Research Article

Species Diversity of Freshwater Fish in the Agriculture Conservation Areas of Eastern Bangkok, Thailand

Weerawich Wongroj[1] and Ruthairat Siriwattanarat[2*]

Received: 17 March 2021
Revised: 17 May 2021
Accepted: 18 May 2021

ABSTRACT

This paper analyzes the diversity of freshwater fish in the agricultural conservation areas of Eastern Bangkok, Thailand, resulting from a study carried out in the period from January to December 2020. The fish samples were collected every 4 months, covering the hot-dry (April), rainy (August) and cool-dry (December) seasons at eight sampling stations. Fish was caught using cast nets with a mesh size of 1.5 cm and 2.5 cm, and gill nets with a mesh size of ¾ inch, 1.5 inch and 2 inch. All data were analyzed to find out the fish diversity indices. Multivariate method of cluster analysis was used for data analysis. The result indicated that there was a total of 1,415 individual fish representing 29 species belonging to 23 genera and 14 families. The four most dominant fish varieties in the agricultural conservation areas in terms of amount were *Trichogaster microlepis*, *Trichopodus trichopterus*, *Pterygoplichthys disjunctivus* and *Oreochromis niloticus* which were distributed at all research stations. These are fish that have accessory air-breathing organs to tolerate poor quality environments. Species diversity index (H′) of fish was in the range of 1.323 to 2.423, evenness index (E) 0.489 to 0.895 and species richness index (d) from 1.135 to 3.919. The cluster analysis of Bray-Curtis similarity index can divide the fish community into 3 clusters, amongst which there were a similarity percentage ranging between 55.42% and 100%.

Keywords: Species diversity, freshwater fish, agricultural conservation areas, accessory air-breathing organ fishes, floodgate

[1]Srinakharinwirot University Prasarnmit Demonstration School (Elementary)
[2]Faculty of Science and Technology, Suan Sunandha Rajabhat University
[8]Corresponding author, email: ruthairat.si@ssru.ac.th

Introduction

Over the last few decades, Thailand's capital city, Bangkok, has changed into a modern city. It is now the country's spiritual, cultural, diplomatic, commercial, and educational hub. It covers an area of more than 1,500 square kilometers, and it is a home of approximately ten million people, or more than 10% of the country's population. Bangkok has set a town plan to have a city subdivided into industrial areas and agricultural areas to support changes in economic, social, cultural, and environmental conditions, especially those affecting the rural and agricultural conservation areas in Eastern Bangkok. This area of the city is a lowland basin at the mouth of the Chao Phraya River, which is under the influence of sea level fluctuations. In addition, the Bangkok area has canal systems of various sizes where both natural canals and many dug canals are connected. On average, every one square kilometer area, the length of the canal is almost one kilometer, which is a factor causing flooding in Bangkok, and surrounding areas [1]. Agricultural conservation areas in Eastern Bangkok are flooded annually. Approximately 20% of the area is currently developed. This area still needs to be preserved because it performs the important function of slowing down floodwaters, helping to prevent wider flooding in Bangkok [2].

The lowland basin region, which can be a significant habitat for freshwater fish but is also heavily modified by human activities, is one of the agricultural conservation areas in Eastern Bangkok. That connectivity between tributary creeks and mainstem channels is often constrained by structures such as dikes and floodgates, which are designed to protect urban and agricultural areas from flooding. The Royal Irrigation Department has been working to improve the water condition and drainage system in the lower Chao Phraya River basin, the eastern side of which diverts water into Bang Pakong River and the Gulf of Thailand. Dredged shallow streams in agricultural conservation areas in Eastern Bangkok were dredged to improve river conditions and make it easier for greater volumes of water to flow. Removing and widening all impediments including improving the river's slope by digging new waterways to add depth allow water to flow. This allows the water to flow easily along the river and can drain large amounts of water through it efficiently [3]. While they play important roles in flood mitigation, floodgates can diminish habitat quality and block fish from accessing tidal creeks. Floodgate operations varied substantially, with floodgates that seldom opened were associated with greater differences in fish communities and with reduced upstream native species richness by about one species on average. Where floodgates opened infrequently, we also found lower upstream dissolved oxygen concentrations than at sites where floodgates opened for longer periods of time [4].

Freshwater fish are not only the most diverse group of vertebrates but also have the greatest proportion of threatened species [5-6]. Fish assemblages are also an important element in aquatic ecosystems, which are used as the biological indicators for aquatic ecosystem assessment [7-8]. Over the past few decades, fish resources decreased dramatically, and endemic species have faced continuous threats globally which is caused by the construction of the dam, overfishing, pollution, and other human activities considered as the main threats to fish biodiversity [5]. River ecology is dominated by flow seasonality imposed by monsoonal rains with profound consequences for fishes [9]. The diversity and abundance of fish community in the lotic water ecosystem are influenced by natural factors such hydrologic features, habitats, and feeding types, and also by water quality variables such as altitude, gradient, tidal velocity, elevation and water temperature, as a result, if the conditions of the water source change, the diversity and abundance of sensitive species can decrease. It will have both direct and indirect effects on fish habitat depletion. For example, building a dam or building a floodgate blocks the chances of inheriting the genetic diversity of aquatic life and destroying the original habitat in which the native species used to live. The abundance of fish community was used to determine the importance of spatial and environmental factors on fish distributions and to assess the use of fish as indicators of the environmental conditions [9-10]. Therefore, freshwater fish has reduced ability for inter-basin movement in this relatively limited space [7], which was at the root of the conservation problems [5-7].

Research into biodiversity in particular fish populations and observations of species diversity and distribution of fish were carried out in the river of Eastern Bangkok area. There were two problems faced in this area: polluted water during the dry season and flooding during the rainy season. The negative effects of such problems impact not only humans, but also freshwater fish. This causes severe damage to the ecosystem in the area, especially to freshwater fish resources, which have long been the food source of the community, leading to shortages. Some fish species which used to be abundant have disappeared from this area, and some species' numbers have decreased to a very rare stage [11]. Therefore, the conservation of fish biodiversity has become more important.

There is a concern that damage to natural water sources can have a negative impact on species diversity of freshwater fish and populations of fish species. Therefore, this study was conducted to reveal the freshwater fish diversity in the agriculture conservation areas of Eastern Bangkok. This study aims to establish an inventory of the freshwater fish present in the Eastern Bangkok canal system area. The results are needed to develop baseline data that will be valuable to assess the future environmental impacts of development and conservation.

Materials and Methods

Study area

A field study in the agricultural conservation areas of Eastern Bangkok composed of the freshwater fishes by drawing a grid to cover the geographic system from the digital map in Google Earth (version 6.0.3). The grid is 5 arcminutes per square, representing 83.36 spaces per square; study area separated into eight stations: 1) Sam Wa canal (ST1) (13°54'42.7"N 100°43'43.3"E); 2) Saen Saep canal (ST2) (13°51'28.4"N 100°51'15.2"E); 3) Tanot canal (ST3) (13°48'50.7"N 100°46'36.5"E); 4) Lam Phra Ong canal (ST4) (13°46'30.6"N 100°49'11.0"E); 5) Prawet Burirom canal (ST5) (13°42'04.8"N 100°51'03.5"E); 6) Song Ton Nun canal (ST7) (13°46'34.5"N 100°44'19.6"E); 7) Sip canal (ST8) (13°55'50.5"N 100°48'51.5"E); 8) Sip Sam canal (ST6) (13°55'42.1"N 100°53'34.2"E) for cover both upstream, midstream and downstream sample collection in the study area where water bodies are main and branch canals. In addition, there were 5 floodgates that control the flow of water in the canals according to the irrigation system in each season: 1) G1 Samwa canal floodgate; 2) G2 Saen Saep canal floodgate; 3) G3 Sip Sam canal floodgate; 4) G4 Song Ton Nun canal floodgate; 5) G5 Prawet Burirom canal floodgate (Figure 1).

Sample collection

The fish specimens were collected every 4 months in the period from January to December 2020, covering the hot-dry (April), rainy (August) and cool-dry (December) seasons at eight sampling stations in the area of Eastern Bangkok (ST1-ST8), using cast nets with a mesh size of 1.5 cm and 2.5 cm, gill nets with a mesh size of ¾ inch, 1.5 inch and 2 inch., labeled by location and date of collection, and transported to the laboratory. Fish samples preserved in 10 percent formalin-freshwater solution, and deposited at the Faculty of Science and Technology, Suan Sunandha Rajabhat University, Bangkok. The species identification was conducted by following Kottelat [12] and Nelson [13], Rainboth [14], Smith [15], Vidthayanon *et al*. [16].

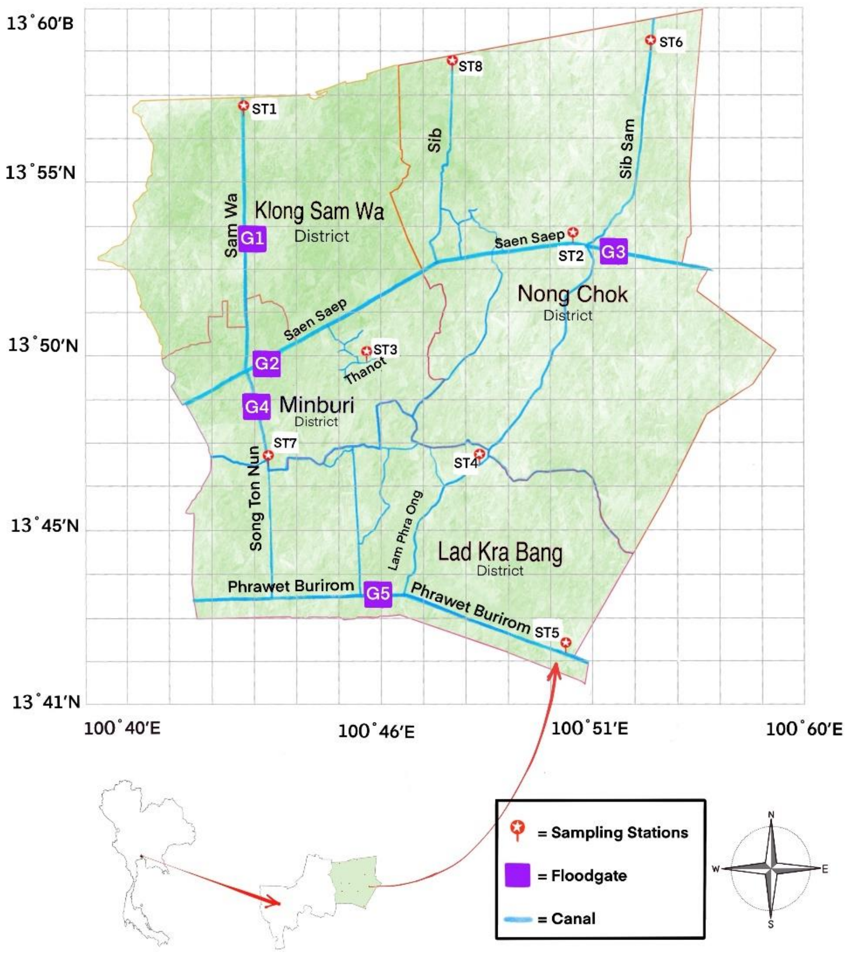

Figure 1 Map of agriculture conservation areas of Eastern Bangkok Note: ST1 Sam Wa canal, ST2 Saen Saep canal, ST3 Tanot canal, ST4 Lam Phra Ong canal, ST5 Prawet Burirom canal, ST6 Song Ton Nun canal, ST7 Sip canal, ST8 Sip Sam canal, G1 Samwa canal floodgate, G2 Saen Saep canal floodgate, G3 Sip Sam canal floodgate, G4 Song Ton Nun canal floodgate, G5 Prawet Burirom canal floodgate

Table 1. Freshwater fish diversity in the agricultural conservation areas of Eastern Bangkok, Thailand

Family	Species	Amount (ind)	Location	Distribution (%)
Notopteridae	*Chitala ornata*	3	1,5,8	37.5
	Notopterus notopterus	2	1,8	25
Cyprinidae	*Esomus metallicus*	1	4	12.5
	Cyclocheilichthys enoplos	10	1,2,6	37.5
	Puntioplites proctozystron	12	1,2,6	37.5
	Barbonymus altus	16	1,2,5,8	50
	Barbonymus gonionotus	29	1,2,5,8	50
	Barbonymus schwanenfeldii	3	2	12.5
	Hampala macrolepidota	1	8	12.5
	Labeo rohita	2	8	12.5
Bagridae	*Mystus mysticetus*	32	2,8	25
Pangasiidae	*Pangasianodon hypophthalmus*	20	1,2,5,7,8	62.5
	Pangasius larnaudii	1	8	12.5
	Pangasius macronema	14	1,7,8	37.5
Clariidae	*Clarias macrocephalus*	31	1,2,5,7,8	62.5
	Clarias gariepinus	2	1,8	25
Synbranchidae	*Monopterus albus*	2	4,6	25
Ambassidae	*Parambassis siamensis*	2	6	12.5
Cichlidae	*Oreochromis niloticus*	69	1,2,3,4,5,6,7,8	100
Eleotridae	*Oxyeleotris marmorata*	15	1,6,8	37.5
Anabantidae	*Anabas testudineus*	47	1,2,4,5,6,7,8	100
Pristolepididae	*Pristolepis fasciata*	5	1,8	25
Osphronemidae	*Trichogaster microlepis*	214	1,2,4,5,6,7,8	62.5
	Trichopodus trichopterus	397	1,2,3,4,5,6,7,8	100
	Trichopodus pectoralis	256	1,2,3,4,5,6,7,8	100
	Osphronemus goramy	6	7,8	25
Channidae	*Channa striata*	67	1,2,3,4,5,6,7,8	100
	Channa micropeltes	3	8	12.5
Loricariidae	*Pterygoplichthys disjunctivus*	153	1,2,3,4,5,6,7,8	100

Remark: ST1–ST8 = Sampling stations for collecting fish

Results and Discussion

Fish composition

The fish composition consisted of species belonging to 23 genera and 14 families. The result showed the number of fish species in the Eastern Bangkok area. The observation in each station revealed that station 1 was dominated by *Trichopodus trichopterus* (62 individuals) and *Trichogaster microlepis* (55 individuals), station 2 by *Trichopodus trichopterus* (38 individuals) and *Trichogaster microlepis* (31 individuals), station 3 by *Trichopodus trichopterus* (39 individuals) and *Trichopodus pectoralis* (16 individuals), station 4 by *Trichopodus trichopterus* (43 individuals) and *Trichogaster microlepis* (28 individuals), station 5 by *Trichopodus trichopterus* (38 individuals) and *Trichogaster microlepis* (21 individuals), station 6 by *Trichopodus trichopterus* (47 individuals) and *Trichogaster microlepis* (19 individuals), station 7 by *Trichopodus trichopterus* (57 individuals) and *Trichogaster microlepis* (39 individuals) and station 8 by *Trichopodus trichopterus* (73 individuals) and *Trichopodus pectoralis* (66 individuals).

Nile tilapia *O. niloticus*, three spot gourami *T. trichopterus*, snakeskin gourami *T. microlepis*, and suckermouth catfish *P. disjunctivuswere* collected in all the research stations (100%). The family of Cyprinidae was represented by 8 species and Osphronemidae was represented by 4 species (Table 1).

The occurrence and comparison of fish species in each station

Station 8, with 23 species, had the highest number of species, followed by station 1 with 19 species, station 2 with 15 species, station 5 and station 6 with 12 species, station 7 with 10 species, station 4 with 9 species, station 2 with 15 species and station 3 with 5 species.

The species diversity index (H′) at each station ranged between 1.323 to 2.423, the evenness index (E) 0.489 to 0.895, and species richness index (d) from 1.135 to 3.919 (Table 2). Saen Saep canal (Station 2) had the highest diversity of fish species i.e. with H′ = 2.423, evenness index, E = 0.895, and Sip Sam canal (Station 8) had the highest species richness index, d = 3.919 (Table 3).

A comparison of the Bray-Curtis similarity index of fish community in the agricultural conservation areas of Eastern Bangkok found the range of the level of similarity between the survey point was 55.42-100%. Tanot canal (Station 3) had almost the same percentage fish species composition as Lam Phra Ong canal (Station 4) at 100%, while Prawet Burirom canal (Station 5) had different fish species composition to Sip Sam canal (Station 8) 55.42% (Table 4). The cluster analysis of Bray-Curtis similarity index can divide the fish community into 3 clusters (Figure 2).

Table 2. The presence or absence of fish in each station

Family	Species	Station							
		1	2	3	4	5	6	7	8
Notopteridae	*Chitala ornata*	1				1			1
	Notopterus notopterus	1							1
Cyprinidae	*Esomus metallicus*				1				
	Cyclocheilichthys enoplos	5	3				2		
	Puntioplites proctozystron	6	4				2		
	Barbonymus altus	4	8			2			2
	Barbonymus gonionotus	6	10			5			8
	Barbonymus schwanenfeldii		3						
	Hampala macrolepidota								1
	Labeo rohita								2
Bagridae	*Mystus mysticetus*		11						21
Pangasiidae	*Pangasianodon hypophthalmus*	3	5			4		2	6
	Pangasius larnaudii								1
	Pangasius macronema	5						2	7
Clariidae	*Clarias macrocephalus*	7	8			3		4	9
	Clarias gariepinus	1							1
Synbranchidae	*Monopterus albus*				1		1		
Ambassidae	*Parambassis siamensis*						2		
Cichlidae	*Oreochromis niloticus*	10	9	5	5	4	4	10	22
Eleotridae	*Oxyeleotris marmorata*	4					2		9
Anabantidae	*Anabas testudineus*	8	7		5	4	5	6	12
Pristolepididae	*Pristolepis fasciata*	2							3
Osphronemidae	*Trichogaster microlepis*	39	15	16	12	10	21	35	66
	Trichopodus trichopterus	62	38	39	43	38	47	57	73
	Trichopodus pectoralis	55	31		28	21	19	39	63
	Osphronemus goramy							2	4
Channidae	*Channa striata*	8	10	4	7	9	4	8	17
	Channa micropeltes								3
Loricariidae	*Pterygoplichthys disjunctivus*	24	25	18	15	15	16	18	22

Table 3. The species diversity index (H′), the evenness index (E) and species richness index (d) at each sampling station

Index / Station	Species diversity	Evenness	Species richness
ST1	2.264	0.769	3.258
ST2	2.411	0.895	2.867
ST3	1.323	0.489	1.135
ST4	1.727	0.786	1.890
ST5	2.039	0.820	2.524
ST6	1.873	0.754	2.485
ST7	1.877	0.783	2.115
ST8	2.423	0.769	3.919

Table 4. Bray-Curtis similarity index of fish community in the agricultural conservation areas of Eastern Bangkok

	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
ST1								
ST2	84.39							
ST3	72.88	91.62						
ST4	71.65	92.00	100.00					
ST5	67.64	81.85	69.20	93.52				
ST6	71.14	91.60	94.25	99.57	93.09			
ST7	90.05	90.52	78.10	79.86	75.26	80.28		
ST8	85.36	71.08	58.16	58.97	55.42	58.71	75.62	

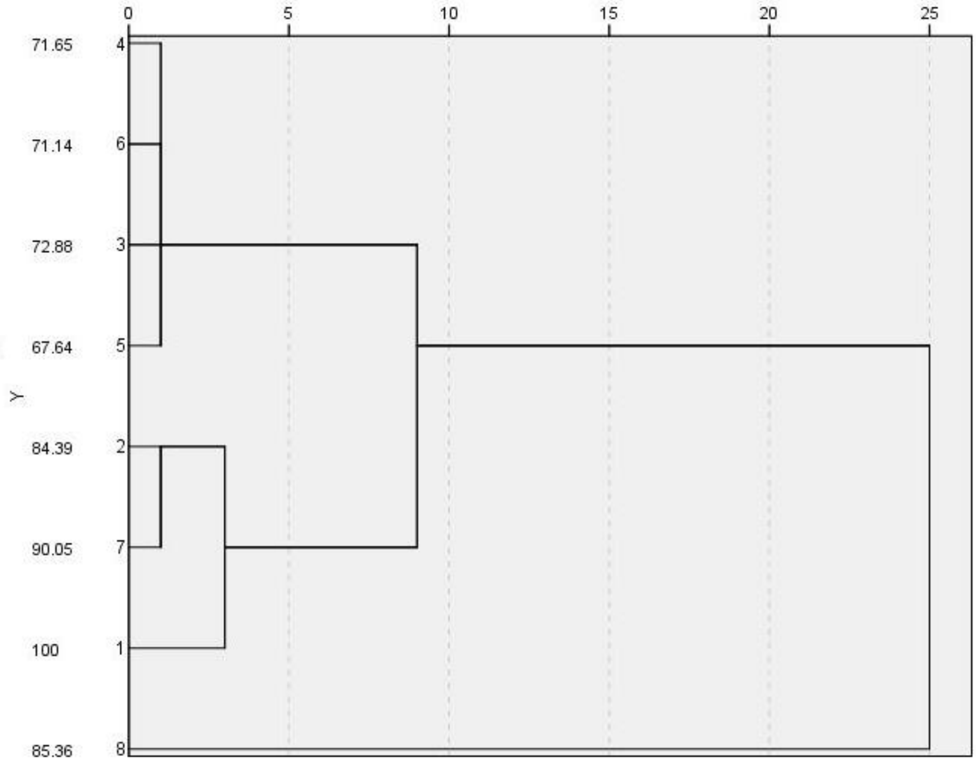

Figure 2. Grouping the agriculture conservation areas based on fish species in each station

Discussion

Dominance by accessory air-breathing organ fishes is very common in the agricultural conservation areas of Eastern Bangkok. These are fish that tolerate poor quality environments due to the presence of an accessory air-breathing organ which allows them to adapt to the environment. Often, less sensitive species have ancillary respiratory mechanisms such as the lung-like labyrinth organ present in *Trichogaster trichopterus, Trichogaster microlepis, Trichopodus pectoralis and Osphronemus goramy*, the supra-branchial organ present in *Pterygoplichthys disjunctivus, Channa striata, Channa micropeltes*, or scale-less species (such as *Mystus mysticetus, Pangasianodon hypophthalmus, Clarias macrocephalus* and *Pangasius macronema*) [17].

Osphronemidae families had the highest number throughout the research stations. It is suspected that species of these families are permanent, or temporary residents in the agricultural conservation areas of Eastern Bangkok. Seemingly, members of the family, Osphronemidae, Cichlidae and Loricariidae, have a widespread habitat. In the Nong Yai Canal, East Thailand, species of Loricariidae families are dominant [18], as they are in Pranburi River, Phetchaburi Province and Prachuap Khirikhan Province. The reservoir ecosystem was described as transparent lentic water, and the low slope area and the floodplains of the mid-Chao Phraya River Basin, where the three main tributary rivers of the Chao

Phraya River meet, has a vast floodplain system. Accordingly, a number of fish species Osphronemidae and Cichlidae were commonly found in this zone [19-20]. These species exhibited abroad distribution because they were highly tolerant to water quality fluctuation, similar to those found in the mainstream ecosystem such as *Trichogaster trichopterus* and *Oreochromis niloticus* which likely lived in the lotic water. The water source in the agricultural conservation areas of Eastern Bangkok was converted into lentic water when the floodgates were installed to regulate the irrigation system. Lentic water has a lower oxygen content than lotic water. This has an impact on fish migration paths, preventing the genetic transmission of freshwater fish [10]. The Osphronemidae families and most accessory air-breathing organ fishes were the most common fish species in the study field. The number of native freshwater fish species, which live in lotic water and are index species of water cleanliness, has decreased, as has the number of Cyprinidae family fish.

The suckermouth armored catfish which invasive alien species obtained from this study, found that were able to collect samples at all stations. They had been behavior burrowing habits displace sediment which can lead to alter water quality as well as uprooting of aquatic macrophytes during the burrowing and foraging. Furthermore, given the degree in which this invasive species are presented in the river, nutrient cycling within the river may be altered [21]. Loricariidae can destroy the eggs of the native catfish *Clarias macrocephalus* and has the potential to reduce the populations of Thai native fish species. It is reported that the decline in the native fish population was relatively in a habitat shared with *Pterygoplichthys* [18].

Cyprinidae families had the highest number of species. However, based on the data obtained from this research survey, the Cyprinid family still has a smaller number and diversity than expected given the diversity of the Cyprinid family of fish species in the River Basin. Generally, dominance by the fishes in family Cyprinidae is common in the Asian freshwater bodies where they may contribute 40% or more of the species in a watershed [10] and cyprinids represented approximately 37.9% of all species captured from habitat characteristics of the Cyprinidae in small rivers in the lower northern of Thailand [22], and based on fish species which were collected by electrofishing from 96 sites, representing 79 species, in lightly exploited rivers in Western Thailand, species' site occupancies were highest for *Devario acrostomus* (76%) in Cyprinidae families [17]. It is worth noting that the diversity of fish species in the Cyprinidae families has disappeared, and it is not certain whether this is temporary or permanent.

Table 2 shows that more fish species visited the station 8 (Sam Wa canal) than the other stations. Accordingly, the species index and species richness index in Sam Wa canal (station 8) were higher than those in Sam Wa canal (station 1), Saen Saep canal (station 2), Tanot canal (station 3), Lam Phra Ong canal (station 4), Prawet Burirom canal (station 5), Song Ton Nun canal (station 6) and Sip canal (station 7). The high diversity in Sam Wa canal might be caused by the located area of study in the eastern zone of the area study, mostly due to this being an agricultural conservation area which is far from the community and industrial areas, including the position set by the researcher to collect samples. This facility is located in the area just before the Sip Sam canal floodgate (G3), which is a northward water intake area, adjacent to the highly bio-fertile Rangsit field. The species richness index of the Tanot canal (Station 3) was the lowest. This situation may be due to the poor water quality conditions in the Tanot canal because of the sampling location of this station is a small branch canal and is located behind the water barrier near the San Saeb canal floodgate (G2). When the floodgates are closed, it restricts the passage of fish by preventing fish from migrating into or out of canal. This area limits fish corridors, making the area a smaller enclosed water source, limiting the proper reproduction and migration of the fish in the traditional habitats. Fragmentation of habitat cause by poor environmental quality, allegedly contributes to the wealth of existing fish species [23].

This study area has geographical and ecological characteristics of floodplains, maintained by dynamic interactions between flooding and landscape. Floodplains are disappearing at an accelerating rate in the Chao Phraya River Basin, primarily as a result of changing hydrology caused by irrigation schemes and dams [20]. On the other hand, flooding has the potential to cause serious damage to the biodiversity of the Bangkok area, which is in the lower-region of the Chao Phraya River Basin. After the 2011 flood in Thailand, large-scale dam building operations have reduced the flood area in the Chao Phraya River Basin by 40% [24]. In the present study, the main stream of the Eastern Bangkok Basin, which has a smaller floodplain area compared with the other rivers, showed a relatively low fish species richness. The reduction in floodplain area secondary to flood control measures may affect species richness, especially of migratory species in the agricultural conservation areas of Eastern Bangkok.

Differences in fish communities above and below floodgates were more pronounced where floodgates were closed for more time. Furthermore, in sites where floodgates seldom opened, upstream fish communities had relatively fewer native species than at sites where floodgates opened more often. Additionally, dissolved oxygen concentrations were lower upstream of floodgates that seldom opened. These findings provide evidence that impacts to water quality and fish communities can vary with the operations of gates [4]. Therefore, the operation of the floodgates can have an impact on fish diversity as well as water quality. A floodgate can affect fish in two main ways: modifying water quality and limiting fish passage. First, a floodgate can alter water quality by limiting tidal exchange. Dead zones due to eutrophication in lotic water [25]. Waterlogging in canal also tends to have high concentrations of nutrients, coliforms and heavy metals. And high turbidity and sedimentation rates [4]. Second, when the floodgates are closed, it restricts the passage of fish by preventing fish from migrating into or out of canal [26-27], these effects may, together, produce observed changes in fish communities involved in floodgates around the world [28], floodgates that hold water away from the main canals. There was a negative correlation between opening the floodgates and noticing differences in fish communities above and below the floodgates, such as that fish communities differed more when the floodgates were less open. Floodgates vary greatly across areas, with most floodgates open on average less than a quarter of the day. Accordingly, there may be opportunities to mitigate impacts to tidal creek water quality, and fish communities by altering floodgate operations [4].

Conclusions

In conclusion, a total of 29 species of fish were collected from eight research stations in the agricultural conservation areas of Eastern Bangkok. *O. niloticus*, *T. trichopterus*, *T. microlepis,* and *P. disjunctivus* had 100% local distribution or were found in all research stations. Table 3 shows the value of Shannon-Wiener (H′) species diversity index of all locations sampled in the agricultural conservation areas of Eastern Bangkok. This index gives an illustration on the species diversity, the productivity of ecosystems, the pressures on ecosystems, and the stability of ecosystems [20]. A value of $1.0 < H' < 3.322$ means moderate diversity, sufficient productivity, with ecosystem conditions being fairly balanced, and medium ecological pressure [29]. From the 8 samples sites none of these indicated high diversity. However, we collected sample the canal with moderate H′index value. The highest one is Sam Wa canal (Station 8) ($H' = 2.423$). The relative species diversity and evenness index was highest indicating that this site had a greater proportion of abundance among fish species and distribution pattern in each species than any other site.

Acknowledgements

The authors are thankful to all partners for supporting this survey.

References

1. Drainage and Sewerage Department. (2020). Action plan for prevention and problem solving Bangkok floods in 2020. Bangkok. Department of Drainage and Sewerage Bangkok Metropolitan Administration. (in Thai)
2. Mark, D. (2016). “It is built against nature”: Floodwalls built after the 2011 floods in central Thailand. Research report. Thailand Development Research Institute Foundation.
3. Molle, F. (2008). The Bang Pakong River Basin Committee: Analysis and summary of experience. FAO.
4. Seifert, E. R., & Moore, W. J., (2017). Floodgate operations and fish communities in tidal creeks of the lower Fraser River (British Columbia, Canada). *Estuaries and Coasts*.

5. Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. J. (2016). Fish conservation in freshwater and marine realms: status, threats and management. *Aquatic Conservation Marine & Freshwater Ecosystems*, *26*(5): 838–857.
6. Liu, X. J., Hu, X. Y, Ao, X. F., Wu, X. P., & Ouyang, S. (2017). Community characteristics of aquatic organisms and management implications after construction of Shihutang Dam in the Gangjiang River, China. *Lake and Reservoir Management*, *34*(1), 42-57.
7. Nogueira, C., Buckup, P. A., Menezes, N. A., Oyakawa, O.T., Kasecker, T. P., Ramos Neto, M. B., & da Silva, J. M. C. (2010). Restricted-range fishes and the conservation of Brazilian freshwaters. *Plos One*, *5*(6), e11390. https://doi.org/10.1371/journal.pone.0011390
8. Yan, Y. Z., Xiang, X. Y., Chu, L., Zhan, Y. J., & Fu, C. Z. (2011). Influences of local habitat and stream spatial position on fish assemblages in a dammed watershed, the Qingyi Stream, China. *Ecology of Freshwater Fish*, *20*(2), 199–208.
9. Suvarnaraksha, A., (2015). Upstream fish adaptation. *Maejoe vision*, *16*(5), 74-80. (in Thai)
10. Alexandre, C. V., Esteves K. E., & Moura M. A. M. (2010). Analysis of fish communities along a rural–urban gradient in a neotropical stream (Piracicaba River Basin, Sao Paulo, Brazil). *Hydrobiologia*, *641*, 97–114.
11. Talbot, C. J., Bennett, E. M., Cassell, K., Hanes, D. M., Minor, E. C., Paerl, H. Raymond, P. A., Vargas, R. Vidon, P. G., Wollheim, W., & Xenopoulos, M. A. (2018). The impact of flooding on aquatic ecosystem services. *Biogeochemistry*, *14,* 439–461.
12. Kottelat, M. (2001). *Fishes of Laos. Wildlife heritage trust*, Colombo: WHT Publications.
13. Nelson, J. S. (2001). *Fishes of the world* (4th ed.). New York: John Wiley & Sons.
14. Rainboth, W. J. (1996). Fishes of Cambodian Mekong. FAO species identification field guide for fisheries purpose. Rome: FAO.
15. Smith, H. M. (1945). The freshwater fishes of Siam, or Thailand. *Bulletin of the United States National Museum*, *188*, 1-622.
16. Vidthayanon, C., Karnasuta, J., & Nabhitabhata, J. (1997). Diversity of freshwater fishes in Thailand. Bangkok: Office of Environmental Policy and Planning, Bangkok. p.102
17. Tongnunui, S., Frederick, H., Beamish, H., & Kongchaiy, C. (2016). Fish species, relative abundances and environmental associations in small rivers of the Mae Klong River Basin in Thailand. *Agriculture and Natural Resources*, *50*, 408-415.
18. Chaichana, R., Pouangcharean, S., & Yoonphand, R. (2013). Foraging effects of the invasive alien fish *Pterygoplichthys* on eggs and first-feeding fry of the native *Clarias macrocephalus* in Thailand, *Kasetsart Journal: Natural Science*, *47*, 581-588.
19. Petsut, N., Kulabtong, S., & Petsut, J. (2017). Species diversity and distribution of fishes in Pranburi River, Phetchaburi province and Prachuap Khirikhan province. *International Journal of Agricultural Technology*, *13*(5), 671-682.
20. Tanaka, W., Wattanasiriserekul, R., Tomiyama, Y., Yamasita, T., Phinrub, W., Chamnivikaipong, T., Suvarnaraksha, A., & Shimatani, Y. (2015). Influence of

floodplain area on fish species richness in waterbodies of the Chao Phraya River basin, Thailand**.** *Open Journal of Ecology*, *5*, 434-451. http://dx.doi.org/10.4236/oje.2015.59036

21. Hussan, A., and T. G. Choudhury. 2016. Suckermouth Sailfin Catfishes: A future threat to aquatic ecosystems of India. *Aquaculture Times*, *2*(6), 20–22.
22. Jutagate, T., Sa-nguansin, J., Deein, G., & Udduang, S. (2011). Fish distribution in a river basin in the lower northern of Thailand and a strategy for conservation following river damming, *Chiang Mai Journal of Science*, *38*(3), 485-502.
23. Abroguena, J. B. R., Bagarinao, T. U., & Chicharo, L. (2012). Fish habitats in a small, human-impacted Sibunag mangrove creek (Guimaras, Philippines): A basis for mangrove resource enhancement. *Ecohydrology and Hydrobiology*, *12*(4), 311–319.
24. Mateo, C.M., Hanasaki, N., Komori, D., Tanaka, K., Kiguchi, M., Champathong, A., Sukhapunnaphan, T., Yamazaki, D., & Oki, T. (2014). Assessing the impacts of reservoir operation to floodplain inundation by combining hydrological, reservoir management, and hydrodynamic models. *Water Resources Research*, *50*, 7245-7266.
25. Gordon, J., Arbeider, M., Scott, D., Wilson, M.S., & Moore, W.J. (2015). When the tides don't turn: floodgates and hypoxic zones in the lower Fraser River, British Columbia, Canada. *Estuaries and Coasts*, *38*(6), 2337–2344.
26. Doehring, K., Young, G. R., Hay, J., & Quarterman, J. A. (2011). Suitability of dual-frequency identification sonar (DIDSON) to monitor juvenile fish movement at floodgates. *New Zealand Journal of Marine and Freshwater Research*, *45*, 413–422.
27. Wright, V. G., Wright, R. M., & Kemp, S. P. (2014). Impact of tide gates on the migration of juvenile sea trout, Salmo trutta. *Ecological Engineering*, *71*, 615–622.
28. Scott, C. D., Arbeider, M., Gordon, J., & Moore, W. J. (2016). Flood mitigation structures transform tidal creeks from nurseries for native fishes to non-native hotspots. *Canadian Journal of Fisheries and Aquatic Sciences*, https://doi.org/10.1139/cjfas-2015-0311.
29. Karr, J. R. (1981). Assessment of biotic integrity using fish communities. *Fisheries*, *6*, 21–27.