Philippine Journal of Science
148 (3): 565-578, September 2019
ISSN 0031 - 7683
Date Received: 08 May 2019

Small Maar Lakes of Luzon Island, Philippines: Their Limnological Status and Implications on the Management of Tropical Lakes – A Review

Milette U. Mendoza[1,6]*, **Jonathan Carlo A. Briones**[1,2,3], **Masayuki Itoh**[4], **Karol Sophia Agape R. Padilla**[1], **Jaydan I. Aguilar**[1], **Noboru Okuda**[5], and **Rey Donne S. Papa**[1,2,3]

[1]The Graduate School, University of Santo Tomas 1015 Philippines
[2]Department of Biological Sciences, University of Santo Tomas 1015 Philippines
[3]Research Center for the Natural and Applied Sciences, University of Santo Tomas 1015 Philippines
[4]School of Human Science and Environment, University of Hyogo, 1-1-12 Shinzaike-Honcho, Himeji 670-0092 Japan
[5]Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kita-ku, Kyoto 603-8047 Japan
[6]Department of Environmental Science, School of Science & Engineering, Ateneo de Manila University 1108 Philippines

In developing countries such as the Philippines, the inadequacy of even the most basic limnological datasets available has hindered planning and implementation of science-based management policies for inland waters. This situation is aggravated by overutilization of natural resources for ecosystem services such as water usage, aquaculture, fishing, and tourism. We reviewed published researches related to the Seven Maar Lakes (SMLs) in Luzon Is., Philippines to summarize information invaluable for the protection and sustainable use of these resources. Popular scientific search engines were utilized to gather peer-reviewed research articles and reports from both private institutions and government agencies. Literature and timeline from the 1930s to 2019 was classified into topics – namely socioeconomics, fisheries, biodiversity, and environment. Based on the literature survey, a variety of challenges, knowledge gaps, and promising research directions were identified, which are essential to the sustainable ecosystem management of the SMLs. Aquaculture practices impacting the lakes and its underestimated biodiversity were described. Measured vertical profiles of dissolved oxygen (DO), temperature, conductivity, pH, and salinity was supplemented by our preliminary limnological survey in the SMLs. Past and present monitoring data of selected physicochemical parameters were assessed from which the changing limnological status of the lakes was determined. We recommended measures motivated by strategic environmental assessments while still considering maintained economic yields. A sustained collaborative effort from different sectors is strongly suggested not only to manage the SMLs but also to address trade-offs among critical ecosystem services. Aside from the need for well-designed, long-term water quality monitoring, we also stress the synergistic interpretation of all available knowledge, which can contribute to the resolution of environmental issues at both local and global scales.

Keywords: lake management, Seven Maar Lakes, tropical limnology

*Corresponding author: milette.mendoza.gs@ust.edu.ph

INTRODUCTION

Freshwater lakes are essential to humanity as they provide critical ecosystem services and serve as sentinels and integrators of a range of environmental processes (Williamson *et al.* 2008). Small lakes in the Philippines – defined here with surface area (SA) of ≤ 2,000,000 m^2 (Brillo 2016a, b) – often receive less research and management attention compared to bigger lakes, even though they are equally important for conservation (Briones *et al.* 2016, Scheffer *et al.* 2006). Intensive and systematic limnological research is needed for a better understanding of the small lakes, as these ecosystems are more vulnerable than larger lakes to human activities in the catchment and are more sensitive to the resultant environmental changes (Brillo 2015a). Sixty-three percent of the Philippine lakes are classified as small (Brillo 2015b), suggesting its advantage since small aquatic ecosystems have great importance and global impact in nutrient spiraling and retention of important materials, as well as in biotic complexity and richness (Downing 2010).

In terms of sustainable management, tropical and temperate lakes show undisputable differences in productivity and overall limnology, necessitating different approaches (Lewis 2000). Today, gaps evidently remain in our full understanding of tropical lakes. Efforts to provide baseline information on the status of lake ecosystems and their response to environmental changes have been limited for tropical lakes, particularly in developing countries. This data gap hampers the design of effective measures for addressing various issues specific to these ecosystems (Legaspi *et al.* 2015). At present, lake ecosystems face numerous threats to which the impacts of a changing climate are added. Moreover, local environmental issues such as water quality have arisen as a consequence of anthropogenic disturbances that can affect lakes' structure, functioning, and stability (Vincent 2009).

The utilization of lake resources for fisheries and aquaculture benefits society by providing food and employment. In the Philippines, the fishing industry greatly contributes to the country's gross domestic product valued at Php 196 billion (USD 3.7 million) (FAO 2018). Although aquaculture's importance continues to grow worldwide (Krause *et al.* 2015), the fishing industry in the country has yet to be sustainably managed, with key challenges traced to inadequate management systems and structures (FAO 2018). The financial benefits generated by aquaculture may be outweighed by environmental costs such as water pollution and biodiversity loss, with implications for the deterioration of ecosystem functioning and services (Legaspi *et al.* 2015). Considering such a trade-off, there is substantial social demand for well-developed and science-based management for lake ecosystems. This management must include integrated knowledge (*i.e.*, physical, chemical, biological, and socio-economic data) in order to make careful decisions based on trade-offs among ecosystem services critical to humanity (Levin *et al.* 2009).

This paper presents an overview of existing knowledge on the SMLs of San Pablo City, Laguna, Philippines through peer-reviewed journals, books, professional society conference proceedings, and technical reports. We review available studies and identify challenges, knowledge gaps, and future research directions based on what is already known. We also present our preliminary limnological monitoring data such as vertical profiles of chemical (*i.e.*, water temperature, DO, pH, conductivity and salinity) and biological properties (*i.e.*, trophic status) in order to assess the past and present water quality status of the SMLs. Some of these were previously gathered through classical methods but can be updated using equipment unavailable in the past. This review will support a more comprehensive understanding of these tropical aquatic ecosystems and help to propose a new monitoring scheme to collect limnological data needed for ecosystem management that promotes environmental stewardship of the SMLs.

MATERIALS AND METHODS

Study Sites

In the Philippines, tropical and oceanic climates exist – characterized by abundant rainfall, relatively high temperature, and high humidity due to the surrounding bodies of water. Located on the island of Luzon in the Philippine archipelago, approximately 102.2 km from Manila, are the seven volcanic crater lakes (hence also called 'maar lakes') of San Pablo City – namely Lakes Calibato (14.1036000 °N, 121.3769528 °E); Pandin (14.1153278 °N, 121.3686028 °E); Yambo (14.1181583 °N, 121.3675222 °E); Mohicap (14.1222556 °N, 121.3347417 °E); Palakpakin (14.1112889 °N, 121.3384000 °E); Sampaloc (14.0784500 °N, 121.3340139 °E); and Bunot (14.0807639 °N, 121.3424139 °E) (Figure 1). Based on the rainfall distribution, the location of the SMLs falls under Type 1 climate (Kintanar 1984), described as having short dry season per year. As the climate is mainly influenced by location, physical geography, and large-scale climate systems, the SMLs has a tropical monsoon climate (Köppen-Geiger Am) with an average annual rainfall of 2,069 mm (Villarin *et al.* 2016). The average warmest air temperature in the province is recorded in May (32 °C during daytime; 24 °C during nighttime) while the coldest is recorded during January (27 °C during daytime; 21 °C during nighttime) (https://www.ncdc.noaa.gov/; NOAA).

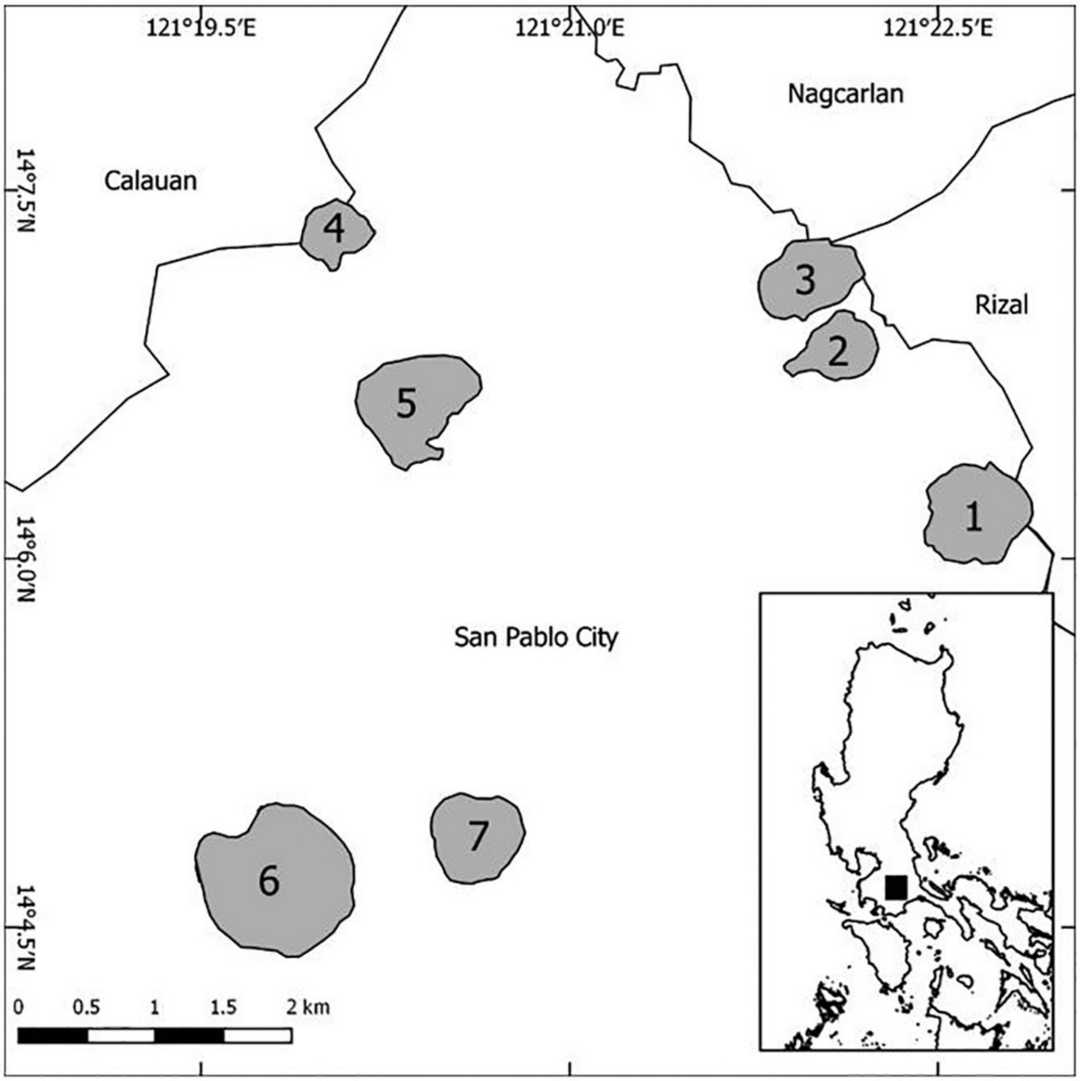

Figure 1. Map of the SMLs: 1) Calibato, 2) Pandin, 3) Yambo, 4) Mohicap, 5) Palakpakin, 6) Sampaloc, and 7) Bunot. Map generated using QGIS Software Version 2.18.

The SMLs, located on the island of Luzon in the Philippines, have been the subject of several studies across various disciplines. Since the 1970s, the Laguna Lake Development Authority (LLDA) has been managing water quality monitoring in Lakes Yambo and Mohicap (Sta. Ana *et al.* 2005d, e) and – since the 1980s – in the remaining five lakes (Sta. Ana *et al.* 2005a, b, c, f, g). Some of the challenges faced in this task were equipment malfunctioning, power interruptions, and limited funding and allocation for specialized chemical analyses – which made it difficult to acquire consistent quarterly data. Despite these difficulties, the LLDA has tried to take quarterly measurements of the water quality in the SMLs. Chemical parameters measured include water temperature, DO, pH, total suspended solids, total dissolved solids, turbidity, chloride, nitrate, ammonia, phosphate, biochemical oxygen demand, and chemical oxygen demand. Biological parameters such as phytoplankton, zooplankton, and chlorophyll α are also being monitored quarterly.

In 2014, the SMLs were proclaimed to be 'threatened lakes' by the Global Nature Fund, and were given protected status by the Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB) as candidate key biodiversity areas with moderate pollution, sedimentation, and ecological stress (DENR-EMB 2014). These small lakes are of great scientific interest and are highly valued, yet many of their most basic and important limnological characteristics are still not available in the conventional literature. Among the SMLs, Lake Sampaloc is known to be the youngest maar, formed about 500–700 years ago (GVP 2013). One research work gave findings on the age of three of the SMLs using radiocarbon dating techniques confirming the 700 years of Lake Sampaloc, 260 years of Mohicap, and 300 years of Lake Yambo's lake existence (Bannister *et al*. 2019). This type of work has great importance in knowing the lakes' histories and rates of biotic and tectonic evolution (Cohen *et al.* 1986).

These lakes are of great importance to local communities as they are utilized for fish cage aquaculture, communal fishing grounds, and tourism (Brillo 2016d). Some of the lakes are popular as tourism sites – particularly Pandin, Yambo, Sampaloc, and Mohicap – with the local community having a clear, equitable share of all profits (Brillo 2016d, e). While generally the SMLs also serve as aquaculture and fishing sites, this activity is concentrated in Lakes Calibato, Bunot, Palakpakin, and Sampaloc (Brillo 2015b, 2016c, d, e). Human population in settlements surrounding each lake, using data from the National Statistics Office (NSO) Region IV-A as of August 2015 (Table 1), was estimated highest in Lake Sampaloc (18,600) since it is located close to the city proper. The highest estimate was followed by Lakes Pandin (8,500), Calibato (8,500), and Bunot (8,300). While the least populated lakeshore areas were in Lakes Mohicap (3,800) and Yambo (2,000).

Literature and Data Search

We used popular scientific search engines (*e.g.*, Google, Google Scholar) to gather peer-reviewed journal articles, books, professional society conference proceedings, and technical reports – both from private institutions and government agencies – that highlighted all the SMLs or at least one. Articles gathered were classified into four dominant topics: 1) socioeconomics, 2) fisheries, 3) environment, and 4) biodiversity. 'Socioeconomics' accounts include social studies mainly dealing with challenges and gaps in the development of the SMLs as livelihood and natural resources. Accounts under 'fisheries' include reports of problems faced as the aquaculture industry in the SMLs became extensive. Under this category also fall accounts suggesting actions or methods for operations and regulations towards sustainable aquaculture, open fisheries, and lake usage. 'Environment' accounts include known information on the climate, land use, and physical limnology of each lake. Lastly, the number of documented aquatic animal species was gathered and summarized in the 'biodiversity' category. All gathered, classified, and tallied literature were evaluated and discussed based on their relevance.

The present SA devoted to aquaculture using fish cages in each lake was estimated through Google Earth maps, while previous data for 2017 were retrieved from the LLDA.

Preliminary Survey of the SMLs

Measurement of chlorophyll α concentration was conducted to assess the trophic status of the SMLs from October 2016 to September 2017. In addition to this, we deployed a water quality sonde (Exo1, YSI Inc., USA) in August 2018 when the lake was stratified. The deployment was done in the deepest portion of each lake to examine the vertical profiles of basic physicochemical parameters such as temperature (°C), DO (mg L^{-1}), pH, conductivity (µS cm^{-1}), and salinity (PSU) from the surface to the bottom of each lake. These data were standardized and compared to gathered water quality data to provide insights into past and present environmental conditions of the SMLs.

RESULTS AND DISCUSSION

Dominant Research Topics in the SMLs

Our literature search yielded a total of 55 published papers; this total includes papers published between

Table 1. Physical characteristics of the seven lakes of San Pablo City, Laguna, Philippines.

Lake	Bunot	Calibato	Mohicap	Palakpakin	Pandin	Sampaloc	Yambo
Elevation (masl)	110	1706	80	100	160	106	160
Surface area (m^2)	305,000	430,000	228,900	479,800	240,000	1,060,000	305,000
Maximum water depth (m)	23	156	30.4	7.7	61.75	27.6	38
***Trophic condition**	E	E	M	E	M	M	M
Fish cage surface area percentage, 2017 *vs.* 2018 (%)	13.08 18.70	14.47 22.36	6.16 5.77	11.78 17.25	2.46 1.80	9.56 7.68	2.20 2.07
+Settlement population	8,300	8,500	3,800	8,200	8,500	18,600	2,000
Notes	F	F	F, T	F	F, T	F, T	F, T

F – fishery, T – tourism
*Lake trophic conditions (Fuller and Jodoin 2016) of the SMLs of San Pablo City based on average chlorophyll α concentrations from October 2016 to September 2017 (M – mesotrophic, E – eutrophic).
+Settlement population data collected from NSO Region IV-A.

1939 and 2019. These papers were categorized into four dominant topics – namely socioeconomics, fisheries, environment, and biodiversity (Figure 2). Most of the accounts (N = 24) were focused on the lake environment, particularly studies and assessment on the water quality and ecological interactions. Limited studies that dealt solely on the physical limnology of the SMLs were found. The fewest accounts (N = 7) were focused on biodiversity or biological communities, including inventory data on aquatic species from individual lakes. Of the seven lakes, Lake Sampaloc was the most studied (N = 33) and was also the first (*ca.* the 1930s) to have been studied. Other lakes have received considerably less attention (Brillo 2016a), with only 7–12 published works each.

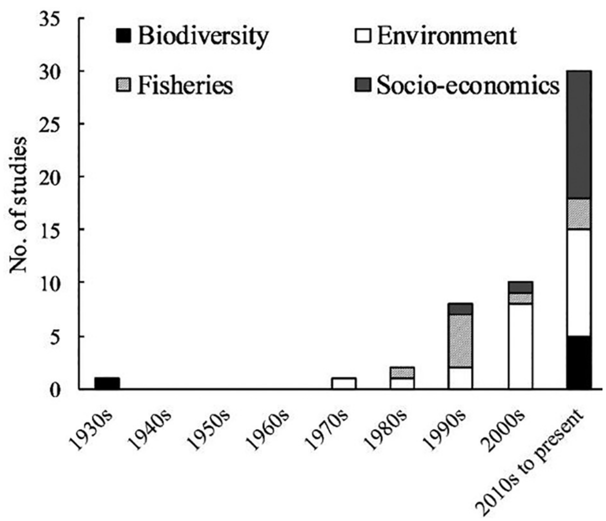

Figure 2. Timeline of SML case studies under the four major categories: biodiversity, environment, fisheries, and socioeconomics.

Socioeconomics: Developments and challenges faced by the SMLs. Like all freshwater ecosystems, the SMLs have been playing important roles in the lives of the people living near each catchment. Aquaculture and inland capture fisheries had a growing importance in fish production for human consumption and poverty reduction, especially in rural areas (FAO 2014). Legaspi *et al*. (2015) and Bannister *et al*. (2019) presented information about the SMLs prior to the introduction of aquaculture through sedimentary histories of Lakes Sampaloc, Mohicap, and Yambo. They detected abrupt environmental changes by looking on variation in the diatom assemblages before, during, and after the introduction of aquaculture. Widespread aquaculture practices began in the SMLs in 1975, with challenges accumulating as the decades progressed such as mismanagement arising from unregulated aquaculture practices in some of the lakes. Historically, small fishermen operating fish cages in the SMLs formed a federation that traditionally established the aquaculture methods. These methods entail using fish cages of a common size (10 × 20 × 5 m), stocked three times per year with 3,150 pieces of tilapia (*Oreochromis niloticus*), which consumes 1.25 tonnes of commercial feeds per day (Santiago and Arcilla 1993).

Challenges in the management of the SMLs were identified such as conflicting interests among stakeholders, inappropriate zoning plans for fish cages, domestic wastes from informal settlers on the lakeshore, and policy and institutional disputes (LLDA 2014). In almost all of the SMLs, sustainable development initiatives and programs were lacking (Brillo 2015a, b, 2017; Amit *et al.* 2016). Other challenges were brought by the degree of power and influence in the use of lake resources (Amit *et al.* 2016) and spreading urbanization (Brillo 2015b). In the face of the demands by a growing population, the expansion of fish cages in the SMLs – such as in Lake Sampaloc (Santiago and Arcilla 1993) – was unmanaged and uncontrolled in the past. Then in 1998 – through the Philippines Fisheries Code (Republic Act 8550) – licenses for fish cage operations were implemented, as was an allotment of 10% of each lake's SA for fish cages and other structures for aquaculture. These policies were further amended through R.A. 10654 – an act for the prevention and elimination of illegal, unreported, and unregulated fishing – which were included by 2015. These ensure the rational and sustainable development, management, and conservation of the fishery and aquatic resources in the Philippine waters. However, these policies were founded on legal considerations rather than scientific ones (LLDA 2014).

After two decades of implementing the code, excessive total SA devoted to aquaculture can still be observed – especially in Lakes Calibato, Bunot, and Palakpakin – where the present estimations of fish cage SA exceed the 10% allowable lake SA devoted to fish cages (Table 1). In Lake Calibato, fish cage SA percentage was estimated at 14.47% in 2017 but has reached 22.36% in 2018. Increasing unrestricted operations can also be observed in Lake Bunot with 18.70% SA and Lake Palakpakin with 17.25% SA for fish cages, following somewhat more acceptable 2017 data: 13.08% SA and 11.78% SA, respectively. Meanwhile, the remaining lakes – Sampaloc, Mohicap, Yambo, and Pandin – conformed to the allowable fish cage SA. This may be due to the gradual trend of using the lakes for ecotourism rather than for aquaculture, as efforts from local government units determined to turn the SMLs into venues for ecotourism (Brillo 2017). The managers of the SMLs (*i.e.*, LLDA and local government units) issued a new fishing structure zoning map, massively demolished fish cages of an area of 900 million m^2, relocated over 400 families of illegal settlers around the lake circumference, and offered alternative livelihood to those who were displaced by the new promulgations (Cinco 2017).

The SMLs were shown to have important roles in tourism, agriculture, and aquaculture, as well as urban expansion (Quintal *et al.* 2018). These lakes also give identity to its city, San Pablo, known as the 'City of the Seven Lakes.' Realizing the SMLs importance to the local community, managers executed zoning and land use requirements through Ordinance No. 2012-40, which requires an easement area of 30 m away from the lakes if it will be used for urban purposes. Implementation of prior permits for conversion of land use in forest areas (*e.g.*, residential, commercial, or industrial) through the Department of Environment and Natural Resources (DENR) is also passed (Quintal *et al.* 2018). Aside from these implementations, careful monitoring is necessary to determine whether these were strictly followed.

Fisheries: Aquaculture practices impacting the lakes. Occasional fish kill events, mainly affecting aquaculture sites, were documented in the SMLs (*e.g.*, Calibato, Mohicap, Sampaloc, and Bunot). These events, which happened in the 1990s and 2000s, may be related to the decline of the water quality in the SMLs. This deterioration may have been brought by nutrient inputs from the fish cages, excessive use of commercial fish feeds, domestic waste, as well as upwelling of anoxic waters that happens during the "cold" months (*i.e.*, December to February) (Brillo 2015a; 2016a, c, f; Diana 2009). Aeration was already attempted – for example in Lake Palakpakin wherein an automated aerator was installed together with wireless sensors measuring and recording DO, temperature, and conductivity – so as to detect critical water quality values at the onset of fish kill events (Solpico *et al.* 2014).

Agencies with deep involvement and interest in the SMLs seek sustainable measures to protect and rehabilitate the lakes, as the extensive utilization of fish cages with excessive use of fish feeds pose a great threat to the aquatic life and stand to lead to faster deterioration of the lakes (Orosa 2014). The SMLs' development and management plan recommend assessing the carrying capacity of aquaculture in order to establish a baseline relative SA for fish cage volume (LLDA 2014). This recommendation is expected to help determine and control the stocking density and feeding requirements of the fish cages (R.A. No. 8550). In the future, GIS-based research may help to evaluate the relative importance of domestic loading coming from each lake's catchment *vs.* from aquaculture loading.

Underestimated biodiversity of SMLs. In these small tropical maar lakes, plankton research comprised most of the published data on biodiversity. Much of these were in the form of taxonomic researches investigating distributional patterns of zooplankton in Philippine inland waters (Papa *et al.* 2012, Pascual *et al.* 2014, Dela Paz *et al.* 2016). This includes a report on the presence of an invasive calanoid copepod, *Arctodiaptomus dorsalis*, which has potentially displaced native and or endemic calanoid copepod species in many Philippine lakes, including the SMLs (Papa *et al.* 2012). Limited research on phytoplankton communities has also been conducted as part of the water quality reporting by local government institutions (Zapanta *et al.* 2008). In Lake Mohicap, for instance, studies on phytoplankton abundance and composition have revealed that an increase in nutrient levels was caused by anthropogenic factors, particularly by aquaculture and domestic waste inputs (Cordero and Baldia 2015, Sambitan *et al.* 2015). An earlier study compared phytoplankton diversity between Lakes Pandin and Sampaloc regarding the latter as eutrophic and 'organically polluted' lake (Zafaralla 2010). While documentation of microalgae in the SMLs and in the nearby Crocodile Lake was done by Zafaralla (2014). In the said study, seven classes, 19 orders, 38 families, and 98 genera were documented – from which most were collected from Lakes Pandin, Sampaloc, and Crocodile – and with only few representatives from the remaining lakes.

Most of the biodiversity researches in the SMLs were done in Lake Sampaloc, including the earliest study in the SMLs which was a taxonomic account of the shrimp *Palaemon talaverae* (Blanco 1939). A study on gastropod diversity was also conducted in Lake Sampaloc, which was then compared to two other lakes in the southern Luzon island region – Laguna de Bay and Lake Taal (Adorable-Asis *et al.* 2016). Studies on fish parasites have also been heavily concentrated in Lake Sampaloc (de la Cruz *et al.* 2013, Briones *et al.* 2015, Paller *et al.* 2015).

With limited biodiversity research conducted in these small maar lakes, it should be noted that the present listing of all flora and fauna in the lakes may not be accurate. For example – although the apparent aquatic species richness (59 species) of Lake Sampaloc is highest among the SMLs – this may be merely a consequence of research effort concentrated on Lake Sampaloc, rather than a real diversity peak. From this perspective, lower apparent species richness in other lakes may result solely from the lack of research effort there. In the same light, it would be interesting to determine if native species recorded in Lake Sampaloc are also present in other lakes. These lakes are yet to be assessed, not only for common and charismatic species (large species such as fish) but also for smaller and non-charismatic species (insects and benthos), in order to view without bias the holistic response of aquatic communities exposed to considerable and potentially irreversible environmental changes.

Environment: Assessment of past and present water quality status. Currently, we have limited knowledge on the physical limnology of the SMLs in spite of the known importance of determining the dynamics behind stratification, transport processes, and vertical gradients in lake ecosystems (Boehrer and Schultze 2008). Monitoring the SMLs' water quality over time is important to allow the managers and stakeholders to follow trends, detect the lakes' health, and sense unforeseen problems as they emerge. In spite of this, efforts were still done to maintain the water quality of the SMLs. A management framework was initially drafted for Lake Pandin and eventually implemented for the rest of the SMLs. The LLDA aimed to maintain 'Class C' water quality, according to the national criteria set by the DENR in Administrative Order (DAO) 2016-08 and DAO No. 34 (LLDA 2014, DENR 2016). These standards were set for freshwaters intended primarily for the propagation of fish and other aquatic resources; for recreation such as boating, fishing, and other similar activities; and for industrial water supply, agriculture, irrigation, and livestock watering (DENR-EMB 1990).

On this basis, these orders determined that the maximum temperature shifts within the water column should only be 3 °C. Our present monitoring (during August 2018) revealed that the maximum water temperature shifts in the first 5 m depth of each of the lakes remain within this limit (Figure 3). Meanwhile, the ideal pH range for the thriving of fish species – according to the standard adopted for Class C fishery water – has to remain between 6.5 and 8.5 (Hallare *et al*. 2005). From the water quality monitoring report of LLDA (Zapanta *et al*. 2008), the averaged pH values of the SMLs from 2006 to 2008 still fall within the said limits. Bannister *et al*. (2019) presented pH data collected during February, May, August, and November 2017 at Lakes Yambo, Mohicap, and Sampaloc. They presented annual pH estimates from the summed and averaged monthly data, from which certain depths (*i.e.*, 10–20 m of Yambo, 5–10 m of Mohicap, and all depths for Sampaloc) revealed pH estimates outside the ideal range during May and August 2017. While our present pH measurement, taken August 2018, revealed that Lakes Yambo (5–40 m, averaged values 6.31 ± 0.10); Pandin (0–15 m, 5.16 ± 0.22); and Calibato (all depths, 5.74 ± 0.33) with pH levels less than the 6.5 limit (Figures 3e, f, and g). Implications of low pH levels in lakes, specifically within 5.8–6.0, were reported to severely affect the growth and reproduction of aquatic organisms (Kelly *et al.* 1984). Our present pH readings may still be out of the said critical range for aquatic organisms, but we should note already that it has now out limited the Class C standards. For this reason, we insist on more intensive monitoring of important physicochemical parameters (such as pH) to aid in maintaining good water quality, predict trends, and avoid future aquaculture disasters.

DO, another important parameter for the survival of aquatic organisms and in turn indicates good water quality, was also being monitored by the LLDA. The minimum

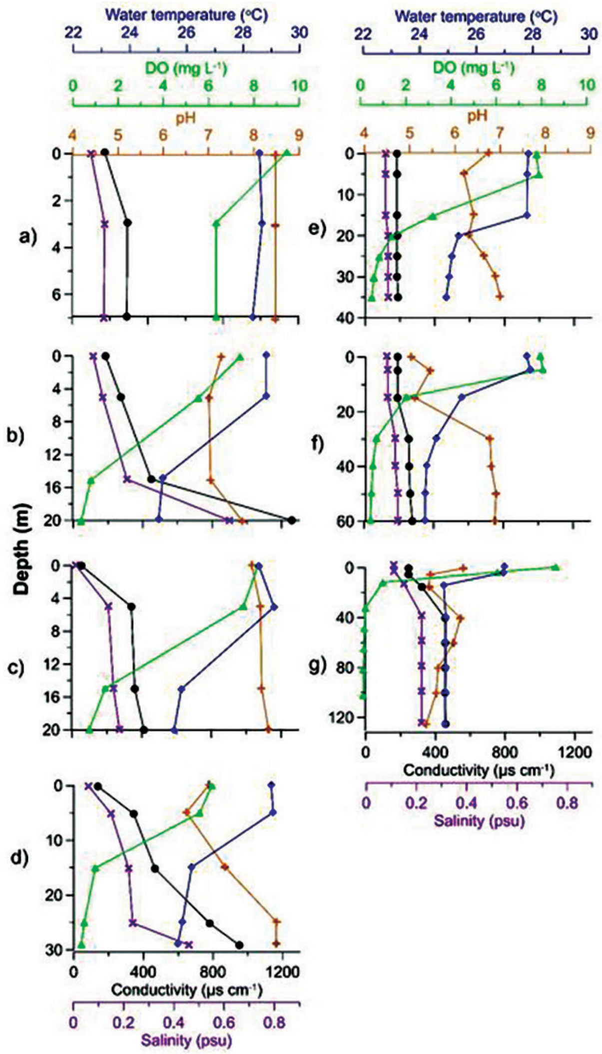

Figure 3. Vertical profiles of water temperature (♦), DO (▲), pH (+), conductivity (●), and salinity (x). Each value shown represents measurements at each depth during August 2018. Lakes are arranged according to maximum depth: a) Palakpakin, b) Bunot, c) Sampaloc, d) Mohicap, e) Yambo, f) Pandin, and g) Calibato.

DO at the present water temperature range in the SMLs (24.24–28.98 °C) is required to remain at or above 60% saturation *i.e.*, 8.4 to 7.7 mg/L, respectively (Rice *et al.* 2012). Below this level and the established Water Quality Class C standard at 5 mg/L, DO requirement was met in each lake only for the shallowest few meters of depth, or not at all, with some variation among SMLs (Figure 3). This was especially the previous observation in Lakes Bunot, Mohicap, and Calibato – where the acceptable DO amounts were attained only at 2 m depth from 2006 to 2008 (Zapanta *et al.* 2008).

Strong evidence from an extensive body of research shows the impacts of human population demands on the physical characteristics of lakes. In particular, the transport of dissolved organic carbon, which causes oxygen depletion, is detrimental to the aquatic community (Poff *et al.* 2002). In Lake Mohicap, Legaspi *et al.* (2015) examined the impacts of the developing freshwater aquaculture along with expected effects of relevant regulations. They further pioneered the use of paleolimnological methods to reconstruct the long-term dynamics of lake ecosystems in the Philippines. In 2018, Engels *et al.* (2018) used data on spheroidal carbonaceous particles from sediment cores collected from Lakes Yambo, Mohicap, and Sampaloc as an atmospheric pollution indicator. Their data was then compared to those from Lake Tasik Chini (Malaysia) and Singapore Reservoir (Singapore) to trace the development of air pollution in the Philippines, Malaysia, and Singapore.

As an indicator of the trophic status of lakes, chlorophyll α concentrations were measured monthly as a pilot for a future monitoring scheme for the SMLs (Table 1). In general, Lakes Palakpakin, Bunot, and Calibato were categorized as eutrophic (6.1–22 μg/L), while Lakes Sampaloc, Mohicap, Yambo, and Pandin were classified as mesotrophic (2.2–6 μg/L). Lakes Yambo and Pandin were previously reported as oligotrophic (Zapanta *et al.* 2008), but our data reveal that these lakes' trophic status has shifted to mesotrophic over the past decade. This may suggest that current rehabilitation efforts have not been fully successful, and that cultural eutrophication is still happening in these two lakes. Further efforts should be made to reduce nutrient loadings into the SMLs, which have been intensively used for aquaculture.

Recommendations and Call for Science-based Lake Management

Several frameworks for sustainable management of fisheries and aquaculture for freshwaters have already been proposed. From this, strict implementation and clear sanctions should be established if the enforcements are not followed. As fish cage aquaculture in the SMLs has already been one of the major sources of livelihoods, it is impossible to simply eradicate this practice to solve the deteriorating health of the lakes. Biological perspectives on fisheries problems can be complemented by taking an economic and political point of view (Kumar 2014). While we benefit in the farming of non-native fish such as tilapia, native fish species face threats since the inevitable escape of tilapia in fish cages result in competition for food and space, hence tend to be invasive (Vicente and Fonseca-Alves 2013). Lake managers and lawmakers may consider promoting native fish fingerling seeding for open-water fishing. They may further organize events encouraging lake users to realize the importance of responsible fishing for the health of the lakes. New measures should be motivated by science while being mindful of sustainability and maintaining reasonable yields.

As lakes are sensitive to climate-related changes, we must also identify limnological variables that could show lake responses to climate forcing and the influence of the catchment (Adrian *et al.* 2009). Such analyses could also provide a better understanding of these lakes, making way for the development of management strategies capable of increasing their resiliency to the direct impacts of climate change. This was fulfilled by Bannister *et al*. (2019) by presenting paleo- and contemporary limnological data that provides insights into past and present states of three of the SMLs (*i.e.*, Lakes Yambo, Mohicap, and Sampaloc). High-quality research work such as the previously mentioned published paper is a breakthrough in understanding and knowing the present state of these crucial ecosystems and natural resources, as well as in formulating science-based recommendations for more efficient management. After the publication of scientific results, experts should try to share and transform the knowledge in a way that managers, lawmakers, and locals could use.

With the present state of the SMLs, we further recommend continuous and consistent water quality monitoring of the SMLs by the LLDA. The identified challenges in their monitoring task could be resolved if the focus on important water (*i.e.*, water temperature, DO, pH, and salinity) and biological (*i.e.*, macro and micro invertebrates, fish, and plants) parameters will be done based on clear and well thought out targets. Capture fisheries stock assessments and improvement of native fish stocks could significantly help in the sustainable use of the SMLs. Good aquaculture practices and use of environment-friendly floating fish feeds is also advised.

Rehabilitation efforts and management programs for eutrophic lakes have been the focus of many nations using dilution, aeration, aquatic plant management, and the curbing of nutrient influx (Peterson *et al.* 1974, Born 1979). Although not all have been successful, several strategies in lake rehabilitation have been effective in some cases (*e.g.*, Lakes Biwa in Japan, Constance in Germany, and Erie in North America). Since lakes are found in different latitudinal regions, each with its own set of unique limnological properties, generalizations regarding lake protection and management cannot be made (Lewis EM 2000). Most importantly, the sustained collaborative efforts from the LLDA, the city government, and various stakeholders of the SMLs – including fishermen, landowners, local government officials, non-government organizations, academe, and other agencies – is the key to conserve and protect all the SMLs.

CONCLUSION

From this report about small tropical maar lakes, we hope to further stimulate the increasing curiosity about the limnological features of small lakes in the tropical region, which can lead to improved monitoring and management. Challenges, knowledge gaps, and future research directions were identified for a better understanding of these tropical lake ecosystems. To effectively manage these natural resources, it will be fruitful to effectively portray their economic and ecological importance by synergistically interpreting the scattered knowledge of physical, chemical, and biological properties of tropical lake ecosystems. Such a critical overview will aid in policymaking, especially in cases of decisions that will require trade-offs among critical ecosystem services. These natural resources necessitate a well-designed monitoring scheme and more in-depth analysis to understand how small tropical lakes respond to and have impacts on environmental changes. We highlight the need for awareness regarding anthropogenic factors (*i.e.*, increasing urban homogenization, aquaculture and alteration of lake environments) that affect biodiversity. Lastly, our preliminary data serves to update and in some ways supplement what is currently known about the SMLs, especially the vertical profile of several important limnological characteristics. This in itself constitutes a contribution to the further development of limnology in the Philippines, which mirrors the state of limnological research in many developing countries, particularly in the tropics.

ACKNOWLEDGMENTS

We would like to thank the Department of Science and Technology – Accelerated Science and Technology Human Resource Development Program Scholarship for MU Mendoza, KSA Padilla, and JF Aguilar. We would also like to thank the University of Santo Tomas – Research Center for the Natural and Applied Sciences for access to its facilities. Thank you to Edna Marie Mijares, Christian Angelo H. Ilao, Patricia Demi T. Lim, Zayin Benjamin A. Villanueva, and Lovelle P. Vizcarra for assisting in the fieldwork in the SMLs. This work was supported by the Japan Society for the Promotion of Science Grant-in aid (no. 24405007 and 16H05774) and Research Institute for Humanity and Nature Project (D06-14200119) through N Okuda and M Itoh.

NOTES ON APPENDICES

The complete appendices section of the study is accessible at http://philjournsci.dost.gov.ph

REFERENCES

ADORABLE-ASIS AGA, CAUYAN GA, PAGULAYAN RC, MAGBANUA FS, PAPA RDS. 2016. The macrogastropod communities of aquaculture-intensive lakes in the Philippines. Molluscan Res 36: 223–230. doi: 10.1080/13235818.2016.1201016

ADRIAN R, O'REILLY CM, ZAGARESE H, BAINES SB, HESSEN DO, KELLER W, LIVINGSTONE DM, SOMMARUGA R, STRAILE D, VAN DONK E, WEYHENMEYER GA, WINDER M. 2009. Lakes as sentinels of climate change. Limnol Oceanogr 54: 2283–2297. doi: 10.4319/lo.2009.54.6_part_2.2283

AMIT MGC, BICOMONG RB, SANDALO RM. 2016. Exploring Stakeholders' Participation in Ecotourism of Pandin Lake in San Pablo City, Laguna. National Graduate Student Leadership and Research Conference; 18–19 Aug 2016; Graduate School, University of the Philippines Los Baños.

BANNISTER W, MCGOWAN S, SANTOS-BORJA AC, QUAK J, FONG LS, MENDOZA MU, PAPA RDS, TAYLOR D. 2019. Potential anthropogenic regime shifts in three freshwater lakes in Tropical East Asia. Freshw Biol 64: 708–722. doi: 10.1111/fwb.13256

BLANCO GJ. 1939. Two new decapods from the Philippines. Philipp J Sci 69: 167–171.

BOEHRER B, SCHULTZE M. 2008. Stratification Lakes. Rev Geophys 46: 1–27. doi: 10.1029/2006RG000210.1

BORN SM. 1979. Lake Rehabilitation: A Status Report. Environ Manage 3: 145–153. doi: 10.3917/ris.107.0095

BRILLO BBC. 2015a. Development issues regarding Bunot Lake: The Lesser Lake among the seven lakes of San Pablo City, Philippines. Lakes Reserv Res Manag 20: 155–165. doi: 10.1111/lre.12096

BRILLO BBC. 2015b. The status of Philippine lake studies: Scholarly deficit in social science and small-lake research. Asia-Pacific Soc Sci Rev 15: 78–101.

BRILLO BBC. 2016a. The case of Yambo Lake of San Pablo City, Nagcarlan and Rizal, Laguna, Philippines. Soc Sci 11: 5693–5702. doi: 10.3923/sscience.2016.5693.5702

BRILLO BBC. 2016b. Development of a small lake: Ecotourism enterprise for Pandin Lake, San Pablo City, Philippines. Lakes Reserv Res Manag 21: 284–292. doi: 10.1111/lre.12150

BRILLO BBC. 2016c. An Assessment of Development of a Transboundary Small Lake: Calibato Lake, San Pablo City and Rizal, Laguna, The Philippines. Asian J Water, Environ Pollut 13: 55–67. doi: 10.3233/AJW-160017

BRILLO BBC. 2016d. Developing a small lake: The case of Palakpakin Lake, San Pablo City, Philippines. Water Resour 43: 611–620. doi: 10.1134/S0097807816040035

BRILLO BBC. 2016e. Urban lake governance and development in the Philippines: The case of Sampaloc Lake, San Pablo City. Taiwan Water Conserv 64: 66–81.

BRILLO BBC. 2016f. Developing Mohicap Lake, San Pablo City, Philippines. Soc Sci 11: 283–290.

BRILLO BBC. 2017. The Politics of Lake Governance: Sampaloc Lake, Pandin Lake and Tadlac Lake of the Laguna de Bay Region, Philippines. Asia-Pacific Soc Sci Rev 17: 66–79.

BRIONES JCA, PAPA RDS, CAUYAN GA, MENDOZA N, OKUDA N. 2016. Fish diversity and trophic interactions in Lake Sampaloc (Luzon Is., Philippines). Trop Ecol 57: 567–581.

BRIONES JCA, PAPA RDS, CAUYAN GA, URABE M. 2015. Research note. the first report of three acanthocephalan parasite species isolated from Philippine fishes. Helminthol 52: 384–389. doi: 10.1515/helmin-2015-0061

CINCO M. 2017 (Aug 02). Next LLDA targets: Fish cages in San Pablo's Sampaloc Lake. Philippine Daily Inquirer. Retrieved from https://newsinfo.inquirer.net/919522/next-llda-targets-fish-cages-in-san-pablos-sampaloc-lake

COHEN AS, SOREGHAN MJ, SCHOLZ CA. 1986. Estimating the age of formation of lakes: An example from Lake Tanganyika, East African Rift system. Geology 21: 511–514. doi: 10.1130/0091-7613(1993)021

CORDERO CS, BALDIA SF. 2015. Temporal variation of phytoplankton community structure in Lake Mohicap, San Pablo City, Laguna, Philippines. Int J Pure Appl Biosci 3: 377–385.

DE LA CRUZ CPP, BANDAL JR. MZ, AVILA ARB, PALLER VGV. 2013. Distribution pattern of *Acanthogyrus* sp. (Acanthocephala: Quadrigyridae) in Nile tilapia (*Oreochromis niloticus* L.) from Sampaloc lake, Philippines. J Nat Stud 12: 11–17.

DELA PAZ ES, HOŁYŃSKA MK, PAPA RDS. 2016. *Mesocyclops* and *Thermocyclops* (Copepoda, Cyclopidae) in the major Visayas Islands (central Philippines). Crustaceana 89: 787–809. doi: 10.1163/15685403-00003547

[DENR] Department of Environment and Natural Resources. 2016. DENR Memorandum Circular No. 2016-08. Quezon City, Philippines.

[DENR-EMB] Department of Environment and National Resources – Environmental Management Bureau. 2014. National water quality status report 2006–2013. Quezon City, Philippines.

[DENR-EMB] Department of Environment and National Resources – Environmental Management Bureau. 1990. DENR Administrative Order No. 34. Quezon City, Philippines.

DIANA JS. 2009. Aquaculture Production and Biodiversity Conservation. Bioscience 59: 27–38. doi: 10.1525/bio.2009.59.1.7

DOWNING JA. 2010. Emerging global role of small lakes and ponds: Little things mean a lot. Limnetica 29(1): 9-24.

ENGELS S, FONG LSRZ, CHEN Q, LENG MJ, MCGOWAN S, IDRIS M, ROSE NL, RUSLAN MS, TAYLOR D, YANG H. 2018. Historical atmospheric pollution trends in Southeast Asia inferred from lake sediment records. Environ Pollut 235: 907–917. doi: 10.1016/j.envpol.2018.01.007

[FAO] Food and Agriculture Organization of the United Nations. 2014. Sustainable aquaculture development. Retrieved from http://www.fao.org/focus/e/fisheries/sustaq.htm on 10 Nov 2018.

[FAO] Food and Agriculture Organization of the United Nations. 2018. Fishery and Aquaculture Country Profiles: The Republic of the Philippines. Retrieved from http://www.fao.org/fishery/facp/PHL/en on 08 Feb 2018.

FULLER LM, JODOIN RS. 2016. Estimation of a Trophic State Index for selected inland lakes in Michigan, 1999–2013: U.S. Geological Survey Scientific Investigations Report 2016–5023, 16p., http://dx.doi.org/10.3133/sir20165023

[GVP] Global Volcanism Program. 2013. San Pablo Volcanic Field (273060). In: Volcanoes World, v. 4.6.6. Venzke E ed. Washington, DC: Smithson. Inst. Retrieved from http://volcano.si.edu/volcano.cfm?vn=273060 on 02 Mar 2018.

HALLARE AV, PAGULAYAN R, LACDAN N, KÖHLER HR, TRIEBSKORN R. 2005. Assessing water quality in a tropical lake using biomarkers in zebrafish embryos: Developmental toxicity and stress protein responses. Environ. Monit. Assess 104: 171–187. doi: 10.1007/s10661-005-1610-z

KELLY CA, RUDD JWM, FURUTANI A, SCHINDLER DW. 1984. Effects of lake acidification on rates of organic matter decomposition in sediments. 29:

687–694.

KINTANAR RL. 1984. Climate of the Philippines. Quezon City: Philippine Atmospheric, Geophysical and Astronomical Services Administration. Retrieved from http://bagong.pagasa.dost.gov.ph/information/climate-philippines#climate on 15 Oct 2018.

KRAUSE G, BRUGERE C, DIEDRICH A, EBELING MW, FERSE SC, MIKKELSEN E, PÉREZ AGÚNDEZ JA, STEAD SM, STYBEL N, TROELL M. 2015. A revolution without people? Closing the people-policy gap in aquaculture development. Aquaculture 447: 44–55. doi: 10.1016/j.aquaculture.2015.02.009

KUMAR MS. 2014. Sustainable Management of Fisheries and Aquaculture for Food Security and Nutrition: Policies Requirements and Actions. Agric Res 3: 97–103. doi: 10.1007/s40003-014-0111-0

LEGASPI KL, LAU AYA, JORDAN P, MACKAY A, MCGOWAN S, MCGLYNN G, BALDIA S, PAPA RDS, TAYLOR D. 2015. Establishing the impacts of freshwater aquaculture in tropical Asia: The potential role of palaeolimnology. Geogr Environ. p. 148–163. doi: 10.1002/geo2.13.

LEVIN PS, FOGARTY MJ, MURAWSKI SA, FLUHARTY D. 2009. Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. PLoS Biol 7. doi: 10.1371/journal.pbio.1000014

LEWIS WM. 2000. Basis for the protection and management of tropical lakes. Lakes Reserv. Res. Manag. 5: 35–48.

[LLDA] Laguna Lake Development Authority. 2014. Pandin Lake Development and Management Plan. Quezon City, Philippines.

[NOAA] National Oceanic and Atmospheric Administration. Laguna weather averages. Retrieved from https://www.ncdc.noaa.gov/

OROSA RL. 2014 (Feb 03). Laguna's 7 Crater Lakes proclaimed world's most threatened. Philippine Star. Retrieved from https://www.philstar.com/headlines/2014/02/03/1285996/lagunas-7-crater-lakes-proclaimed-worlds-most-threatened

PALLER VGV, BANDAL MZ JR., DE LA CRUZ CP. 2015. Acanthocephalan parasites in freshwater fishes from the Seven Lakes of San Pablo, Philippines: a prospective heavy metal biosink in aquatic ecosystem. 81st General Membership Assembly, The National Research Council of the Philippines; March 2014; Manila Hotel, Manila, Philippines.

PAPA RDS, LI H, TORDESILLAS DT, HAN B, DUMONT HJ. 2012. Massive invasion of *Arctodiaptomus dorsalis* (Copepoda, Calanoida, Diaptomidae) in Philippine lakes: A threat to Asian zooplankton biodiversity? Biol Invasions 14: 2471–2478. doi: 10.1007/s10530-012-0250-9

PASCUAL JAF, RIZO EZC, HAN B, DUMONT HJ, PAPA RDS. 2014. Taxonomy and distribution of four cladoceran families (Branchiopoda: Cladocera: Moinidae, Bosminidae, Chydoridae and sididae) in Philippine inland waters. Raffles Bull Zool 62: 771–794.

PETERSON JO, BORN SM, DUNST RC. 1974. Lake rehabilitation techniques and experiences. Water Resour Bull 10: 1228–1245.

POFF NL, BRINSON MM, DAY JW. 2002. Aquatic ecosystems & Global climate change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Prep Pew Cent Glob Clim Chang 1–56. doi: 10.1039/b211160h.

QUINTAL AL, GOTANGCO CK, GUZMAN MAL. 2018. Forecasting Urban Expansion in the Seven Lakes Area in San Pablo City, Laguna, the Philippines Using the Land Transformation Model. Environ Urban ASIA 9: 69–85. doi: 10.1177/0975425317748531

REPUBLIC OF THE PHILIPPINES. 1998. The Philippine Fisheries Code of 1998 (R.A. No. 8550). Tenth Congress of the Philippines.

RICE EW, BAIRD RB, EATON LS. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition. American Public Health Association, American Water Works Association, Water Environment Federation.

SAMBITAN KAP, PAPA RDS, BALDIA SF. 2015. Phytoplankton community structure of Lake Paoay and Lake Mohicap with notes on the first record of *Ceratium* (Dinophyta) in Lake Paoay. Acta Manila Ser A 63: 51–60.

SANTIAGO AE, ARCILLA RP. 1993. Tilapia cage culture and the dissolved oxygen trends in Sampaloc Lake, the Philippines. Environ Monit Assess 24: 243–255.

SCHEFFER M, VAN GEEST GJ, ZIMMER K, JEPPESEN E, SØNDERGAARD M, BUTLER MG, HANSON MA, DECLERCK S, DE MEESTER L. 2006. Small habitat size and isolation can promote species richness: Second-order effects on biodiversity in shallow lakes and ponds. Oikos 112: 227–231. doi: 10.1111/j.0030-1299.2006.14145.x

SOLPICO DB, LIBATIQUE NJC, TANGONAN GL, CABACUNGAN PM, GIRARDOT G, MACARAIG RM, PEREZ T, TERAN A. 2014. Solar-powered field server and aerator development for Lake Palakpakin. J Adv Comput Intell Informatics 18: 755–763. doi: 10.13140/2.1.3021.0245

STA. ANA JG, ENCARNACION BP, CABRERA R, ALCANTARA MF, DALISAY JS, NICOLAS JU, TINGAL DT, DE LA CRUZ AR. 2005a. Water Quality Report on Pandin Lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority.

STA. ANA JG, ENCARNACION BP, ESCULTOR RM, DE LA CRUZ AR. 2005b. Water Quality Report on Palakpakin Lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority.

STA. ANA JG, ENCARNACION BP, ESCULTOR RM, DE LA CRUZ AR. 2005c. Water Quality Report on Calibato Lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority.

STA. ANA JG, ENCARNACION BP, ESCULTOR RM, DE LA CRUZ AR. 2005d. Water Quality Report on Yambo Lake. Quezon City, Philippines: Laguna Lake Development Authority.

STA. ANA JG, RIVERA A, ENCARNACION BP, CABRERA RR, ALCANTARA FMB, DALISAY JS, NICOLAS JU, DE LA CRUZ AR, PASCUAL MST. 2005e. Water Quality Report on Mohicap Lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority.

STA. ANA JG, RIVERA AC, ENCARNACION BP, CABRERA RS, ALCANTARA FMB, DALISAY JS, NICOLAS JU, TINGAL DT, DE LA CRUZ AR, PASCUAL MST. 2005f. Water quality report on Bunot lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority. p. 1–26.

STA. ANA JG, RIVERA AC, ENCARNACION BP, CABRERA RR, ALCANTARA FMB, DALISAY JS, NICOLAS JU, DE LA CRUZ AR, PASCUAL MST. 2005g. Water Quality Report on Sampaloc Lake 1996–2005. Quezon City, Philippines: Laguna Lake Development Authority. 31p.

VILLARIN JT, ALGO JL, CINCO TA, CRUZ FT, DE GUZMAN RG, HILARIO FD, NARISMA GT, ORTIZ AM, SIRINGAN FP, TIBIG LV. 2016. 2016 Philippine Climate Change Assessment (PhilCCA): The Physical Science Basis. The Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation Inc. and Climate Change Commission.

VICENTE IST, FONSECA-ALVES CE. 2013. Impact of introduced Nile Tilapia (*Oreochromis niloticus*) on non-native aquatic ecosystems. Pak J Biol Sci 16: 121–126.

VINCENT WF. 2009. Effects of Climate Change on Lakes. In: Encyclopedia of Inland Waters, Vol. 3. Likens GE ed. Oxford: Elsevier. p. 55–60.

WILLIAMSON CE, DODDS W, KRATZ TK, PALMER MA. 2008. Lakes and streams as sentinels of environmental change in terrestrial and atmospheric processes. Front Ecol Environ 6: 247–254. doi: 10.1890/070140

ZAFARALLA MT. 2010. Plankton biodiversity, water quality and environmental status of Los Baños' Crocodile Lake and San Pablo City's seven lakes (Lakes Sampaloc and Pandin). International System for Agricultural Science and Technology. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=PH2012000144

ZAFARALLA MT. 2014. Microalgae of the Seven Lakes of San Pablo City & Crocodile Lake of Los Baños. Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development. ISBN: 978-971-547-317-0.

ZAPANTA IR, SALANDANAN M, DIRECTO MG, MAMADRA UD, NICOLAS JU, DE LA CRUZ AR. 2008. Water Quality Report of the Seven Crater lakes 2006–2008. Quezon City, Philippines: Laguna Lake Development Authority.

APPENDIX

Table I. Provisional species list documented in the SMLs of San Pablo City, Laguna, Philippines.

Phytoplankton	Macrophyte	Zooplankton	Fish	Gastropod	Other invertebrate
Anabaena sp. (7)	*Eichhornia crassipes* (6)	*Arctodiaptomus dorsalis* (1–7)	*Carassius gibelio* (6)	*Bullastra cumingiana* (6)	*Acanthogyrus* sp. (6)
Aulocoseira granulata (3)	*Nymphaea pubescens* (6)	*Asplachna sieboldi* (1–7)	*Cichlosoma* sp. (6)	*Cipangopaludina chinensis* (6)	*Palaemon talaverae* (6)
Ceratium sp. (5)	*Pistia stratiotes* (6)	*Bosmina longirostris* (1–7)	*Hypopthalmichthys nobilis* (6)	*Jagora asperata* (6)	
Cladophora spp. (6)		*Brachionus angularis* (1, 2, 3, 5, 6)	*Channa striata* (4, 5, 6)	*M. tuberculate* (6)	
Closterium sp. (5)		*Brachionus calicyflorus* (1–7)	*Cyprinus carpio* (4, 5, 6)	*Melanoides cf. turriculus* (6)	
Coelastrum sp. (1–7)		*Brachionus caudatus* (2, 4, 5, 7)	*Oreochromis aureus* (4, 5, 6)	*Physastra hungerfordiana* (6)	
Cosmarium sp. (5)		*Brachionus diversicornis* (3)	*Oreochromis niloticus* (1–7)	*Plotia scabra* (6)	
Crucigenia sp. (1–7)		*Brachionus falcatus* (1–5, 7)	*Parachromis managuensis* (4, 5, 6)	*Pomacea canaliculata* (6)	
Cyanophyta sp. (7)		*Brachionus forficula* (1, 2, 3, 5, 6)	*Giuris margaritacea* (4, 5, 6)	*Tarebia granifera* (6)	
Fragilaria crotonensis (3)		*Brachionus quadridentatus* (2,4,5)	*Glossogobius aureus* (6)	*Thiara winteri* (6)	
Glenodinium sp. (5)		*Brachionus* sp. (1)	*Leiopotherapon plumbeus* (4, 5, 6)		
Hormidium sp. (1–7)		*Brachionus urceolaris* (1, 2, 3, 6)	*Clarias batrachus* (6)		
Melosira sp. (1–7)		*Ceriodaphnia cornuta* (1–7)	*Pangasianodon hypopthalmus* (6)		
Microcystis sp. (1–7)		*Diaphanosoma excisum* (1–7)	*Vieja* sp. (4, 5, 6)		
Navicula sp. (5)		*Diaptomus sp.* (1, 3, 5, 6)			
Nitzschia sp. (1–7)		*Filinia longiseta* (1, 2, 3, 4, 5, 6)			
Oscillatoria sp. (7)		*Filinia opoliensis* (1, 3, 4, 5, 6)			
Oocystis sp. (5,6)		*Hexarthra fennica* (2–7)			
Schroederia sp. (1–7)		*Keratella* sp. (1–7)			
Staurastrum sp. (5)		*Kurzia* sp. (6)			
Stephanodiscus sp. (5)		*Lecane* sp. (3,5)			
Aulacoseira granulate (3, 6, 7)		*Lecane ungulata* (1, 2, 4, 6)			
Cyclotella meneghiniana (3, 6, 7)		*Macothrix* sp. (6)			

Discostella stelligera (3, 6, 7)	*Mesocyclops* sp. (1–7)
Discostella pseudostelligera (3, 6, 7)	*Moina* sp. (4)
Nitzschia palea (3, 6, 7)	*Synchaeta* sp. (1,5)
	Thermocyclops crassus (1–7)
	Thermocyclops decipiens (1, 3)
	Thermocyclops sp. (2)
	Thermocyclops taihokuensis (1, 3, 4, 5, 6)
	Trichocerca sp. (1–7)
	Trichocerca ungulata (4)

References: Adorable-Asis *et al.* 2016; Bannister *et al*. 2019; Blanco 1939; Briones *et al.* 2016; de la Cruz *et al.* 2013; Dela Paz *et al.* 2016; Legaspi *et al.* 2015; Papa *et al.* 2012; Sta. Ana *et al.* 2005a, b, c, d, e, f, g; Zapanta *et al.* 2008
1) Bunot, 2) Calibato, 3) Mohicap, 4) Palakpakin, 5) Pandin, 6) Sampaloc, and 7) Yambo