Fish diversity in selected small lakes in Mindanao, Philippines

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Abstract. It is said that species richness depends on the size and distance of water bodies and that the larger and closer the lakes are, the more species they have, more than smaller and more distant lakes. Based on the literature, large lakes covering large areas are given more research importance, while the global role of small lakes is less studied. For this reason, this study aimed to determine the relationship between the surface area and fish species diversity of the six isolated lakes found on the island of Mindanao, namely Lakewood, Apo, Napalit, Holon, Tiktikan, and Kanlunes lakes. Five of these lakes are considered open and connected, while Kanlunes Lake is closed and isolated. Results show an acidic pH value of 4.73 in Lakewood. Only Napalit Lake was able to achieve excellent oxygen saturation. A total of 33 families with 59 species were recorded, 46 of which are native to the Philippines, one is endemic, *Rasbora everreti*, and 11 are known to be introduced. It was observed that the introduced *Oreochromis niloticus* was common to the five lakes, except for Tiktikan Lake. This lake is the most species-rich and abundant, but showed significant unevenness in its population. Also, results showed that the lake surface area has no significant effect on species diversity and evenness. Though the value of strength association is insignificant, a directly proportional relationship between surface area, diversity, and evenness can be observed. It should also be noted that the actual relationship between taxon diversity and lake size differs widely among species. But it should also be stressed that the existing relationship between taxon diversity and lake size might vary widely among species. The diversity observed among the six lakes could also be attributed to many other ecological factors, including the anthropogenic factor, and should be further studied.

Key Words: association, evenness, lake size, species richness, water parameters.

Introduction. Inland waters such as rivers and lakes are considered important for hydrology sources and fisheries (Groombridge & Jenkins 1998; Jenkins 2003; BAS 2014; Mutia et al 2018). These waters are considered a source of food for many poor people and communities (Fernandez-San Valentin & Berja 2012; van der Ploeg 2017), especially their contribution to the Philippines' economy (delos Angeles 1990; Israel 2008). However, pollution, overexploitation, invasive species, and rapid land-use transitions have led to a severe decline in biodiversity in these many aquatic resources (Kottelat & Whitten 1996; Araullo 2001; Ong et al 2002; DENR-PAWB 2005; Dudgeon et al 2006; Delgado 2003; Macusi et al 2015; Cuvin-Aralar 2016; Appleton et al 2006; Nieves et al 2020; Su et al 2021). These even pose biosecurity issues such as outbreaks and the spread of diseases (Pruder 2003; Lightner 2003; Mendoza et al 2019). Since aquaculture is one of the most critical industries in the Philippines, these resources must be conserved, protected, and properly managed. These can be done by looking into the fish inventory present as ecological indicators, fisheries stability descriptors, and ecological integrity of aquatic habitats (Ikpi & Offem 2011; Karr 1991; Welcomme 1995; Zampella & Bunnell 1998). Impacts of habitat deterioration, invasive alien species, and climate change across spatial and temporal scales should also be included (Nisikawa & Nakano 1998; Zampella & Bunnell 1998; Guerrero 2002; Ramsundar 2004; Kwak & Peterson 2007; Ter Braak & Verdonschot 1995; Angermeier & Davideanu 2004; Anticamara & Go 2016). Many studies conducted in the Philippines have shown the importance of biodiversity assessment of many inland aquatic resources to the integrity of the aquatic ecosystem (Aralar 2016; Angeles 2005; Romero et al 2016; Paller et al 2013; Corpuz et al 2015a, 2015b, 2016; Guzman & Capaque

2014; Romero et al 2016; Briones et al 2016; Quimpang et al 2016; Estal-Mercado 2018; Paller et al 2017; Garcia et al 2018; Baysa et al 2019; Roque et al 2019). Most studies on inland waters cover the large lakes of the world, which cover the most area and are generally considered important for research (Downing et al 2006; Downing 2010). The global role of small lakes has been doubly missed because the spatial area has been underestimated (Downing 2010). However, it is important to note that small lakes and ponds dominate the world's lake area (Wetzel 1990; Downing et al 2006). Thus, studies on small lakes, especially in the Philippines, where they are most abundant, are crucial since they are more exposed to intensive activity like erosion, deposition, and landscape alteration, making them more dynamic than large water bodies (Downing 2010).

Material and Method

Description of the study sites. The sampling area covers the small and isolated lakes located in the different regions of Mindanao Island, Philippines (Figure 1; Table 1). The physical characteristics of each lake were considered to have uniformity in its sampling area. Secondary data regarding the features of the lake were also collected and recorded through key informant accounts and the local government agencies/offices.

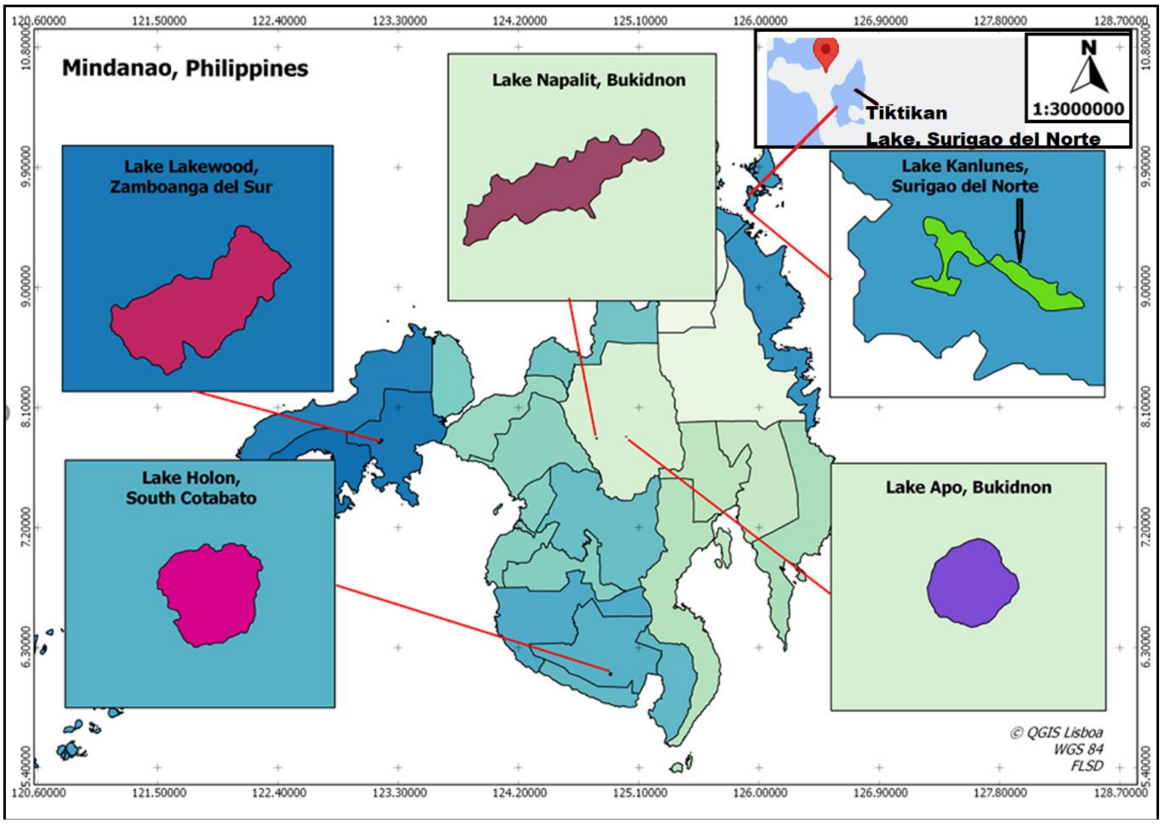

Figure 1. The map of the Mindanao Island, specifically the sampling area in the different lakes of various provinces considered in the study.

Data collection. Physical properties of the lake water were determined using a glass mercury thermometer for temperature, Oakton Instruments Waterproof Big Display pH Tester for pH, and Extech DO600 ExStik II DO Meter for the dissolved oxygen. The data were collected on-site between 9-11 a.m. and recorded with three replicates to avoid biases. The collection of fish used different local fishing methods in various study areas, suitable for each area. In Lakewood and Holon's lakes, locals use hook-and-line, drift nets, and traps, which are set every afternoon around 4 p.m. Spearguns were also used every early morning around 4 a.m. In Apo and Napalit lakes, locals used rift nets and spear guns. In Kanlunes and Tiktikan lakes, locals used traps and spear guns for fish collection. The collection lasted for four days at each lake sampling site from January to May 2017. Live fish were collected in different areas of the lake with the help of the residents. The samples were individually photographed using a 20.1 megapixels Sony digital camera and taxonomically identified using the field guide Fishes of the Philippines: A Guide to Identification of Families (Broad, 2003) and the website FishBase.

Table 1

List of the sampling area considered in the study

Region	*Province*	*Lakes*
IX	Zamboanga del Sur	Lakewood
X	Bukidnon	Apo
		Napalit
CARAGA	Surigao del Norte	Tiktikan
		Kanlunes
XI	South Cotabato	Holon

Data analysis. Species diversity was determined using species richness, Shannon–Wiener diversity, evenness, and dominance indices (Moore 2013). Multivariate linear regression analysis of the physicochemical parameters of the water in lakes was done using the Paleontological Statistics (PAST) software (Hammer et al 2009).

Results and Discussion. Table 2 presents the characteristics of the six lakes. It can be seen from the results that five are open and connected lakes, while only one, Kanlunes Lake, is closed and isolated, since no river tributaries are linked to it. The six lakes are either volcanic or tectonic lakes. Lakewood has the largest surface area (740.66 ha) among the lakes, while Tiktikan is the smallest. The five lakes are economically exploited for tourism and fisheries except for Kanlunes, which is unexplored.

The water quality of the lake measured is presented in Table 3. The results showed that only Apo Lake was within the acceptable range, while for the inland lakes Tiktikan and Kanlunes, a pH slightly higher than the optimal range was observed. Tiktikan Lake is visibly connected to a lagoon where an exchange of fresh and saltwater is evident. At the same time, Kanlunes Lake has no visible outlet or inlet of seawater, and the locals made an underground channel. Only Napalit Lake has an excellent DO saturation, while Lakewood has low DO levels. Variations in the number and amount of nutrients were also observed among the lakes.

Thirty-three families with 60 species were observed and recorded in the six lakes (Table 4). Qualitative inspection of the data shows differences in the occurrence of the species among the lakes. *Oreochromis niloticus* was familiar in five lakes, except Tiktikan. The fish composition of Tiktikan Lake is far different from the rest of the lakes, as most of its fish species are usually from marine waters. This could be due to the direct connection of the lake to a lagoon, in which seawater enters the lake at high tide. Some of the fish that can be observed in Kanlunes Lake were also observed in marine waters. According to the local communities, this observation is possible because of an underground inlet, where saltwater can enter.

The salinity in the lake area is also high. The bodies of most fish are not impermeable to water. The absorption takes place mainly in skin and gill membranes (LeBlanc et al 2010). Fish live in a solution of water that resembles the fluids in their bodies. The difference in concentration of dissolved substances within the fish and surrounding water causes pressure on water to flow into or out of the fish. The continued gain or loss of water and related electrolyte imbalance could lead to death (Takvam et al 2021). But fish can adapt to changes. Fish that live in freshwater tend to have less saline body fluids than their surroundings. There is pressure for water to move from the less saline side to the more saline side. Freshwater fish tend to gain significant water through their gills and skin. Fish scales help to retard this movement (LeBlanc et al 2010)

Table 2

Summarized morphology and physical characteristics of the different lakes in Mindanao, Philippines, selected in this study

	Mindanao Small Lakes					
Characteristics	*Lakewood*	*Apo*	*Napalit*	*Holon*	*Tiktikan*	*Kanlunes*
Type	Open/Connected	Open/Connected	Open/Connected	Open/Connected	Open/Connected	Closed/Isolated
Origin	Volcanic	Volcanic	Tectonic	Volcanic	Island/Tectonic	Island/Tectonic
Location	Lakewood, Zamboanga del Sur	Valencia, Bukidnon	Pangantucan, Bukidnon	T'boli, South Cotabato	Socorro, Surigao del Norte	Socorro, Surigao del Norte
Latitude	7.847057	7.880584	7.868214	6.101409	9.608366	9.585296
Longitude	123.1703	125.006458	124.784436	124.887245	125.913298	125.916809
Maximum depth (m)	109.73	26	24.38	unknown	3	unknown
Surface (ha)	740.66	24	44.44	328.35	4.62	17.31
Maximum length (m)	4420	487.11	1340	1980	374.36	1010
Maximum width (m)	2150	482.95	429.44	2090	204.02	335.05
Altitude asl (m)	318	643	1041	1338	22	30
Water input Source/Inflow	Known to have 8 bottom springs	Bottom spring	Bottom spring, twin falls (Didilusan & Dawikwikan)	Bottom spring and Ga-o River	Bottom springs & sea water encroachment (high tide)	Bottom spring
Water drainage/ outflow	Biswangan River	Canal	River	5 large rivers	Tiktikan Lagoon	None
Economic value	Irrigation, livestock raising Tourism/Recreation Fish pens Source of the rivers in the area	Tourism, fishing	Tourism, fishing, fish pens (breeding)	Fishing (community) Tourism Source of water in five large rivers in the region	Aquaculture for milkfish, tourism	None
Anthropogenic activities	Local government concern for pollutants (against fish), tourism, and outlet for used water from resort and farmland	Tourism, swimming, Jet ski, kayaking	Fish pen, tourism, swimming	Tourism, swimming, kayaking, overnight camping	Fish feeding, introduction of fishes	None

Note: Open/Connected – means a lake where water constantly flows out under almost all climatic circumstances and is connected to a river; Closed/Isolated – means no water flows out, and water that is not evaporated will remain in a closed lake indefinitely; asl - above sea level.

Table 3

The physicochemical properties of water samples from the six different lakes of Mindanao, the Philippines, with the standard water quality criteria

Parameters	*Descriptive statistics*	*Sampling sites*					*WQ Criteria DAO 34*
		L	*A*	*N*	*H*	*K*	*Class C*
pH		4.73	7.45	---	---	9.1	6.5 - 8.5
	Mean	4.73	7.45	---	---	9.10	
	SD	0.52	0.05	---	---	0.10	
Water temperature (°C)		29.6	26.13	23.63	22.7	27.5	3 [(d)]
	Mean	29.60	26.13	23.63	22.70	27.50	
	SD	0.53	0.51	0.12	0.10	0.50	
DO (mg L^{-1})		4.97 (64%)	3.50 (41%)	8.84 (103%)	5.68 (65%)	4.2 (53%)	5 (60 % saturation) 25°C
	Mean	4.97	3.50	8.83	5.70	4.20	
	SD	0.12	0.50	0.12	0.17	0.20	

Note: (d) - the allowable temperature increase over the average ambient temperature for each month; L – Lakewood lake; A – Apo lake; N – Napalit lake; H – Holon/Maughan lake; K – Kanlunes lake; SD – Standard Deviation; DO - dissolved oxygen; WQ - water quality; DAO - Department of Environment and Natural Resources Administrative Order.

Table 4

Fish species inventory observed and collected from the different lakes in Mindanao

Family	*Scientific name*	*Common name*	*Local name*	*Habitat*	*Conservation status*	*Selected Lakes in Mindanao*					
						L	*A*	*N*	*H*	*T*	*K*
Ambassidae	*Ambassis agrammus*	Sailfin glass perchlet	Tiktikan	F, B	Intro, NE	0	0	0	0	1	0
Osphronemidae	*Trichopodus trichopterus*	Three spot gourami	Gourami	F	Intro, LC	1	0	1	0	0	0
Poeciliidae	*Xiphophorus hellerii*	Red swordtail	Reddish fish	F, B	Intro, NE-pp	0	0	0	1	0	0
	Xiphophorus clemenciae	Yellow swordtail	White fish	F	Intro, NE-pp	0	0	0	1	0	0
Acanthuridae	*Acanthurus gahhm*	Black surgeonfish	Hindangan	M	Intro, LC	0	0	0	0	1	0
Anabantidae	*Anabas* sp.	Perch	Puyu	F	Native, LC	1	0	1	0	0	0
Anguillidae	*Anguilla marmorata*	Giant mottled eel	Kasili	F, M	Native, LC	1	1	0	1	0	1
Apogonidae	*Cheilodipterus artus*	Wolf cardinalfish	Ibis	M	Native, NE	0	0	0	0	1	0
	Fibramia amboinensis	Amboina cardinalfish	Moong	M	Native, DD	0	0	0	0	1	0
	Ostorhinchus compressus	Ochre-striped cardinalfish	Ibis	M	Native, LC	0	0	0	0	1	0
	Sphaeramia orbicularis	Orbiculate cardinalfish	Bakag	M	Native, NE	0	0	0	0	1	0
Atherinidae	*Hypoatherina temminckii*	Samoan silverside	Gono 1	M	Native, NE	0	0	0	0	1	1
	Hypoatherina tropicalis	Whitley's silverside	Gono 2	M	Native, NE	0	0	0	0	1	1
Balistidae	*Pseudobalistes flavimarginatus*	Triggerfishes	Pakol	M, B	Native, NE-Rcp	0	0	0	0	1	0

Family	Scientific name	Common name	Local name	Habitat	Conservation status	Selected Lakes in Mindanao					
						L	*A*	*N*	*H*	*T*	*K*
Carangidae	*Caranx sexfasciatus*	Bigeye trevally	langog	M, F, B	Native, LC	0	0	0	0	1	0
Chanidae	*Channa melasoma*	Black snakehead	Haloan	F	Native, LC	1	1	1	1	0	1
	Channa maculata	Blotched snakehead	Elabo	F	Native, LC	1	0	0	0	0	0
	Chanos chanos	Milkfish	Bangus	F, B	Intro, NE	0	0	1	0	1	0
Cichlidae	*Oreochromis niloticus*	Nile tilapia	Tilapia	F, B	Intro, Inv, NE-pp	1	1	1	1	0	1
	Oreochromis sp.	Red tilapia	Gintong biyaya	F, B	Intro, Inv, NE-pp	1	0	0	0	0	0
Clariidae	*Clarias macrocephalus*	Bighead catfish	Pantat	F, B	Native, NT	1	0	1	0	0	1
Cyprinidae	*Puntius binotatus*	Spotted barb	Pait-pait	F	Native, LC	1	0	1	1	0	0
	Rasbora everetti	Carps	Porang	F	Native, End, NE	1	0	0	0	0	0
	Cyprinus carpio	Common carp	Karpa	F, B	Intro, VU-pp	1	1	1	1	0	1
Engraulidae	*Stolephorus indicus*	Anchovy	Bulinaw	M, B	Native, NE	0	0	0	0	1	0
Ephippidae	*Platax pinnatus*	Dusky Batfish	Alibangbang	M	Native, NE	0	0	0	0	1	0
Gerreidae	*Gerres erythrourus*	Deep-bodied mojarra	Palotpot	M, B	Native, LC	0	0	0	0	1	0
Gobiidae	*Acentrogobius caninus*	Goby	Payu	M, F, B	Native, LC	0	0	0	0	1	0
	Cryptocentrus leptocephalus	Pink-speckled shrimpgoby	Goby	M	Native, NE	0	0	0	0	1	0
	Exyrias puntang	Puntang goby	Goby	M, B	Native, NE	0	0	0	0	1	0
	Valenciennea muralis	Mural goby	Goby	M	Native, NE	0	0	0	0	1	0
	Acentrogobius janthinopterus	Robust Mangrove Goby	Goby	M, F, B	Native, NE	0	0	0	0	0	1
	Amblygobius buanensis	Buan Goby	Bantay buho	M	Native, LC	0	0	0	0	1	0
	Amblygobius stethophthalmus	Freckled Goby	Borod	M	Native, NE	0	0	0	0	1	0
	Glossogobius sp.1	Goby	Payu	M, B	Native	0	0	0	0	0	1
	Glossogobius sp.2	Goby	Payu	M, B	Native	0	0	0	0	1	1
Hemiramphidae	*Hyporhamphus affinis*	Tropical halfbeaks	Sigwil	M	Native, NE	0	0	0	0	1	1
Holocentridae	*Neoniphon sammara*	Sammara squirrelfish	Baga-baga	M	Native, LC-v	0	0	0	0	1	0
	Sargocentron tiere	Blue lined squirrelfish	Bagas	M	Native, LC	0	0	0	0	1	0
Labridae	*Halichoeres* sp.	Wrasse	Labajan	M	Native	0	0	0	0	1	0
	Halichoeres papilionaceus	Weed wrasse	Labajan	M	Native, LC	0	0	0	0	1	0
	Halichoeres argus	Argus wrasse	Labajan	M	Native, LC	0	0	0	0	1	0
	Halichoeres sp.	Wrasse	Labajan	M	Native	0	0	0	0	1	0
Lethrinidae	*Gnathodentex aureolineatus*	Striped large-eye bream	Gapas-gapas	M	Native, LC-rcp	0	0	0	0	1	0
Lutjanidae	*Lutjanus fulvus*	Blacktail snapper	Agngan	M, F, B	Native, LC-rcp	0	0	0	0	1	0
Pangasiidae	*Pangasianodon hypophthalmus*	Striped Catfish	Bangrap	F	Intro, EN	0	0	1	0	0	0
Pomacentridae	*Stegastes rectifraenum*	Cortez damselfish	Payata	M	Native, LC	0	0	0	0	1	0
	Stegastes variabilis	Cocoa damselfish	Payata	M	Intro, NE	0	0	0	0	1	0
Serranidae	*Epinephelus coioides*	Orange-spotted grouper	Pugapo	M, B	Native, NT	0	0	0	0	1	0

Family	*Scientific name*	*Common name*	*Local name*	*Habitat*	*Conservation status*	*Selected Lakes in Mindanao*					
						L	*A*	*N*	*H*	*T*	*K*
	Epinephelus ongus	White-streaked grouper	Pugapo	M, B	Native, LC	0	0	0	0	1	0
	Plectropomus areolatus	Squaretail coralgrouper	Pugapo	M, B	Native, VU-rcp	0	0	0	0	1	0
Siganidae	*Siganus canaliculatus*	Rabbitfishes	Danggit	M, B	Native, LC-v	0	0	0	0	1	0
	Siganus guttatus	Orange-spotted spinefoot	Danggit	M, B	Native, LC-v	0	0	0	0	1	0
Soleidae	*Synaptura marginata*	White-margined sole	Payad/ Dali-dali	M, B	Native, NE	0	0	0	0	1	0
Synanceiidae	*Synanceia verrucosa*	Stonefishes	Gatasan	M	Native, NE-v	0	0	0	0	1	0
Synodontidae	*Synodus* sp.	Lizardfish	Taliktiki	M	Native, LC	0	0	0	0	1	0
Sphyraenidae	*Sphyraena jello*	Pickhandle barracuda	Borson	M, B	Native, NE-rcp	0	0	0	0	1	0
Tetraodontidae	*Arothron hispidus*	White-spotted puffer	Butete	M, B	Native, LC-pte	0	0	0	0	1	0
	Unknown					0	0	0	1	0	0

Note: M – marine, but also detected; B – brackish; F – freshwater; L – Lakewood; A – Apo; N – Napalit; H – Holon; T – Tiktikan; K – Kanlunes; 0 - absent; 1 - collected and as reported by the locals; Intro - introduced; End - endemic; VU - vulnerable, VU-pp - vulnerable-potential pest; DD - data deficient; EN - endangered; NE - not evaluated; NE-pp - not evaluated potential pest; NE-rcp - not evaluated-reports of ciguatera poisoning; LC - least concerned; LC-v - least concerned-venomous; LC-rcp - least concern reports of ciguatera poisoning; LC-pte - least concern poisonous to eat; NT - near threatened.

The six lakes were examined based on species richness, abundance, dominance, and sample size (Table 5). It can be seen from the results that the lake with the most number of species was Tiktikan Lake (42), while the least number was found in Apo Lake (4) (Figure 2).

Table 5

Fish species diversity index of the six different lakes in Mindanao, Philippines

Sampling sites	*Surface*	*Diversity indices*						
		Richness	*Abundance*	*Diversity*				*Evenness*
				Shannon Index		*Simpson Index*		
				Raw index (H)	*True Diversity index [exp(H)]*	*Raw index (D)*	*True Diversity index [1/(1-D)]*	
Lakewood	740.66	8	286	1.347	4	0.327	2	0.4806
Apo	24	3	65	0.159	1	0.940	17	0.3907
Napalit	44.44	6	71	1.146	3	0.387	2	0.5245
Holon	328.35	6	321	1.262	4	0.312	2	0.5888
Tiktikan	4.62	42	708	1.355	5	0.532	2	0.09452
Kanlunes	17.31	8	177	1.753	6	0.200	1	0.7214

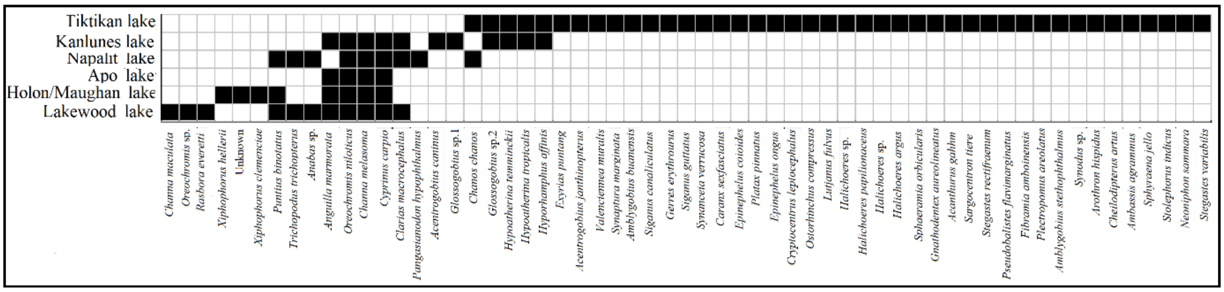

Figure 2. Seriation of the presence/absence of the fish species identified among the six lakes.

Some lakes were found to have common species - Lakewood, Holon, and Napalit have one species; Lakewood and Holon also have one common species, Lakewood and Napalit have three species. Five lakes (Lakewood, Holon, Apo, Napalit, and Kanlunes) have five common species. Four lakes (Lakewood, Holon, Apo, and Kanlunes) have four common species. Apo and Napalit have three species; Napalit and Kanlunes four species; Napalit and Tiktikan one species; and Kanlunes and Tiktikan four common species (Figure 2). Thirty-seven species are found only in Tiktikan Lake, three species each for Lakewood and Holon, 2 for Kanlunes, 1 for Napalit, and none are unique for Apo Lake.

Looking at the distribution of fish species, 46 out of 60 species observed in the six lakes are native to the Philippines. Of the 11 species introduced, two were invasive, *O. niloticus* was introduced in five lakes except for Tiktikan, and one species *Oreochromis* sp. was introduced in Lakewood Lake. Results also show one species, *Rasbora everreti,* endemic to Lakewood Lake. *Plectropomus areolatus* was found only in Tiktikan Lake and *Cyprinus carpio* was found in five lakes, except Tiktikan, these being vulnerable species. One species, *Pangasianodon hypophthalmus*, found only in Napalit lake, was already considered to be endangered according to IUCN status (http://www.redlist.org).

Tiktikan Lake was species-rich and is most abundant among all six lakes, but significantly uneven in its distribution. Species diversity among the lakes as shown by the Shannon-Weiner index, was lower than what is expected. Species richness is considered a valid diversity index. However, by converting the Shannon index to an accurate number of species or true diversity index [exp(H)], and the Simpson True Diversity index [1/(1-D)], results showed that the species richness in all communities was no longer equal to the

Shannon and Simpson adequate number of species (Table 5). This result indicates the degree of unevenness or dominance in the community (Jost 2016), as the evenness values vary from 0 to 1, where 1 means complete evenness.

The strength of association between surface area and diversity and surface area and evenness are presented in Figure 3. The association is very low (A r^2=0.035; B r^2=0.03), and the correlation coefficient is insignificant.

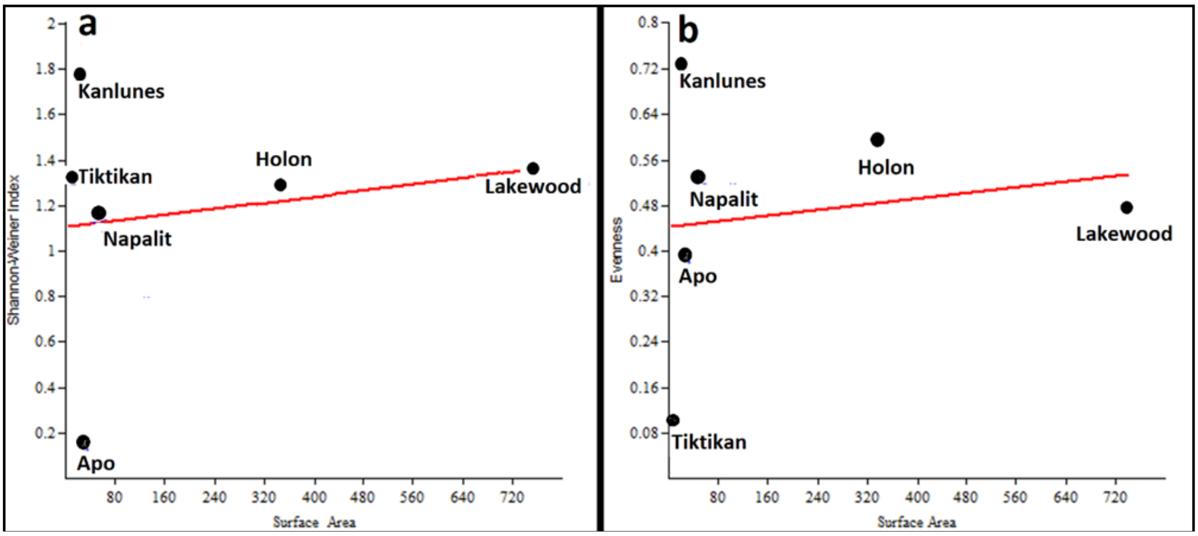

Figure 3. Multivariate linear regression showing the relationship between (a) surface area and diversity and (b) surface area and evenness of different lakes towards the average diversity index and evenness of its fish composition.

Lakes have relatively uniform habitats in each area and are seen as highly productive water bodies in the Philippines. These contribute up to 15% to the annual total fish production (Fellizar 1995) and serve as transport routes and sources of irrigation supply, hydropower, and cooling water for industries. However, little is known about Mindanao lakes (Guerrero 2001). Mindanao islands have approximately 31 known lakes, and some are unidentified. Most of these lakes are considered not significant and are primarily found in isolated areas of the island. Some of these lakes constitute essential habitats and food resources for a diverse array of fish, but lake ecosystems are fragile and are subject to change through time (Garn et al 2003). Some lakes in Mindanao, especially the small ones, are underutilized, but universally, these lakes are highly useful for studying productivity-diversity relationships. Since they are bounded ecosystems embedded in a terrestrial matrix, enumeration of locally coexisting species is relatively reliable (Korhonen et al 2011). Therefore, the ability of species to exist and coexist within these small lakes limits their diversity. A study has shown that the diversity of natural populations is partially dependent on the environmental variables, which always affect the competing species (Hossain et al 2012). The current study shows the status of fish biodiversity, but the correlation coefficient between surface area and diversity and surface area and evenness is insignificant. Several factors may have affected species diversity by the size of the habitat, and the actual relationship between taxon diversity and lake size differs widely among species (Scheffer et al 2006). The biotic complexity and abundance of the six small lakes are distinguished. As the lake becomes smaller, it is more likely to be in a vegetated state, which will promote species richness (Scheffer et al 2006), as shown by the Tiktikan lake. Small lakes have a more complex thermal structure than large ones (Xenopoulos & Schindler 2001), which may be vital in maintaining differences in biodiversity and stability (Downing 2010). In ecological research, Barbour & Brown (1974) found significant relationships between lake area and the number of fish species present (McA Eadie et al 1986). Our study shows that lake size did not influence fish species diversity, but is likely to have solid and complex influences on ecosystem functioning and energy flow pathways in these small lakes (Eloranta et al 2015).

An ecological assessment focused on published and unpublished researches on the different large lakes in the Philippines shows these lakes are either critically degraded, threatened, or underdeveloped. The productivity and biodiversity of these lakes have become vulnerable to various environmental and human pressures resulting from rapid economic development, including pollution from untreated sewage and industrial waste, overfishing, sedimentation, and illegal reclamation (Guerrero 1996, 1999; Araullo 2001; Ong et al 2002; Zafaralla et al 2002; DENR-PAWB 2005; Santos-Borja & Nepomuceno 2006; Mayuga 2009; Jacinto 2011; Magcale-Macandog et al 2014; Edwards 2015; Global Nature Fund 2015; Cox 2017). Lake-based studies are also rare in the Philippines, beyond a few primary ecological surveys and research to improve aquaculture productivity (Myers 1960; Aypa et al 1975; Mercene & Alzona 1990; Soliman 1994; Beniga 1997; Yambot 2000; Zafaralla 2001; Araullo 2001; Zafaralla et al 2002; DENR-PAWB 2005; Santos-Borja & Nepomuceno 2006; Israel 2008; Mayuga 2009; Papa & Mamaril 2011; Papa & Mamaril 2011; Jacinto 2011; Magcale-Macandog et al 2014; Mendoza et al 2015; Uy et al 2015; Global Nature Fund 2015; Corpuz et al 2016; Briones et al 2016). Looking at the characteristics of the six small lakes being studied, we can surmise that some of the ecological variables investigated above may also have contributed to the differences in species diversity observed. More ecological studies on these six lakes and other more lakes in Mindanao are needed.

Conclusions. Among the six lakes, Apo, Tiktikan, and Kanlunes show significant differences in diversity, although all the communities indicate dominance and unevenness. The Tiktikan lake community has a very attention-grabbing value, unlike the rest. Though the importance of strength association is insignificant, a directly proportional relationship between surface area, diversity, and evenness can be observed. It could be that the balance of species diversity depends on both the size of the habitat and whether it is in the vegetated state, with the latter itself being influenced by habitat size. But it should also be stressed that the actual relationship between taxon diversity and lake size might differ widely among species. The diversity observed among the six lakes could also be attributed to many other ecological factors, including the anthropogenic factor, and should be further studied.

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