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Research Article

Spatio-temporal distribution of the invasive Knifefish *Chitala ornata* (Gray, 1831) in Laguna De Bay, Philippines

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ABSTRACT

To determine the environmental factors influencing the dynamics of knifefish invasion in Laguna de Bay, spatio-temporal distribution of *Chitala ornata* was evaluated at 11 sampling stations in East, West and Central Bay. Overall knifefish catch was highest in May 2015 and dropped to 50% in August 2015. Total knifefish catch was higher at East Bay than that recorded in West and Central Bay. Knifefish caught from West and Central Bay were longer and larger than those caught at East Bay. Generalized Linear Mixed Modelling showed that the most significant predictors of total knifefish catch were dissolved oxygen, secchi depth, and pH, with the first two factors inversely correlated, and pH positively correlated with total catch. Temperature was the significant predictor for knifefish mean total length, and the combination of salinity and conductivity influenced their mean weight. Higher knifefish catch at East Bay could be attributed to high turbidity and pH, and low dissolved oxygen, suggesting that measures to improve environmental conditions such as better water quality management are needed to prevent increase of invasive knifefish. Results demonstrate the importance of local environmental influences on population characteristics of invasive fish and provides framework on how to control and manage invasive species.

Key words: bioinvasion; freshwater fish; water quality

INTRODUCTION

The invasion of non-native fish species has been recognized as one of the most significant contributors to threat of extinction of native fauna in freshwater ecosystems, one that has been aggravated by other disturbances such as habitat loss and fragmentation, hydrologic alteration, climate change, over exploitation, and pollution (Dudgeon *et al*. 2006). Fish invasion has been considered a worldwide concern due its significant social, ecological, evolutionary, and economic impacts (Rahel, 2000; Pimentel, 2000; Jeschke & Strayer, 2005; Ricciardi & Kipp, 2008; Lodge, 1993).

Invasive species has been a great concern worldwide due to their establishment impacting various ecosystems and habitats (Karatayev *et al*., 2009; Cucherousset & Olden, 2011; Winfield *et al*., 2011), hence, increasing attention has been devoted to their management during the last decade (Sutherland *et al*., 2009; Gozlan *et al*., 2010; Britton *et al*., 2011). A number of measures have been developed and adopted to remove, control and manage invasive species. Some of these methods include physical removal (Ludgate & Closs, 2003; Wimbush *et al*., 2009), chemical eradication (e.g. rotenone; Ling, 2002), the use of sex pheromones (Li *et al*., 2002; Arbuckle *et al*., 2005), and bio-manipulation (Saunders *et al*., 2010; Britton *et al*., 2011).

To effectively optimize control and management strategies to minimize expansion and promote control, and eradication of invasive fish, it is necessary to understand patterns and population dynamics to predict timing and pathways of population expansion (Brown & Walker, 2004; Arim *et al*., 2006). The ultimate goal is to determine the underlying factors influencing their spread.

Regarded as the largest freshwater lake in the Philippines, Laguna de Bay is home to a total of about 33 fish species comprised of 14 indigenous, 5 of which are migratory, and 19 exotic or introduced (Llasco & Espaldon, 2005). Because of the introduction and subsequent establishment of invasive species such as knifefish (*Chitala ornata*), these indigenous fish are currently under threat (Cagauan, 2007). *Chitala ornata* (Gray, 1831) is native in Mekong River and is a known carnivore preying on small fishes (Poulsen *et al*., 2004). According to Cagauan (2007), knifefish was initially introduced in the Philippines mainly for ornamental purposes, however, a number of individuals have found their way into the lake either by escaping from ornamental fish farms or aquarium or deliberately released by some fish owners and later successfully established their population in the lake. Because of the voracious feeding habit of knifefish it has been considered a nuisance species, actively preying on larvae and juveniles of economically important fish species such as *Chanos chanos*, *Oreochromis niloticus*, *Leiopotherapon plumbeus*, and *Cyprinus carpio*.

Most of the information on knifefish invasion in Laguna de Bay is anecdotal and there is no scientific data on the biology and ecology of this species. Some of the adverse effects of knifefish reported by local fisherfolks include predation, competition, habitat alteration,

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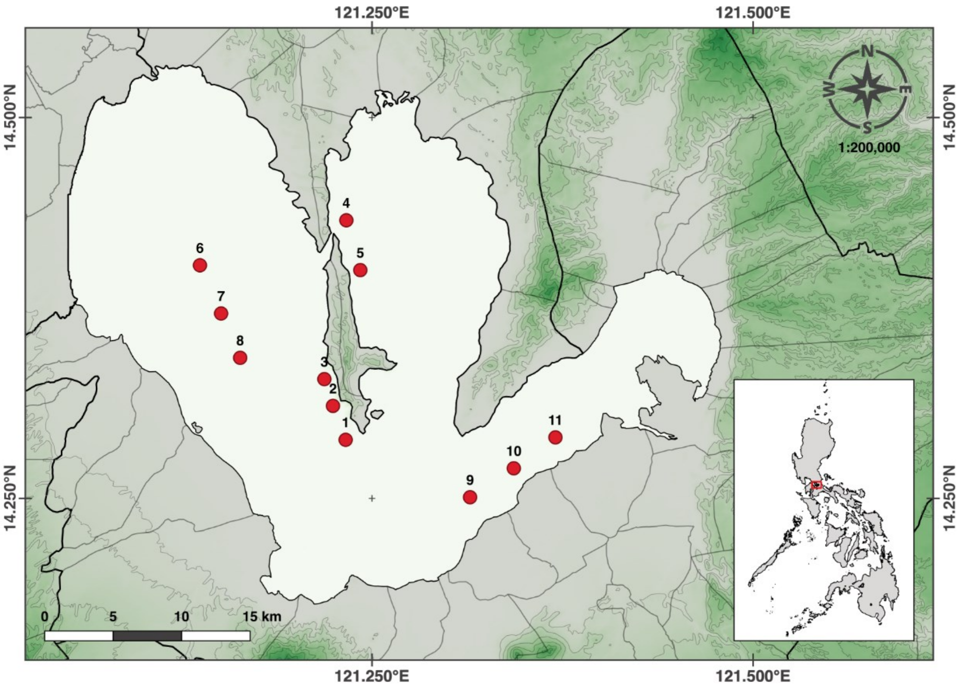

Figure 1. Relative location of sampling stations (Stations 1-11) in Laguna de Bay, Philippines.

and displacement of native species in Laguna Lake, but there are no technical bases for this information. There is a need for a more scientific approach of controlling and eradicating this alien fish species. One approach is to study population dynamics of knifefish, particularly its temporal and spatial distribution. Mapping out their distribution and establishing their habitat range are essential to effectively control knifefish population in the wild. Once their distribution in Laguna Lake is established, it would be easier to control their population. Factors affecting their distribution, say their aggregation in a certain area could be identified to effectively control their number. The main objective of the study is to determine the environmental factors, which would influence the spread or invasion of knifefish in Laguna de Bay, and identify the best predictors of knifefish population characteristics (i.e. density, spatial and temporal distribution). This will lead to a better understanding of the ecology of invasive knifefish populations, which is necessary for the development of effective population control and management strategies of the invasive species in Laguna de Bay.

MATERIALS AND METHODS

Study Site

Laguna Lake or Laguna de Bay is the largest lake in Southeast Asia and regarded as the most important lake the Philippines, located in the island of Luzon, southeast of Manila, with watershed covering the provinces of Laguna and Rizal. It has a surface area of about 90,000 ha, an average depth of about 2.8 m and a maximum depth of 6.5 m (Felizar, 1995). The lake is shaped like a 'W', with two peninsulas, the East and West Bay, and between these peninsulas, the middle lobe or the Central Bay, where the large island of Talim is located, which occupies the large volcanic Laguna Caldera. About 45,000 km^2 (17,000 sq mi) of catchment areas and its 21 major tributaries are the major sources of water in the lake. Pagsanjan River contributes to about 35% of the Lake's water while Santa Cruz River about 15% of the Lake's water (LLDA, 1995; Nepomuceno, 2006). The lake continues to serve as a multi-purpose lake, used for aquaculture, open water fishery, contact recreation, domestic and industrial uses. Industrial areas occupy the northwestern part of Laguna Lake, agricultural areas are observed at the southern and eastern portions of the lake, while fish cages occupy most of the middle areas. It also serves as source of irrigation water, water for hydroelectric power generation and as source of domestic water supply for Metro Manila. The ecological state of the lake has been established as extremely stressed needing rehabilitation as evidenced by declining fish yield, impaired biodiversity, pollution, siltation, perennial turbidity, eutrophication and declining alkalinity (Tamayo-Zafaralla *et al*., 2002).

Knifefish Survey

Knifefish survey was conducted at a total of 11 sampling stations: five in the Central Bay (Stations 1-5; Habagatan, Tabon, G. Sanay, Subay and Cardona), three in the West Bay (Stations 6-8; Muntinlupa, Biñan and san Pedro) and three in the East Bay (Stations 9-11; Pila, Sta. Cruz and Victoria) (Table 1). Figure 1 shows the relative location of the 11 sampling stations surveyed in this study.

Monthly sampling of knifefish was done from May 2015 to May 2016 for 11 months. Two types of fishing methods were used namely: drift long line (*kitang*) and purse seine (*pangulong*). *Kitang* is a series of hook in line that stretches up to 250-300 meters, which uses live *Oreochromis niloticus* fingerlings as bait. Another method used was the *pangulong*, which is a fishnet with a mesh size of about 3.5 inches. Knifefish sampling was conducted from 5-6 h at each sampling station. The number of knifefish individuals collected at each station was counted, and their weight and length measured using digital weighing scale and caliper, respectively.

Table 1. Location and coordinates of the 11 sampling stations in Laguna de Bay.

Station	Bay	Name of Station	Location	Coordinates	
				Northing	Easting
1	Central	Habagatan	Habagatan, Talim Island, Binangonan, Rizal	14°17'18.45"N	121°13'57.73''E
2	Central	Tabon	Tabon, Talim Island, Binangonan Rizal	14°18'38.63"N	121°13'27.76''E
3	Central	G. Sanay	G.Sanay, Talim Island, Binangonan Rizal	14°19'41.86"N	121°13.1'1.43''E
4	Central	Cardona	Patunhay, Cardona, Rizal	14°25'57.19"N	121°13'59.34'E
5	Central	Subay	Subay, Talim Island, Binangonan Rizal	14°23'59.49"N	121°14'32.30''E
6	West	Muntinlupa	Bayanan, Muntinlupa, Metro Manila	14°24'10.85"N	121°16.97''E
7	West	San Pedro	Landayan, San Pedro, Laguna	14°22'16.97"N	121°9'3.58''E
8	West	Binan	Sinalhan, Biñan, Laguna	14°20'32.26"N	121°9'48.63''E
9	East	Victoria	M.H. Del Pilar, Victoria, Laguna	14°15'2.77"N	121°18'51.58''E
10	East	Pila	Aplaya, Pila, Laguna	14°16'11.14"N	121°20'34.82''E
11	East	Sta. Cruz	Gatid, Sta. Cruz, Laguna	14°17'24.20"N	121°22'13.20''E

Water Quality Measurements

Water quality parameters were measured monthly on-site at 11 sampling stations from May 2015 to May 2016 using YSI 556 Handheld Multiparameter Instrument. Water quality parameters measured include pH, temperature, dissolved oxygen, total dissolved solids, salinity and conductivity. Secchi depth transparency at each station was also estimated using a fabricated Secchi disc.

Statistical Analyses

Total catch, mean total length and mean weight values of knifefish caught at eleven sampling stations from May 2015 to May 2016, as well as water quality data among stations were compared. Information-theoretic technique through model averaging (Grueber *et al*., 2011) was conducted to measure the influence of the seven water quality parameters on total count, mean total length and mean weight of knifefish in Laguna de Bay from August 2015 to May 2016. A generalized linear mixed-effect model (GLMM) was used to analyze the data using R software (R Development Core Team, Vienna, Austria). In defining the model parameters, total count, mean total length and mean weight were coded as response variables while temperature, conductivity, pH, salinity, total dissolved solids (TDS), conductivity, and Secchi depth were identified as fixed effects, while site was identified as the random variable. Each model was assigned a Poisson error distribution for the total count, while Gaussian distribution for mean total length and mean weight (Burnham & Anderson, 2002). A global GLMM using the lme4 package (Bates & Maechler, 2009) was first fitted. After the global model was defined, the input variables were standardized using arm package (Gelman *et al*., 2016). This generated a summary of variables estimates with their standard error (extreme values suggest poor model convergence) and relative importance (a value of 1.0 being the most significant). All residual data generated did not show evidence of overdispersion. To extract a sub model from the global model, a dredge function was implemented in the MuMln package (Barton, 2009). In the final model averaging step, Akaike's information criterion corrected for small sample size (AICc) was used to assess model support, ranking each using ΔAICc (Burnham & Anderson 2002). The most parsimonious model was indicated by the biggest AICc weight. The values were obtained by extracting the top 5 AICc, using the function model in the MuMln package.

RESULTS

Spatio- Temporal Distribution of Knifefish

A total of 1,385 knifefish individuals were caught from May 2015 – to May 2016 at 11 sampling stations in Laguna de Bay (Figure 2). The highest knifefish catch was recorded in May with a total catch of 206 individuals. Fish catch decreased by 50% in June, slightly increased in July and dropped by about 50% in August. Fish catch doubled in September and decreased slightly for two months (October –November). The lowest catch was recorded in August with only 64 individuals.

The total number of knifefish caught at each sampling station from May 2015 to 2016 varied among sampling stations from 106 to 159 individuals. The highest catch was recorded at Pila, while the lowest at Cardona. Average catch at the East Bay (Victoria, Pila and Sta. Cruz) was higher (149 fish inds.), compared with that recorded at the West (Muntinlupa, San Pedro and Binan) and Central Bay (Habagatan, Tabon, G. Sanay, Cardona and Subay), with fish catch values of 119 and 116 knifefish inds. (Figure 3).

The average length of knifefish did not differ much among sampling stations, however, relatively larger individuals were caught at Cardona, compared with other stations. In addition, relatively small-sized individuals were caught at Victoria, Pila and Sta. Cruz (East Bay), compared with those caught at the rest of the stations located in West and Central Bay (Figure 4). The average weight of knifefish at 11 surveyed stations ranged from 1.4 kg to 2.7 kg, with the highest recorded at Cardona and the lowest at Victoria. Knifefish caught

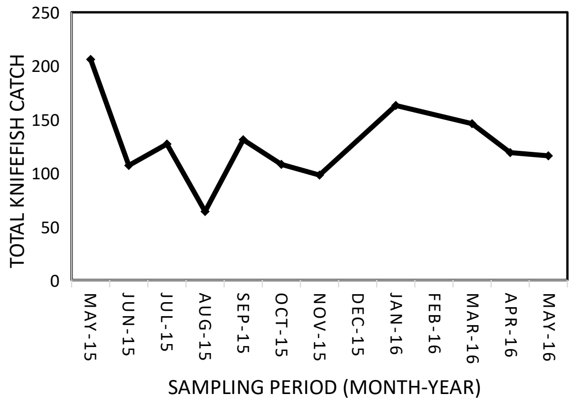

Figure 2. Overall knifefish catch at Laguna de Bay from May 2015 to May 2016.

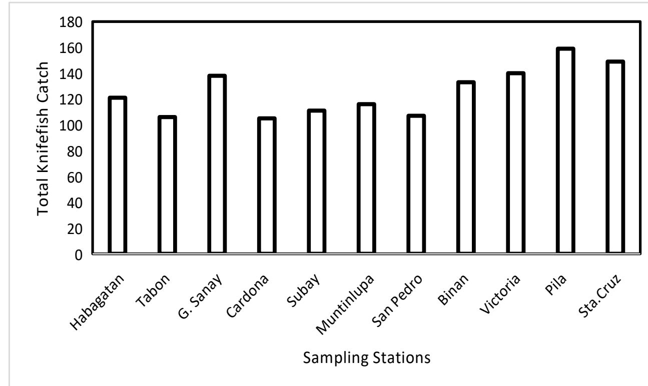

Figure 3. Total knifefish catch at 11 sampling stations from May 2105 to May 2016.

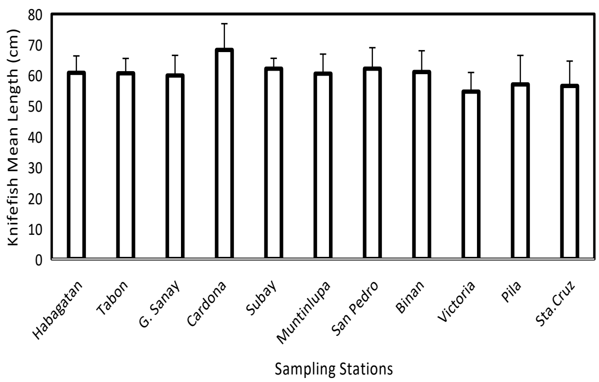

Figure 4. Average length (cm ± SD) of knifefish caught at 11 surveyed stations in Laguna de Bay from May 2015 to May 2016.

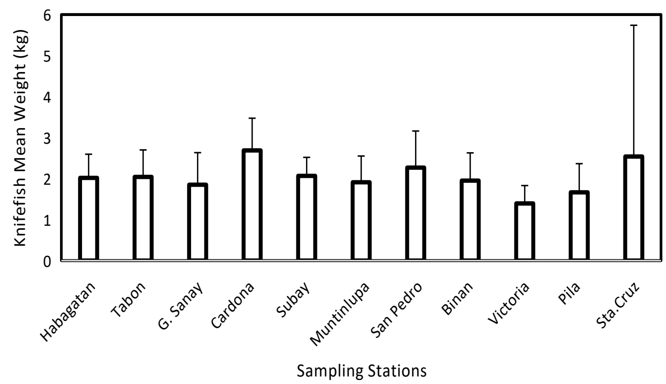

Figure 5. Mean weight (kg ± SD) of knifefish caught at 11 surveyed stations in Laguna de Bay from May 2015 – May 2016)

at Cardona and Sta. Cruz had relatively higher average weight compared with those caught at nine remaining stations. High variability in weight of knifefish individuals was apparent at Sta. Cruz (SD value of 3.2). Meanwhile the average total length of knifefish ranged from 52.67 cm to 66.93 cm (Figure 5).

Table 2 shows the mean values of water quality parameters measured at 11 sampling stations in Laguna de Bay. Temperature values at the Central (Habagatan, Tabon, G. Sanay, Cardona and Subay) and West Bay composed of Muntinlupa, San Pedro and Bina (mean values of 33.12 °C and 33.73 °C, respectively) were found relatively higher than that recorded at the East Bay (32.87 °C). Conductivity, TDS and salinity values showed similar pattern, with higher values recorded at Central and West Bay compared with that observed at East Bay. Secchi depth was relatively higher at Central and West Bay (46.03 cm and 47.22 cm, respectively) than that recorded at East Bay (44.06). Meanwhile, dissolved oxygen levels at 11 sampling stations were high and pH levels generally basic, showing not much differences among Bays.

Generalized Linear Mixed Modelling

Results of GLMM showed that the most significant predictor of total knifefish catch were dissolved oxygen (E= -0.0810; P=0.01046), pH (E= 0.6027; P=7.29e-05), and secchi depth transparency (E=-0.0088; P=0.00927). Dissolved oxygen and secchi depth transparency were found to be inversely correlated with knifefish total catch. Meanwhile, pH was found positively correlated with total catch. Temperature (E= 2.7400; P= 0.0113) was the significant predictor for knifefish mean total length, but the combination of conductivity, pH, salinity and temperature would best explain spatio-temporal variations in mean total length of knifefish (ΔAICc=0.00, wAICc=0.0.64). Combination of salinity and conductivity somehow influenced the mean weight of knifefish (ΔAICc=0.00, wAICc=0.0.69) recorded at 11 sampling stations from August 2015-May 2016 (Tables 3 and 4).

DISCUSSION

In this study, monthly variations in knifefish catch was observed suggesting seasonality in abundances, which can be attributed to the timing of spawning season. The highest knifefish catch observed in May and the lowest catch in August coincided with the peak of spawning season, which has been reported to occur in April and May, and the end of the spawning season, respectively (Castro *et al*., 2018). These observations are in agreement with the study of Kimirei & Mgaya (2007), which confirmed the existence of seasonal variability of Clupeid catch in the Kigoma River of Lake Tanganyika in relation to meteorological, physical and chemical factors. The effect of wind speed on nutrient availability causing an increase in chl a and consequently an increase in clupeid catch was observed. Other environmental factors such as temperature variations and monsoon winds can serve as plausible explanation for variations in monthly catch of knifefish. Monsoon winds

Table 2. Mean values (±SD) of water quality parameters measured at 11 sampling stations in Laguna de Bay from May 2015 to May 2016

Stations	Temperature (°C)	Conductivity (uS/cm)	TDS (g/l)	Salinity (ppt)	DO (mg/l)	pH	Secchi Depth (cm)
CENTRAL BAY	**33.12**	**2.22**	**1.31**	**0.97**	**9.907**	**9.02**	**46.03**
Habagatan	32.57	1.08	0.61	0.46	7.86	8.87	44.67
SD	0.35	0.02	0.01	0.01	0.49	0.02	1.15
Tabon	33.50	1.17	0.66	0.49	8.94	8.79	40.83
SD	0.38	0.03	0.02	0.01	0.38	0.12	1.04
G. Sanay	33.64	1.36	0.77	0.58	8.43	8.88	40.33
SD	0.05	0.02	0.01	0.00	1.12	0.18	2.08
Cardona	32.57	3.61	2.38	1.62	7.61	8.97	58.33
SD	0.39	0.04	0.60	0.02	1.20	0.07	2.08
Subay	33.31	3.89	2.15	1.70	16.67	9.57	46.00
SD	2.87	0.13	0.03	0.03	0.67	0.02	1.80
WEST BAY	**33.73**	**1.12**	**0.63**	**0.46**	**11.32**	**9.27**	**47.22**
Muntinlupa	33.78	1.11	0.62	0.46	12.42	9.35	48.33
SD	0.05	0.02	0.01	0.01	0.23	0.06	0.58
San Pedro	33.83	1.13	0.63	0.47	11.24	9.27	46.33
SD	0.42	0.02	0.01	0.01	0.91	0.05	2.52
Binan	33.57	1.13	0.63	0.47	10.30	9.20	47.00
SD	0.38	0.02	0.01	0.01	0.89	0.08	2.65
EAST BAY	**32.87**	**0.79**	**0.51**	**0.33**	**9.45**	**9.08**	**44.06**
Victoria	33.55	0.82	0.46	0.34	12.11	9.31	45.33
SD	0.59	0.00	0.00	0.01	0.17	0.07	1.15
Pila	31.98	0.78	0.63	0.33	6.29	8.76	42.00
SD	0.57	0.00	0.28	0.00	0.92	0.08	2.00
Sta Cruz	33.07	0.78	0.44	0.32	9.95	9.17	44.83
SD	1.21	0.02	0.00	0.00	0.28	0.02	1.04

Table 3. Generalized linear mixed models (GLMM) testing each environmental variable on the total count, mean total length and mean weight of knifefish caught at 11 sampling stations in Laguna de Bay from August 2015 to May 2016.

Parameter	Estimate*	SE	P
Total Count			
Dissolved oxygen	-0.0809767	0.0311682	0.01046 *
pH	0.6026835	0.1497663	7.29e-05 ***
Secchi depth	-0.0088173	0.0033418	0.00927 **
Temperature	-0.0055257	0.0152362	0.71888
Total dissolved solids	0.000248	0.0008012	0.75886
Conductivity	-0.0068413	0.0361112	0.85143
Salinity	-0.0141242	0.0782838	0.85847
Mean Total Length			
Conductivity	-119.17221	64.83865	0.0702
pH	-3.40993	2.88734	0.2447
Salinity	275.30303	142.87605	0.0577
Temperature	2.74004	1.06559	0.0113 *
Dissolved oxygen	0.03687	0.45803	0.9368
Mean Weight			
Conductivity	-1.0266	1.9045	0.595
Salinity	3.3859	4.2994	0.437

Table 4. Summary statistics of model averaging for the total count, mean total length and mean weight of knifefish caught at 11 sampling stations in Laguna de Bay (n=88) from August 2015 to May 2016. Models are ranked based on Akaike's Information Criterion corrected for small size (AICC). DO (dissolved oxygen), SD (Secchi depth), Temp (temperature), TDS (Total dissolved solids), S (salinity), C (conductivity).

Component Models	k*	AICs	AICs	wAICs
Total Catch				
DO+pH+SD	5	672.1	0	0.35
DO+pH+SD+Temp	6	673.15	1.04	0.21
DO+pH+SD+TDS	6	673.49	1.39	0.18
C+DO+pH+SD	6	674.05	1.95	0.13
DO+pH+S+SD	6	674.08	1.98	0.13
Mean Total Length				
C+pH+S+Temp	7	589.45	0	0.64
C+DO+pH+S+Temp	8	590.58	1.13	0.36
Mean Weight				
C+S	5	196.16	0	0.69
S	4	197.74	1.57	0.31

influence the strength of current, hence, increase in water movement may have decreased catch abundances of knifefish during the months of June, July, and August. On the other hand, increase in knifefish catch may be attributed to weak monsoon winds, hence weak current resulting in higher productivity during summer season, providing an abundance of food for the spawning knifefish individuals. Meanwhile, population dynamics of other invasive species have been attributed to the characteristic of the invasive species themselves. Forsyth *et al*. (2013) concluded that the rapid spread of the Boolara strain of invading common carp (*Cyprinus carpio*) through the Murray-Darling Basin in Australia was facilitated by high initial population growth rates and that the lag period between an invader establishing, and increasing to high abundances was predicted to be characterised by logistic-type population growth. In another study, other factors such density-dependent factors may influence population abundances of invasive species. Decline in the sustainable total biomass of *Dreissneria polymorpha*, after reaching an initial maximum population size, was attributed to different factors such as density-dependent processes, including substrate and food limitation, effects of competition as well as that of predation (Lvova, 1977; Karatayev *et al*., 1997, 2002, 2011; Hunter & Simons 2004; Hecky *et al*., 2004; Patterson *et al*., 2005; Burlakova *et al*., 2006).

Local fish assemblage has long been established to be influenced by environmental variables at different spatial scales (Schlosser, 1982, 1987; Marsh-Matthews & Matthews, 2000; Jurevics *et al*.,2012; Chan *et al*., 2017; Penha *et al*., 2017). Chan *et al*. (2017) established that water level fluctuation had the greatest influence on fish abundance in Tonle Sap Lake in Southeast Asia. They also emphasized that hydrological and geographical features influence spatio-temporal distribution in the lake. The importance of interchange of flooding and drying and spatial connectivity on fish assemblage structure including composition, density and biomass of fish was also confirmed by Penha *et al*. (2017). They established that fish diversity in lakes of Pantanal wetland increased from early flood to early dry and that it was higher in temporarily connected lakes than in Permanently connected lakes. Jurevics *et al*. (2012), in their study of spatio-temporal distribution in the northern part of Lake Svente confirmed that light regime (time of the day) was the most significant factor influencing the abundance and distribution of fishes in the pelagic area of the deeply-straified lake. Robinson and Tonn (1989) surveyed 45 lakes in Central Alberta and revealed that piscivory, maximum depth, surface area, and isolation were most important in structuring fish assemblages. Akina *et al*. (2005) showed that salinity and turbidity had the strongest influence on the observed fish assemblage structure of Koycegiz Lagoon–Estuarine System (KLES), located on the northwestern Turkish coast of Mediterranean. In this study, spatio-temporal distribution of the invasive knifefish, *Chitala ornata* was established, and the influence of environmental/habitat on total catch, mean total length and mean weight was evaluated. Secchi disk transparency or Secchi depth and dissolved oxygen were found to influence temporal and spatial distribution of knifefish. Both parameters were found to be negatively correlated with knifefish total catch. This agrees with the findings of Ouboter (2007), who reported that turbidity caused increase in the hatching rate and survival of knifefish in Mamanari Creek in Suriname, South America. High knifefish survival was primarily attributed to their greater efficiency in catching prey with the use of electricity, as opposed to other visual fish predators. This observation also corroborates with the study of Dubey *et al*. (2012), demonstrating that the clown knifefish, *Chitala chitala*, which is a close kin of *Chitala ornata*, was strongly associated with deep and turbid waters of tropical River of Ganga Basin in India. Increase in turbidity has also been found to reduce the vulnerability of juvenile fish prey to rainbow trout and brown trout (Ward *et al*., 2016), which may explain high catch in turbid areas of Laguna Lake. This may explain the relatively higher total catch recorded at the Eastern Bay (Pila, Victoria, and Sta. Cruz), compared with that recorded at the Central Bay and West Bay. Lake siltation in Laguna de Bay has been attributed to high erosion rate due to due to denuded watershed areas. Forest cover has been reported to have decreased by 53% in the late 40s and 8% in the mid-1980s, to about 5% in 1989 (FMB, 1989). Zafaralla *et al*. (2002) reported that about 1,000,000 m3 of sediments are deposited in Laguna Lake annually. They also cited that perennial turbidity was also one of the problems in Laguna de Bay due to the shallow depth of the lake (about 1.5m) allowing resuspension of sediments as triggered by monsoon winds. This condition is highly favourable for hatching of eggs and survival of knifefish which may account for its successful invasion in Laguna de Bay. Temperature was found to be the best predictor of mean total length of knifefish, which may serve as plausible explanation why large-sized individuals were caught at West and Central Bay. This is supported by the findings of Wolter (2007), who reported that there was a general tendency of increased growth length at higher temperature on fishes found in large lowland river, the lower Oder River, Germany. This is also in agreement with the results of a study made by Loeng *et al*. (1995) on cod, haddock and herring at Barents Sea in Northern Norway, showing that there is a tendency for all species that both growth and length of larvae increase with increasing temperature. Azaza *et al*. (2008) also confirmed increase in growth in Nile tilapia (*Oreochromis niloticus*) with increase in temperature in geothermal waters in Southern Tunisia. Increase in growth and metabolism of the European seabass of a Western Mediterranean population was observed from 13 °C to 25 °C, which also supports this observation (Le Ruyet *et al*., 2004).

In conclusion, of the seven water quality parameters or environmental factors examined, dissolved oxygen and Secchi disc transparency (also a measure of turbidity) were found to have the strongest influence on the spatial and temporal distribution of clown knifefish or *Chitala ornata* in Laguna de Bay. Overall results of the study suggest the important role of turbidity in knifefish survival as indicated in high catch recorded in turbid areas of Laguna de Bay. Improvement of water quality of the Bay is therefore needed to reduce population density of the invasive knifefish. This study provides a framework and reference to formulate policies on how to control and manage invasive fish species.

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