Bicol Region. These man-made lakes use water sourced from nearby water bodies such as the Bicol River, which is connected to other freshwater bodies with known populations of *A. dorsalis*. Plankton, especially those with high tolerance to varying physico-chemical parameters, are easily dispersed through water channels in between inland waters (Welker and Walz 1999). The absence of any other species of calanoid copepod in freshwater ecosystems of the Bicol region supports and confirms the study of Papa et al. (2012a) that *Arctodiaptomus dorsalis* is already established in the region. The only previously recorded calanoid copepod in the region was *Tropodiaptomus vicinus*, which was still not encountered from samples collected from Lake Buhi, where it was previously found (Woltereck et al. 1941). As *T. vicinus* was only previously recorded from Lake Buhi and Lake Lanao (Woltereck et al. 1941, Mamaril Sr. and Fernando 1978), this species has not been encountered in more recent collections from the said localities. Interestingly, known distribution records of *A. dorsalis* seem to show that they are established in aquaculture-intensive regions in the country, with two major clusters in southern Luzon (Laguna-Batangas-Mindoro and Bicol), one in Mindoro and another in southwestern Mindanao (Tuyor and Baay 2001, Papa et al. 2012a). This poses a threat to other native species, such as *Mongolodiaptomus birulai, Filipinodiaptomus insulanus* and *Pseudodiaptomus brehmi*, that are still observed in other freshwater systems in the country (Aquino et al. 2008, Papa and Zafaralla 2011, Papa et al. 2012b). *A. dorsalis* may have already displaced other calanoid species as well as other native zooplankton groups. This invasion may result in a shift in community dynamics and affect higher groups of animals in the food chain. Given its capacity to displace established native species, more records of *A. dorsalis* may come up as more Philippine freshwater ecosystems are surveyed for zooplankton.

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CONFLICT OF INTERESTS

The authors declare no conflict of interests.

CONTRIBUTION OF INDIVIDUAL AUTHORS

EZR, JAP, RDP wrote parts of manuscript, supervised the analyses and facilitated the sampling. DJD, JAP and RDP wrote the manuscript for publication. DLD, LJL, RDP, JAP, EZR and CBT conceptualized the initial study design, collected and identified the samples and wrote the preliminary version of this manuscript.

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