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Climate and Human-induced Changes to Lake Ecosystems: What We Can Learn From Monitoring Zooplankton Ecology

Rey Donne S. Papa[1,2,3] and Jonathan Carlo A. Briones[1,3*]

Review Paper

ABSTRACT

Long-term time-series data have been proven useful in analyzing the adaptability of zooplankton communities as a response to environmental change. The unique life history and importance of zooplankton in aquatic ecosystems, coupled with the capability of lakes to integrate changes in the surrounding watershed, has given each the recognition as "beacons and sentinels of climate change," respectively. Aside from this, many lakes have undergone pollution through human-induced eutrophication attributed to extensive lake-shore town development, agricultural waste run-offs, and intensive aquaculture. Implementation of holistic lake management plans in many countries has resulted to the rehabilitation and even reversal of lake eutrophication, and this is, in part, due to regular monitoring and careful analysis of temporal zooplankton community data that came with implemented rehabilitation efforts. As such, monitoring lake zooplankton populations may give us clues as to how changes in the environment, either from human or climate induced changes have already affected lake ecosystems. It is unfortunate however, that such analysis is presently not available in our country due to lack of routine zooplankton monitoring programs. The paper reviewed several successfully implemented lake/zooplankton monitoring programs, highlighted their strong points. The researhcers also suggest integrative feasible concepts that are applicable to the country.

Key words: *lake zooplankton, long-term monitoring*

INTRODUCTION

The Intergovernmental Panel on Climate Change and Millennium Ecosystem Assessment both recognize the threats lake and river ecosystems face today. These mainly come from global changes associated with the changing climate as well as increased anthropogenic pressures (*MEA 2005, IPCC 2007*). The changes have been studied by scientists for a number of years now. However, it was only recently that Filipinos have begun to take notice after the destructive effects of climate change-related catastrophes such as when Typhoon Ketsana (Ondoy) wreaked havoc in the Metropolis. This has caused many lake side towns of Laguna Lake to be submerged in flood waters for several months after the typhoon hit which has dispelled previous beliefs that the effects of climate change are still well into the future. Climate change has brought with it increases in water temperatures which affects the physical, chemical and biological components of aquatic ecosystems. Already, the warming oceans have caused a variety of ecological changes, such as jellyfish blooms (*Ki et al. 2008*), occurrence of warm-water coral species nearer the poles and coral bleaching (*Jones 2011*). Climate warming has a variety of impacts on lake ecosystems (*Blenckner et al. 2007*). It has also been discovered that the rate by which climate change is affecting our planet is hastened by anthropogenic influences. Our need for energy has driven the world's economies to rely on fossil fuels; while our need for food has increased the conversion of forests into agricultural lands and has depleted the ocean's fish stocks. These excesses have contributed to the changes we observe in our climate. The El Nino/Southern Oscillation climate phenomenon affects the climate across the pacific and the frequency of its occurrence has been related to climate variability. Human influences also speed up the rate of environmental decline in inland aquatic ecosystems. The increasing human population has caused lake-side towns to become overpopulated, more often than not, resulting to an increase of solid and organic wastes to be accumulated in lakes and rivers (*Schwarzenbach et al. 2010*; *Thevenon et al. 2011*; *Gomez et al. 2012*). The increased demand for cheaper sources of protein has also caused the boom in aquaculture especially in third world countries. Oftentimes, the lack of sound scientific management of aquaculture has led to increased eutrophication (*Papa et al. 2011*). Industrialization of lake-side towns has also increased the input of excessive amounts of nutrients and pollutants to lake ecosystems (*White et al. 2007*; *Zafaralla et al. 2005*). Recent studies suggest that recovery from anthropogenic eutrophication is a long process and could be altered by large-scale pressures such as climate change (*Anneville et al. 2007a*).

The role of zooplankton in studies that have led to a better understanding of the effects of climate and human-induced change on aquatic ecosystems has already been fully appreciated in other countries. Successful mitigation of eutrophication in several North American,

[1] Department of Biological Sciences, University of Sto. Tomas, España Boulevard, Sampaloc, Manila, 1008, Philippines
[2] Research Center for the Natural and Applied Sciences, University of Santo Tomas, España Boulevard, Sampaloc, Manila, 1008, Philippines
[3] Graduate School, Thomas Aquinas Research Complex, University of Santo Tomas, España Boulevard, Sampaloc, Manila, 1008, Philippines. E-mail: jonathancarlo@ymail.com (*corresponding author)

Asian, and European lakes have utilized long-term zooplankton data to chart the changes that have occurred in relation to implemented lake management strategies. Likewise, zooplankton data have been used to confirm changes in water temperature in relation to climate change. Zooplankton have been called as beacons of climate change due to their unique life histories and importance to aquatic ecosystems (*Richardson 2008*) while lakes have been called sentinels of climate change (*Adrian et al. 2009*). Therefore, lake zooplankton are beacons of sentinels of climate change. The dictionary defines beacons as devices designed to attract attention to a specific location, while a sentinel is a guard that controls security, for example in a country's borders. The role of lake zooplankton can therefore be likened to "flashlights used by guards to attract attention and warn" against the ill-effects of climate and human-induced changes to aquatic ecosystems. This underscores the need to include zooplankton for a holistic study and evaluation of the effects of environmental change on lakes.

In this paper, we review lake and zooplankton monitoring programs in Lake Constance (Germany), Lake Geneva (Switzerland), and Lake Biwa (Japan) and how these have been proven useful in analyzing the impact of climate and human-induced change to lake ecosystems. It is our hope that this leads to an increased awareness to the importance of routine zooplankton monitoring and how educational institutions, particularly those found near our more than 70 lakes nationwide (*Guerrero III 2001*), would be able to help. There are only a few Philippine lakes where limnological data are available, and fewer still are lakes where routine monitoring takes place (*Papa and Mamaril Sr. 2011*).

Lake Constance

Lake Constance is a large, deep, warm monomictic pre-alpine lake on the borders of Germany, Austria and Switzerland. It lies just north of the Alps and is 395 m above sea level (ASL). The lake has a surface area of 473 km^2 has maximum depth of 254 m and mean depth of ~90 m. The entire lake is traditionally divided into the upper and lower Lake Constance. The lake was eutrophic from 1960 to 1980 but has been brought back to an oligotrophic state up to the present time (*Thomas and Eckmann 2007*). The crustacean zooplankton includes three copepod and five cladoceran species (*Huber et al. 2011*). The Institute for Lake Research in Langenarge pioneered routine monitoring programs in the lake starting in 1952. Since 1979, the Limnological Institute of the University of Konstanz also conducts weekly sampling of physico-chemical and biological data including zooplankton in Ueberlingen where a permanent data buoy marks the said sampling site. The R/V Robert Lauterborn (**Figure 1**) anchors in the buoy and collects phyto- and zooplankton, measures Chl-a, and takes vertical profiles of temperature, dissolved oxygen, pH, conductivity etc. using a CTD Profiler. The research vessel is well-equipped for limnological analysis and has its own mini-laboratory for initial processing of samples. There are also fully automated winches to lower samplers accurately to desired depths.

Zooplankton are collected weekly (or bi-weekly in winter months) using a 140 µm Clarke-Bumpus Sampler by taking vertical hauls from 140 m depth. Aside from this routine sampling, separate collection trips are conducted in other parts of the lake to study physical, chemical and biological parameters such as fish, aquatic macrophytes, wind and ship induced wave formations, methane gas ebullition, and invasive species, among others. The excellent set of data that has been obtained on Lake Constance has allowed scientists, who have been tracking the improvements in the trophic status of the lake, to comprehensively analyze the changes that have occurred from oligotrophic to eutrophic and then back again to an oligotrophic state.

Studies such as those by *Straile and Geller* (*1998*) are perfect examples on how changes in the zooplankton community have been used to reflect changes in the trophic status. Paleolimnological evidence put the start of eutrophication in Lake Constance during the start of the 20th century. Phosphorous monitoring since 1952 recorded a 10-fold increase in the amount of P in the lake until 1979. Efforts to treat sewage effluents led to a gradual re-oligotrophication of the lake. At the same time, phyto-and zooplankton communities responded to the changes by altering its species composition and biomass. The extinction of *Heterocope borealis* and *Diaphanosoma brachyurum* happened with increasing eutrophication. At the same time, there was an invasion of *Cyclops vicinus* and *Daphnia galeata*. Species that did not become extinct during eutrophication increased their biomass by a factor of 50. A seasonal shift in the timing of peak abundance from spring to late summer happened in *Eudiaptomus gracilis* with increasing re-oligotrophication (*Seebens et al. 2007*). A temporal shift in the seasonal dynamics of *E. gracilis* had also been observed. However, this was not anymore due to shifts in the trophic status of the lake, but was more attributed to climate change based on higher than normal water temperatures in spring (*Seebens et al. 2007*). Other climate-related changes in the limnology of Lake Constance include the observed warming of water temperature in concert with the warming of the northern hemisphere in recent decades (*Straile et al. 2003*) and the spring dynamics of *Bosmina*. Large climate associated variability may have decreased the power to detect significant reduction in spring *Bosmina abundances* with oligotrophication (*Straile and Muller 2010*).

The contributions of such a comprehensive data set for zooplankton and phytoplankton in Lake Constance have also helped develop the PEG (Plankton Ecology Group) model for succession of planktonic organisms. This model is

Figure 1. The Limnological Institute of the University of Konstanz conducts routine weekly limnological surveys from Ueberlingen in Lake Constance using the R/V Robert Lauterborn.

a universally accepted explanation for plankton succession in temperate lakes (*Sommer et al. 1986*).

Lake Geneva

Lake Geneva is another large, warm monomictic lake and deep lake in Europe, this time located in the French-Swiss border (Area: 582 km^2; Max. depth: 309 m) (*Anneville and Pelletier 2000*). Similar to Lake Constance, it has also been monitored routinely since the late 1950's by the International Committee for the Protection of Lake Geneva (CIPEL) which is administered jointly by the governments of France and Switzerland. The increase in the human population in the catchment area contributed to the eutrophication of the lake starting in the 1970's. This caused phytoplankton blooms which had impacts on the traditional uses of the lake as well as decreased its aesthetic value. Sewage treatment was used to mitigate the increasing nutrient levels in the lake and has started to bring down its trophic state. The rehabilitation of the lake started with the construction of waste water treatment plants and the dephosphorization of water coming into the lake. A ban on the use of phosphates in detergents and the optimization of agricultural practices were also implemented. Lake monitoring programs under the CIPEL have lead to the collection of monthly data on physical, chemical and biological variables since the 1950's. These were useful in the mitigation of eutrophication in Lake Geneva. Conditions in the lake have now been reverted to mesotrophic (*Kaiblinger et al. 2009*). However, these improvements have also happened side-by-side with noticeable climate-induced changes in the lake such as increased temperatures and changes in the timing of stratification. In terms of the changes that have occurred on the zooplankton community during this period, there was a noticeable shift towards the dominance of calanoid copepods (*Anneville et al. 2007b*). A change in seasonal patterns of copepods as well as a long-term trend in the composition of the copepod community was noticed in relation with the changes in the lake trophic status (*Anneville et al. 2007b*). Another study which focused on changes in the cladoceran community of Lake Geneva during the 2003 heat wave in Europe also showed that changes in climate had impacts on the zooplankton community of Lake Geneva by having an unusual seasonal pattern (*Anneville et al. 2010*).

Lake Biwa

Lake Biwa- a rift lake located in the middle of Shiga Prefecture, is the third oldest lake in the world and the largest lake in Japan. It is a biodiversity hotspot due to its high species richness, with 491 species of flora and 595 species of fauna, and is home to 61 endemic species (7 phytoplankton, 2 macrophytes, 37 zoobenthos and 15 fishes). The lake area (674 km^2), is separated into Northern and Southern basins. The maximum depth is about 104 m with the average depth of 41 m with most parts reaching 50 m in the northern basin while the southern basin has an average depth of 4 m with no areas that are over 10 m deep. It is of high cultural value, attracting an average of 45 million tourists each year (*SPGPRD 2009*). The amount of water in the lake is about 27.5 billion m3, and it equals about 30 % of the available freshwater in Japan (*Horai et al. 2009*). Increased anthropogenic activities during the 1960's had worsened the lake's water quality and disturbed its ecosystem. Introduction and population outbreaks of invasive fish species in the lake had endangered local fish species by competing for food resources and direct predation (*Nishizawa et al. 2006*). Most notable is the acceleration of cultural eutrophication, caused by water pollution, coming mainly from household wastes industrial effluents, and agricultural pesticide and fertilizer run-offs which started in 1975 (*Maruoka 1977; Sueshi et al. 1988; Guruge and Tanabe 1997*; *Sudo et al. 2002; Hyodo et al. 2008*; *Kumagai 2008*). This in turn, had resulted in increased amount of degrading organic matter in the lake that had worsened water quality, contributing to many ecological changes such as reduced amount of dissolved oxygen (*Horai et al. 2009*) together with various global phenomena that increased lake water temperature (*Aoki 1987*; *Aoki 1990*), had proved to be detrimental to the ecology of Lake Biwa. In light of these events, the Japanese government established an Environment Agency and enacted the Water Pollution Control Law in 1971 in response to the growing threat of pollution to human health and environment. The Shiga Prefectural Government enacted the ordinance on pollution prevention, based on the national law. These protocols were enacted with the purpose of providing control measures to regulating industrial, household and agricultural effluents, increasing social awareness on environmental education, conservation and rehabilitation of water quality, and the prevention of further eutrophication in Lake Biwa. These actions have had a great effect on water quality, causing decline in the eutrophic state of the lake starting in the 1980's.

Many long-term researches have been conducted in Lake Biwa, which provided useful information on its ecosystem alterations. Long-term periodic sampling of fauna, flora and physico-chemical data, spanning the 1950's up to the present, by various academic and research institutions in cooperation with government agencies had provided valuable data for time-series analysis for various researches, with many implications on ecosystem dynamics. In the literature found, sampling design consistently considered monthly or annual data gathering, with depth and site replicates for plankton analysis, both in littoral and open water areas, with similar recording for abiotic variables, and was linked with meteorological data. Profiling of lake-floor compacted sediments show historical changes in weather patterns and primary productivity (*Hyodo et al. 2008*) while analysis on the fossil pigments of the same sampled sediments illustrate abundance turnover and extinction of various planktonic organisms, which was significantly related to the historical change in water quality of the lake (*Tsugeki et al. 2009*). Historical reorganization of the phytoplankton community (*Hsieh et al. 2010*) and long-term temporal variations in zooplankton abundance (*Hsieh et al. 2011*) had been proven to be driven by the lake's eutrophication and warming history.

Biological specimens record a variety of ecological information in contemporary ecosystem and their isotopic signatures can be a proxy of biodiversity and also useful for biodiversity conservation and management. Periodic archiving and population profiling of a keystone organism in Lake Biwa, such as the endemic *Gymnogobius isaza* had been valuable in the bio-monitoring and impact assessment of local organisms in relation to the lake's trophic status. Long-term changes in size and abundance of benthic gammarids in the lake were directly affected by the population collapse of its fish predator, *G. isaza*, in Lake Biwa. While forty-year diet and parasitological analysis of archived *G. isaza* illustrate a marked change in prey items during the eutrophication and reoligotrophication period of Lake Biwa (*Briones et al. 2012*). This long-term dietary data clarifies certain aspects of temporal changes in its trophic niche attributes, as seen in stable isotope analysis of archived *G. isaza* (*Nakazawa et al. 2010*) that illustrates the need of increased sample number and considering size-related partitioning when analyzing temporal data as a proxy for environmental events.

Local Initiatives to Study Zooplankton Ecology

Studies on Philippine zooplankton have been initiated by great names in the field of limnology from the Wallacea Expedition of the 1930's (*Brehm 1939*; *Kiefer 1939a; Kiefer 1939b; Kiefer 1939c; Brehm 1942; Hauer 1941; Woltereck et al. 1941)*. However, it was only during the time of W. Lewis in Lake Lanao when ecological studies on the zooplankton community of a Philippine lake had been found in the literature (*Lewis Jr. 1979*). Meanwhile, the improvements in freshwater zooplankton taxonomy and systematics were mainly due to the efforts of A.C. Mamaril Sr. in the 1970's. This has resulted to the identification of 125 species from the three major zooplankton groups (Cladocera, Copepoda and Rotifera) collected from a variety of freshwater ecosystems (*Mamaril Sr. 2001*). Other studies by *Cheng and Clemente* (*1954*), *Ueno* (*1966*), *Lai et al.* (*1979*), *Petersen and Carlos* (*1984*), *Tuyor and Segers* (*1999*), *Tuyor and Baay* (*2001*), and *Walter et al.* (*2006*) have discussed taxonomic revisions or new records. Since 2008, a renewed interest in zooplankton ecology and systematics has produced several papers on the zooplankton of Lakes Paoay, Taal, and Laguna de Bay as well as other major lake and river ecosystems in the country. These include findings on the impact of aquaculture and other pollutants on zooplankton spatio-temporal distribution in Lakes Taal (*Papa et al. 2011*) and Laguna de Bay (*Papa et al. 2012a*), the presence of an invasive species of calanoid copepod (*Arctodiaptomus dorsalis*) in 18 out of 27 lakes surveyed (*Papa et al. 2012b*), new species records and new insights into ecology and distribution (*Aquino et al. 2008*; *Lazo et al. 2009*; *Papa and Zafaralla 2011*; *Papa et al. 2012c*) and the description of a new cyclopid copepod species (*Mesocyclops augusti*) in Lake Siloton (Mindanao Is.) (*Papa and Holynska 2013*). Though attempts were made by these studies to come up with a temporal analysis of zooplankton community dynamics, these efforts were still not part of a routine limnological analysis thereby lacking continuity. This was mainly due to limited funding opportunities and manpower. The archipelagic nature of our country has also made it difficult to access more lakes that have been previously under-explored. Several government and multinational agencies such as the LLDA, SEAFDEC and BFAR usually collect zooplankton as part of their limnological surveys such as those performed in Laguna de Bay and the Seven Lakes of San Pablo, Laguna; however, the lack of a publication culture has hampered the utilization of such data sets for a more thorough analysis of its relationship with eutrophication and climate change.

The Challenges Ahead

The studies that have been cited in the previous sections are some of the most important papers that have linked zooplankton community dynamics to climate and human-induced changes in limnic ecosystems. Though generalizations may be drawn on how zooplankton react to such changes based on data from Lakes Constance, Geneva and Biwa, these data sets may not hold true for lakes in the tropics. Tropical lakes and their resident zooplankton have different physical, chemical and ecological characteristics compared to their temperate counterparts (*Lewis Jr. 1987;*

Fernando 2002). Given the number of lakes in the Philippines and their unique geological origins, several Philippine lakes may serve as point references in the study of the effects of climate and human-induced changes to tropical lake ecosystems. It is however sad to note that given the current state of limnological research in the country, drastic steps have to be taken to ensure that lake monitoring programs become successful.

One of the most basic problems in the Philippines is the lack of trained limnologists. This also includes the lack of trained taxonomist to even properly and correctly identify zooplankton. Another problem is the lack of proper sampling equipment for physico-chemical and biological parameters. This may be remedied by fabricating sampling equipments and developing low-cost instruments. However, the greatest challenge so far is the lack of a clear directive, awareness and proper emphasis on the importance of doing such routine investigations. This should come from concerned government departments (environment, agriculture, science and technology and education) that should provide funding and clear objectives as to why routine limnological monitoring should be done. Implementation is then spearheaded by research institutions, especially those in private and public colleges and universities, who may utilize their biology, chemistry and environmental science classes to collect data from lakes in a routine fashion. This may then be compiled using basic worksheet applications such as MS Excel, and documented for a number of years. If there is an absence of trained scientists to look at the data within the school, collaborations must be established to help guide the local scientists on how to properly analyze the collected data sets. The last step is of course to present data in scientific conferences and eventually publish papers in peer-reviewed journals. This would ensure that the larger scientific community would be able to learn more about the lakes being studied, as well as include the data in a bigger analysis (meta-analysis) which may include pooling together data from several lakes collected over a period of time (**Figure 2**). This type of data is most useful for limnologists who want to find out changes in lake characteristics in a regional or global scale. Though the benefits of routine limnological monitoring of Philippine lakes are far into the future, and may even be more for the benefit of succeeding generations of scientists, efforts must be put in to make sure that we no longer waste time in making the necessary steps to learn more about our lakes and how they respond to climate and human-induced changes.

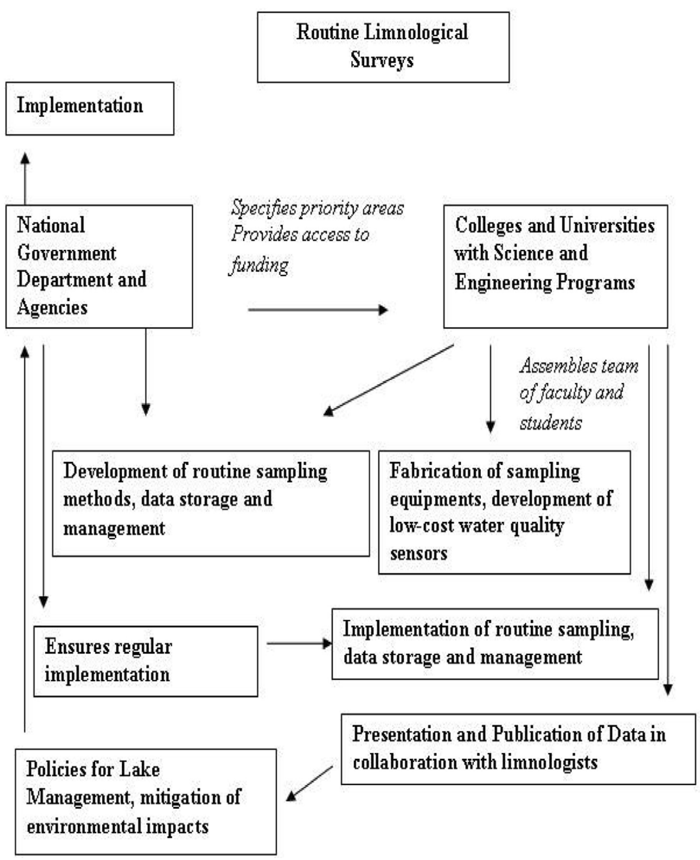

Figure 2. A proposed model by which routine limnological samplings may be implemented using higher educational institutions with close proximity to lake ecosystems nationwide.

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