25 years (1988-2012) of freshwater research in the Philippines: what has been done and what to do next?

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Abstract

Globally, declines in freshwater biodiversity have been recognized to be far greater than those in marine or terrestrial realms. And like the rest of tropical Asia, the Philippine freshwater ecosystems and their biodiversity have been neglected. Our goals in this review are to provide indications where further research is needed, what systems are underrepresented and which organisms have been neglected. In this study, we determined the current knowledge on freshwater ecosystems in the country through critical evaluation of available peer-reviewed literature. A structured search on studies on Philippine freshwater systems published from January 1988 to December 2012 was performed using the Thomson Reuter's Web of Science and Zoological Records. A total of 281 papers that have directly assessed Philippine freshwater systems and/or have actually collected and examined aquatic organisms from these systems were included in the review. More than 70% of the papers were produced solely by local researchers or with international collaborators. There was a significant steady increase in Philippine freshwater studies, with systematics (105 papers) and freshwater fish (78 papers) being the most frequently studied research area and organism, respectively. Rivers (116 studies) and lakes (112 studies) are still the most frequently studied freshwater systems. Among the papers reviewed, Luzon freshwater systems were the focus of most studies with Laguna de Bay being the most researched. Freshwater systems in the Visayas and Mindanao received little research attention. Finally, we presented a four-point research agenda, the results of which could form the basis for policy or management decisions to aid future conservation and sustainable management of freshwater ecosystems and their biodiversity in the Philippines.

Key words :

Freshwater biodiversity
Biomonitoring
Biotic index
Climate change
Protected areas

Introduction

Globally, freshwater species and their habitats are the most imperilled compared to their terrestrial and marine counterparts (Abell et al., 2008; Dudgeon, 2010). Indeed, recent study reveals that between 1970 and 2010, freshwater species population has decline more rapidly (76%) than the terrestrial (39%) or marine (39%) species (WWF, 2014).

Freshwater biodiversity in tropical Asia has been neglected compared to its temperate counterpart (Dudgeon, 2000a; Dudgeon et al., 2006). The low priority given to freshwater research and the indifference of the public on freshwater ecosystems in addition to the rapid pace of development and the growing human population have contributed to the degradation of freshwater ecosystems and loss of biodiversity in the Oriental region (Dudgeon, 2000b). This situation is mirrored in the Philippines where few studies have been done on its freshwater biodiversity such as aquatic insects (Cariaso, 1997; but see Freitag, 2004, 2013), molluscs (Pagulayan, 1997) and freshwater fishes (Mercene, 1997; but see Bucol and Carumbana, 2010; Paller et al., 2011) in spite of their richness and diversity. Equally, there appears to be a conspicuous lack of research on the ecology of Philippine wetlands compared to lakes and the marine ecosystems which are used for aquaculture and fisheries.

Moreover, tropical Asia has high rates of deforestation and

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forest degradation which has been linked to species declines and extinctions in terrestrial biota (Sodhi et al., 2009, 2010a,b). Undoubtedly, riparian forest clearance has influenced stream community structure and ecosystem functioning (e.g., Jowett et al., 2009; Riipinen et al., 2009; Hladyz et al., 2011), but empirical evidence is scarce or poorly reported in the Philippines on how freshwater ecosystems and their organisms respond to human-driven changes in the surrounding landscape. Correspondingly, the Philippines lag behind other Asian countries in using biological communities as indicator of conditions in freshwater ecosystems (Morse et al., 2007; but see David, 2003). Many countries with protective water law and regulatory framework are assessing and monitoring changes in water quality, physical habitat and surrounding catchments based on sentinel organisms (Barbour & Paul 2010, Birk et al. 2012). Regrettably, assessment of water quality in the country still emphasizes chemical and physical measures despite the passage of Republic Act No. 9275, also known as the Philippine Clean Water Act of 2004.

Recent reviews on researches on freshwater ecosystems and their biodiversity have been done on a global (Dudgeon et al., 2006; Vörösmarty et al., 2010), regional (i.e., continental; Nguyen and De Silva, 2006; Darwall et al., 2011) and local scales (i.e., country-wide; Alcocer and Bernal-Brooks, 2010; Ball et al., 2013); but none in the Philippines (although see review on Lake Taal by Papa and Mamaril, 2011). A review of the past research is warranted to determine the “real” state of our current knowledge on freshwater ecosystems in the Philippines. These studies will provide indications where further research is needed, what systems are underrepresented and which organisms have been neglected; thus aiding in the development of management policies and practices for the conservation and sustainable use of these endangered ecosystems upon which over 100 million Filipinos rely.

Scope of Review

Using a structured search through the online search engines Thomson Reuters’ Web of Science (WoS) and Zoological Records (ZR), we examined studies on Philippine freshwater ecosystems published in the last 25 years (from 1 January 1988 to 31 December 2012, inclusive). Our search query was: TOPIC = ([Philippine or Philippines] AND [freshwater OR lake OR river OR stream OR creek OR groundwater OR wetland OR marsh OR swamp OR pond OR reservoir OR phytotelmata]).

Additionally, we look at citations in papers identified in the initial searches, including review papers (Davies, 1997; Papa and Mamaril, 2011) to capture studies that have been published but not indexed in the databases that we searched. We read the abstracts of all the papers that emerged and selected for review those primary studies (not reviews) that have directly assessed Philippine freshwater system and/or those that have actually collected and examined aquatic organisms from this system. Consequently, we did not include systematics studies (e.g. Kohler and Glaubrecht, 2001; Takeda and Ng, 2001) based on the examination of type materials from museum collections abroad. We then read each paper in the candidate list and removed those that had been erroneously retrieved by the search algorithm (e.g., studies in locations other than the Philippines).

From a total of 1576 search results, 281 research papers satisfied the criteria for inclusion in the review. We acknowledge that our dataset of studies is not exhaustive. Nonetheless, by focusing on studies published in WoS- and ZR-indexed journals we are able to capture a full picture of freshwater research in the Philippines for the past 25 years.

What Kind of Research has been Conducted?

Studies on Philippine freshwater ecosystems showed a number of interesting patterns. For example, there has been a generally steady increase in the number of papers published annually from 1988 to 2012 with the highest number of publications in the last 3 years (Fig. 1). Accordingly, the mean (± standard error) annual publication over the last 25 years was 12.12 (± 1.86) papers or simply 1 paper per month. Additionally, when compared to studies by foreign researchers, studies by local researchers increased in the last decade (Table 1). Equally, papers jointly authored by local and foreign researchers considerably improved.

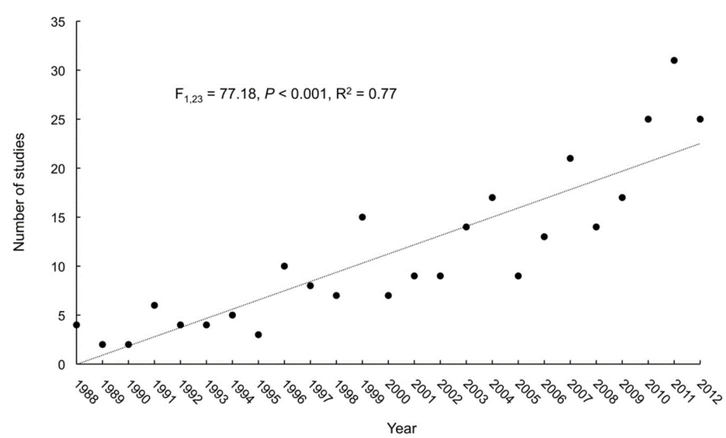

Figure 1. Number of studies on Philippine freshwater ecosystems published in the Thomson Reuter’s Web of Science- and Zoological Records-indexed journals from 1988 to 2012.

Table 1. Total number of studies on a 5-year basis authored by local researchers, foreign researchers or both.

Year	Local	Foreign	Collaboration	Total
1988-1992	11	4	3	18
1993-1997	10	13	7	30
1998-2002	14	23	11	48
2003-2007	23	21	30	74
2008-2012	60	14	37	111
Total (% of total)	118 (42)	75 (27)	88 (31)	281

Types of ecosystems

Across all years, 114 out of 281 studies have been conducted in lotic systems (e.g. streams, rivers, creeks), 101 studies in lentic systems (e.g. lakes, ponds), nine studies in groundwater and wastewater, three in wetlands and 40 studies in a combination of lentic, lotic and groundwater systems. The remaining 14 studies did not specify the system they investigated. However, based on the number of papers for a single type of ecosystem, rivers and lakes are still the most frequently studied freshwater systems with 116 and 112 studies, respectively (Fig. 2). Phytotelmata, wetlands, subterranean systems and falls are significantly less represented, having less than 10 studies each. Note that several of the studies considered in this review covered more than one ecosystem and thus will not add up to 281 when totaled.

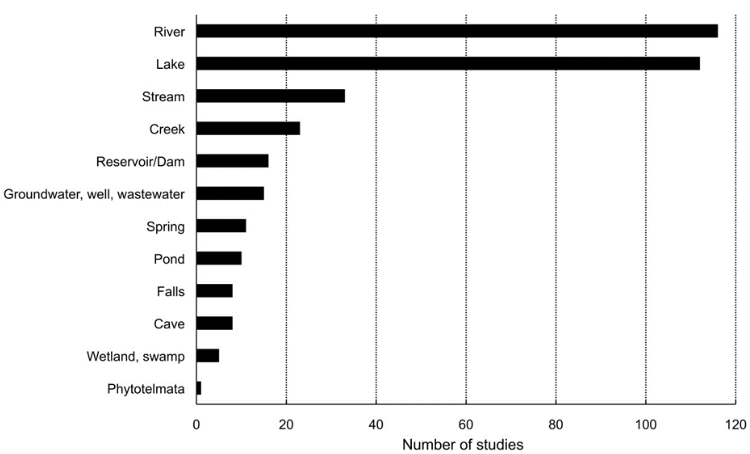

Figure 2. Number of studies per freshwater ecosystem type.

Geographic distribution

Among the 281 papers reviewed, 194 papers (69.0%) focused solely on sites found in Luzon, 40 papers (14.2%) in the Visayas, and 22 papers (7.8%) in Mindanao. In addition, nine papers (3.2%) covered all three major islands and 12 papers (4.3%) in at least two of the island groups. As with the types of ecosystems, 4 studies (1.4%) did not specify the location.

The 15 most frequently studied freshwater systems in the country comprised 201 studies. Laguna de Bay, the largest lake in the country, appeared in 53 of these studies whereas Lake Taal appeared in 25 studies (Table 2). These lakes together with the Puerto Princesa Subterranean River National Park, Pasig River, Cagayan River Basin and Lake Lanao were the research sites in more than 10 studies (Fig 3). The rest of the research sites had 5-9 studies (Table 2). Only Lake Lanao and Lake Sebu are not found in Luzon.

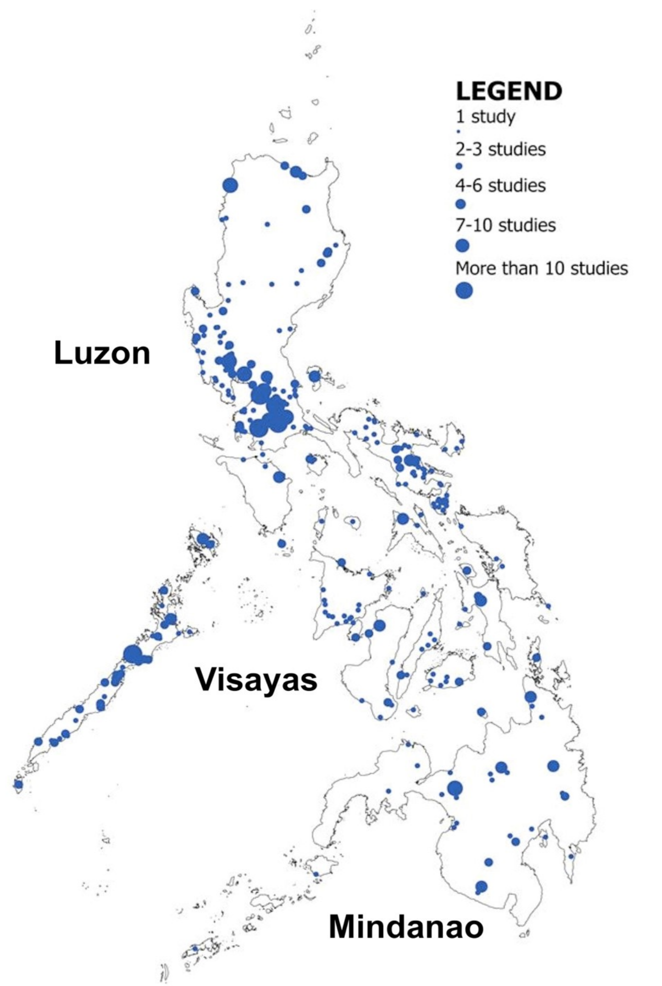

Figure 3. Number of studies per research area.

Table 2. Fifteen most studied freshwater systems in the Philippines.

Site	Province	No. studies
Laguna de Bay	Laguna	53
Lake Taal	Batangas	25
Puerto Princesa Subterranean River National Park	Palawan	14
Pasig River	Metro Manila	12
Lake Lanao	Lanao del Sur	11
Lake Sampaloc	Laguna	9
Mt. Makiling Forest Reserve	Laguna	9
Pagsanjan-Lumban Catchment	Laguna	9
Pampanga River Basin	Pampanga	8
Angat Dam	Bulacan	7
Lake Paoay	Ilocos Norte	7
Marikina River	Metro Manila and Rizal	7
Pasig-Potrero River Basin	Pampanga	7
Lake Buhi	Camarinse Sur	6
Lake Sebu	South Cotobato	5

Research areas

Studies done in the past 25 years were wide ranging, with 13 research areas under which the 281 studies were categorized (Fig. 4). As with the ecosystem types, several of the studies dealt with more than one field of research. Systematics (which, for the purpose of this review, includes taxonomy, biology and life history, and biogeography) was the topic of 105 papers, the highest number was observed in 2007 (12 of 21 total studies for that year) and 2011 (15 of 38 total studies) (Table 3). Although two papers on systematics that were found through the search has been published way back in the early 1990s (Ng, 1991; Stock, 1991), there has been at least one systematics-related paper published every year since. In fact, an average increase of 5.7 (± 0.9) papers per year was observed from 1996 to 2012. This may be attributed to the correspondingly increasing number of taxonomic descriptions using morphological characteristics, molecular data or both. Interestingly, 41.0% of the systematics-related papers were by foreign authors while only 31.40% were by researchers based in the Philippines (data not shown). The remaining 27.6% were collaborations between foreign and local researchers, the earliest of which was by Balete and Holthuis (1992) on a cave shrimp. However, it was only until the study of Primavera (1996) on the diet of penaeid shrimps in riverine mangrove and the study of Pagulayan et al. (1997) on littoral fishes of Lake Taal that papers on systematics were published solely by local scientists; at least, during the period covered in this review.

Second to systematics in terms of number of studies was water quality and quantity, with 60 studies (Fig. 4). Aside from measuring water quality parameters such as pH, dissolved oxygen, temperature, etc., 19 studies correlated the values of several physicochemical parameters with various freshwater organisms (e.g., Cuvin-Aralar et al., 2004; Aquino et al., 2008). Studies under water quantity, on the other hand, concerned flooding (e.g., Abon et al., 2012), drought (e.g., Jaranilla-Sanchez et al., 2011), and water productivity (e.g., Hafeez et al., 2007).

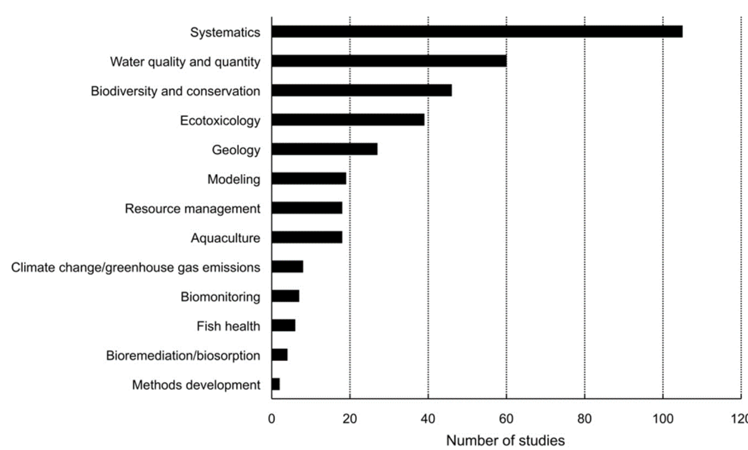

Figure 4. Number of studies for each major organism group.

Table 3. Number of studies by research area by year.

Research area	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Systematics				2	3	1	1	1	3	4	4	8	4	1	6	3	6	2	4	12	4	7	6	15	8	105
Water quality and quantity			1	1		1			2	1	1	2	2	3	1	5	5	4	4	2	2	4	5	6	8	60
Biodiversity and conservation	1	2				1	1	1		1		3		1	1	2	3	2	2	1	5	3	9	4	3	46
Ecotoxicology	1		1	1	1		1		2		1	2		1	1	5	2	2	4	1	2	3	1	3	4	39
Geology				1		1			1	3	1	1	1	1	1		3	1	1	1		1	3	4	2	27
Modeling									1		1					1	2	1			1	1	4	3	4	19
Aquaculture	1		1	1		1	3					1	1	2					1	1		2	1	1	1	18
Resource management	1								1		1			1		2	2		1		2	1	1	2	3	18
Climate change/ greenhouse gas emissions									2			1								1		1	2		1	8
Biomonitoring															1	2	1					1	1		1	7
Fish health								2						2		1									1	6
Bioremediation/ biosorption																			1	2			1			4
Methods development																	1		1							2
Total	4	2	3	6	4	5	6	4	12	9	9	18	8	12	11	21	25	12	19	21	16	24	34	38	36	359

Biodiversity and conservation was the third most popular research area. Among the 46 studies under this field, only 10 papers were published from 1988 to 2000 (Table 3). However, starting 2001, at least 1 paper was published annually. The highest number of publications (9 papers) in a year was observed in 2010, the International Year of Biodiversity. Indices used in biodiversity studies include the Shannon index (H'), Pielou's evenness (J'), Simpson's index (λ) and Sørensen's index of similarity (QS). A total of 15 studies indicated a list of species and/or species richness, while only 8 had information on species endemicity and/or conservation status (e.g., Regodos and Schoppe, 2005). Conservation studies focused on freshwater crocodiles (van de Ven et al., 2009; van der Ploeg et al., 2011), turtles (Regodos and Schoppe, 2005; Diesmos et al., 2008), the endemic cyprinid *Puntius lindog* (Ismail and Escudero, 2011), and otters (Castro and Dolorosa, 2006). Thirty studies had study sites found in Protected Areas, 24 of which also concerned Key Biodiversity Areas (KBAs), critical KBAs (cKBAs), New Conservation Areas of the Philippines Project, Project NOAH (Nationwide Operational Assessment of Hazards) river basins, and Ramsar List of Wetlands of International Importance, but only 6 mentioned the sites' protected area status. Among the papers, only Jumawan et al. (2011) and Papa et al. (2012) focused on the occurrence of invasive species in Philippine freshwater systems. For a recent review on the impacts of introduced freshwater fishes in the country, see Guerrero (2014).

Other research areas which had 18-39 studies were ecotoxicology, geology, modeling, resource management and aquaculture (Table 3). Studies on biomarkers (e.g., Hallare et al., 2005, Beltran and Pocsidio, 2010) and sediment quality (e.g., Isobe et al., 2004) were placed under ecotoxicology, while studies on sedimentation (e.g., Liu et al., 2009) and stream geochemistry (e.g., Rae et al., 2011) were considered under geology. Subtopics under modeling included river flow forecasting (Madsen and Skotner, 2005), risk assessment in surface waters (McAvoy et al., 2003), and flood reconstruction (Abon et al., 2011). Sustainable development, rehabilitation of freshwater systems (Malmgren-Hansen et al., 1998) as well as their economic value (e.g., Briones, 2012) fell under resource management, while most of the studies on aquaculture focused on tilapia (*Oreochromis niloticus*) (e.g., Santiago, 1993, 1994; Cuvin-Aralar et al., 2012). All four preceding research areas had the highest number of studies from 2008 to 2012.

Climate change, biomonitoring, fish health, bioremediation, and method development were the least-studied areas of research with less than 10 studies each. Within the last 25 years, papers on biomonitoring (e.g., David, 2003; Flores and Zafaralla, 2012) and bioremediation (e.g., Parungao et al., 2007; Nacorda et al., 2010) on Philippine freshwater ecosystems started to appear only in 2002 (Galope-Bacaltos and San Diego-McGlone, 2002) and 2006 (Baysa et al., 2006), respectively. Fish health studies discussed the occurrence, transmission, description and/or effects of parasitic worms (e.g., de la Cruz and Paller, 2012), fungi (Callinan et al., 1995), and viruses (Lio-Po et al., 2003) on economically-important fish. Topics under climate change include the assessment of climate change impacts on water balance (e.g., Brown and Carriquiry, 2007), the effects of climate change on water resources (e.g., Jose et al., 1996), and greenhouse gas emissions (Maraseni et al., 2010). With only two studies, methods development appears to be the least studied area; however, it may be due to the fact that most methods in freshwater ecology have been established early on, at least in the temperate region (Wetzel and Likens, 2000; Hauer and Lamberti, 2007). Nonetheless, the first methods development study was the modification of an emergence trap for use in several streams in Palawan (Freitag, 2004), while the second one was on the modification of analytical procedure for the determination of pesticide residues in soil and river water samples from northern Luzon (Cid et al., 2006).

Types of organisms

Among the 11 major groups of organisms considered in the studies covered in this review, fish are the most frequently studied (Fig. 5). The highest number of studies related to fish was observed in 2011. Fish were differentiated from other vertebrates (represented by crocodiles, turtles, frogs, snakes and otters) to see if the number of studies on the former was considerably larger. This was also the case for insects and other invertebrates. Considerably less studied than fish and invertebrates are benthic algae (e.g., Sly et al., 1993), phytoplankton (e.g., Baldia et al., 2003), parasites and pathogens (e.g., Cone et al., 1995), macrophytes (e.g., Baysa et al., 2006) and bacteria (e.g., Parungao et al., 2007), with less than 10 studies each (Fig. 5). As with research areas, several of the studies discussed more than one group of organisms.

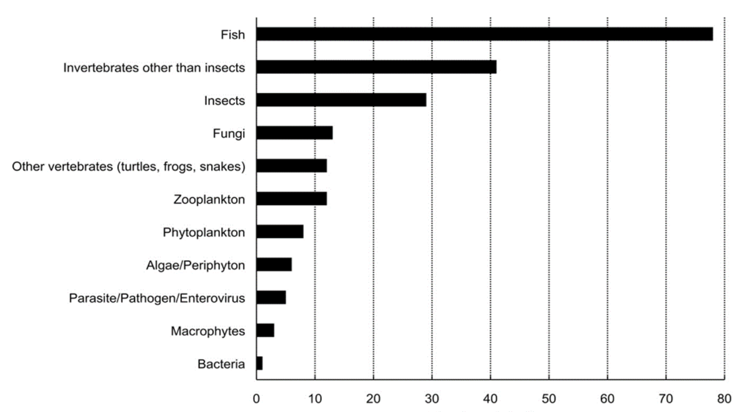

Figure 5. Geographic distribution of the 281 studies.

WHAT TO DO NEXT?

These past 25 years, majority of the research on Philippine freshwater ecosystems focused on Luzon systems. Further studies must therefore be conducted in the Visayas and Mindanao freshwater ecosystems. Additionally, more attention should be given to less-represented fields of research such as methods development, fish health, bioremediation, biomonitoring and the effects of climate change on freshwater ecosystems.

Given the rate of biodiversity loss in freshwater ecosystems, we agree with Dudgeon (2000a) that we do not have the luxury of unlimited time for further studies. And to ensure effective protection of the freshwater ecosystems, their biodiversity and the services they provide to humanity, parallel efforts are therefore needed. While proactive conservation and management actions based on existing ecological information must be applied now, specific ecological research to address knowledge gaps must also continue. The results of which could form the basis for policy or management decisions to aid future conservation and sustainable management of freshwater ecosystems and their biodiversity in the Philippines.

Here, we presented a four-point research agenda for consideration by researchers from the academe and resource managers from implementing agencies, nongovernmental organizations and private institutions involved in watershed management and water quality monitoring programs.

Biodiversity studies

Our review showed that fishes are the well-studied group and fish systematics comprised most of these studies. The availability of exceptionally rich collection of identification tools on fishes of the Philippines (e.g., Conlu, 1986; Broad, 2003) and of Southeast Asia (e.g., Allen et al., 1999; Kottelat et al., 1993) may have contributed to the increased research on fishes. While invertebrates (other than insects and zooplanktons) and insects are the second and third most studied groups, respectively, there is a lack of consolidated reference or monograph that can serve as standard taxonomic guide for the Philippines similar to that of Merritt et al.'s (2008) *An Introduction to the Aquatic Insects of North American* or Yule and Yong's (2004) *Freshwater Invertebrates of Malaysian Region*. But we do have a monograph for the Philippine zooplankton (Mamaril, 1986), which benefitted many of our young researchers. Nevertheless, the existing taxonomic keys on insects and other invertebrates are widely scattered and need to be updated and integrated. An informative and comprehensive illustrated guide on freshwater invertebrates of the Philippines is crucial in the identification of these organisms and thus contribute in the development of the biomonitoring program in the country. This illustrated guide will also serve as a form of information, educational and communication (IEC) material for non-experts including resource managers, teachers, students, volunteers and other appropriate stakeholders who will be involved in the implementation of biomonitoring system for freshwater ecosystems (see Biomonitoring below).

Indeed, ecological research, in addition to taxonomic studies and development of identification tools, must be done in the above organisms and even more so with the least studied groups (algae, bacteria, parasites and macrophytes). Basic ecological information such as knowledge on the structure of freshwater communities in relatively undisturbed sites remains very incomplete. Such information on algae, plankton, benthic macroinvertebrate and fish fauna in the country's few remaining intact, pristine forest ecosystems can be used as reference to compare organisms' responses to human disturbance gradient and thus indicate their potential utility for biological assessment and monitoring. Furthermore, data from longer-term ecological studies on freshwater biodiversity will help establish spatial and temporal variations and separate changes caused by human impacts ('signal') from those due to natural processes ('noise'). Better understanding of the responses of freshwater organisms to environmental changes can help in the management and conservation of these species and ultimately the freshwater ecosystems within and even outside protected area management.

Impact of current protected area regime on freshwater ecosystems and their biodiversity

While there have been several studies on freshwater systems found in PAs, KBAs and cKBAs including Ramsar and other heritage sites, none of the studies directly assess the effectiveness of the protected area management system in conserving freshwater species in a manner similar to that of Chessman (2013a) for the Australia's Murray-Darling Basin or to that of Suurkuukka et al. (2014) for the Woodland key habitats in northern Europe. The Philippine National Integrated Protected Area System (NIPAS), currently on its 24th year of implementation, provides the legal framework for the protection of critical watersheds that are essential for the conservation of biodiversity. Sadly, the Philippines with its 170 terrestrial PAs has "…no overall systematic data on impacts - whether there is improvement in biophysical condition of PAs, quality of life of communities, or increased benefits to the country" (UNDP et al., 2012; p. 18). Such studies will guide planners, resource and park managers on how best to design protected areas to maximize its benefits in conserving the country's biodiversity. We do not know if the current protected areas, which are often delineated based on terrestrial vertebrates and vascular plants (Abell et al. 2007, Heino et al. 2009; Darwall et al., 2011), are ecologically representative and thus optimally protect (Pimm et al. 2014) our freshwater biodiversity. Recent assessment in continental Africa showed that current conservation strategies based on better-known terrestrial species are not providing adequate protection for freshwater ecosystems and the ecosystem services they provide (Darwall et al., 2011). We hope that in the design and establishment of future protected areas and the planned expansion of protected terrestrial area network in the country, freshwater species are not underrepresented and that protection of these species will not be based on groups that are poor surrogates (*sensu* Darwall et al., 2011).

Climate change and freshwater ecosystems

Climate change has profound effects on freshwater ecosystems (Allan et al., 2005; Döll and Zhang, 2010; Woodward et al., 2010). Moreover, climate change is expected to exacerbate other stressors on ecosystems such as habitat fragmentation, loss and conversion, over-exploitation, invasive alien species and pollution (UNDP et al., 2012). Correspondingly, climate change is considered as the leading threat to global biodiversity and the functioning of local ecosystems (Woodward et al., 2010).

The impacts of climate change on biodiversity and water resources in tropical Asia are key areas of concern (IPCC 2001) as climate change affects rainfall distribution which ultimately affects runoff to freshwater ecosystems. Increased occurrence of extreme floods and droughts also intensifies the seasonal and annual amplitudes of water-level fluctuation in lakes, reservoirs and other wetlands (Abrahams, 2008; Zohary and Ostrovsky, 2011).

Our understanding of the effects of these changes on Philippine freshwater ecosystems and their biodiversity is limited. Modeling efforts based on variation in stream flow, precipitation, evapotranspiration and other related processes have recently been made to fully capture the hydrologic responses corresponding to various land use and climate change scenarios in the country (Combalicer et al., 2010, Combalicer and Im, 2012). In particular, the impacts of climate change on water balance reflect dramatic fluctuations in hydrologic events leading to high evaporation losses and decreases in stream flow such as in the Mt. Makiling forest watershed (Combalicer et al., 2010). Moreover, a study on the Pantabangan-Carranglan watershed reveals increasing frequency in the occurrence of drought associated with El Niño episodes over the last 20 years (Lasco et al., 2010). These authors also reported variability in the onset of rainy season that has become a common event in the Pantabangan-Carranglan watershed since 2000. These changes in climatic patterns coupled with water management decisions are expected to directly influence the ecological functioning and biodiversity patterns of the reservoir and its river tributaries (Lasco et al., 2010). Indeed, the Pantabangan reservoir experiences reduced water quality at low water levels and thus affecting its biodiversity (Magbanua et al., 2015).

Evidence that climate change threatens many freshwater species with extinction continues to grow (Chessman, 2013b). Nonetheless, empirical evidence on how freshwater biodiversity responds to reduced flow in streams, or warming in the case of lakes, caused by intensified land use and climate change is scarce or poorly reported in the Philippines. Additionally, the consequences of climate change on Philippine freshwater biodiversity are not clear due to lack of accurate metrics by which to assess the true magnitude of these changes. Given that climate regimes appear to be changing rapidly, the collection of longer-term biological and environmental data related to stream flow and lake thermal stratification and the subsequent monitoring of key sites is imperative and should be undertaken as soon as possible.

Biomonitoring and the Philippine Biotic Index

The diversity of aquatic life represents the ultimate indicator of the conditions in the aquatic ecosystems (Morin et al., 2010). Consequently, biomonitoring or the use of responses of aquatic organisms to identify, evaluate and monitor changes in water quality, changes in physical habitat, and changes to surrounding watersheds (Reece and Richardson, 2000; Bae et al., 2005). Often, these changes are due to anthropogenic activities.

Biomonitoring is widely used in North America (e.g., Lavoie et al., 2014; Justus et al., 2016), Europe (e.g., Birk et al., 2012; Cortes et al., 2013), South America (e.g., Baptista et al., 2013; Dedieu et al., 2015), Africa (e.g. Ollis et al., 2006; Kaaya et al., 2015), Australia (e.g., Chessman et al. 1999; Chessman et al., 2007) and New Zealand (e.g., Gray & Harding, 2012; Lear et al., 2012), and is an integral part of government programs that monitor the quality of water resources. Amongst the key freshwater organisms, benthic macroinvertebrates are the most commonly used organisms for assessing the biological integrity of streams and rivers (Rosenberg and Resh, 1993; Bonada et al., 2006). The use of macroinvertebrates for monitoring water quality has increased in East Asia particularly in China (Morse et al., 1994; Taowu et al., 2008; Li et al., 2010), Japan (Kawai, 1985; Kawai and Tanida, 2005), South Korea (Bae et al., 2005; Jun et al., 2012), Malaysia (Azrina et al., 2006; Al-Shami et al., 2010, 2011), Mongolia (Morse et al., 2007; Maasri and Gelhaus, 2012), Asian Russia (Schletterer et al., 2010, 2011), Thailand (Mustow, 2002; Boonsoong et al., 2009), Indonesia (Trihadiningrum et al., 1996; Sudaryanti et al., 2001), Taiwan (Hu et al., 2007; Narangarvuu et al., 2014), Vietnam (Davidson et al., 2006; Nguyen et al., 2014), and more recently in Singapore (Blakely et al., 2014; Clews et al., 2014).

Sound management of aquatic ecosystems should be based on careful analysis of physical, chemical and biological integrity (Fausch *et al*. 1984). Historically, the Philippines have been measuring physicochemical variables to assess and monitor environmental and water quality of freshwater ecosystems. Moreover, the country lacks an established system of aquatic bioindicators to help evaluate watershed quality and thus preserve freshwater biodiversity and biotic integrity. A tolerance-based index with tolerance values developed specifically for the local fauna should perform well for the Philippines (B.C. Chessman, University of New South Wales, pers. comm.). Indeed, the formulation of a diagnostic biotic index based on tolerance values of stream macroinvertebrate families can be done and proved to be sensitive to effects of land use (Deborde et al., 2016). Clearly, this biotic index needs to be modified and improved further as its application expands to other Philippine streams. A similar index can be developed for lakes, reservoirs and other lentic ecosystems. It is envisaged that these indices will serve as a standard tool to objectively compare the state of freshwater ecosystems across the country and thus addressing a specific gap in the implementation of the Philippine Clean Water Act, which is the assessment and monitoring of biological integrity of aquatic ecosystems.

The Philippine Society for Freshwater Sciences (PSFS)

Finally, there is a great need to enhance freshwater science in the Philippines by training more scientists, students, and local resource managers for effective assessment, monitoring, management, and restoration. A network for freshwater science practitioners will help promote collaboration rather than duplication of research, sharing of capabilities and resources, and most importantly mainstream data publishing.

Through this network, a set of standardized field and laboratory protocols as well as biomonitoring systems may be developed to help make future studies more comparable. These standards may then be implemented by national government agencies, local government units, nongovernmental organization, and private institutions in their respective watershed and environmental management programs.

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