Fisheries' sustainability of three lakes in Jakarta, Indonesia

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Abstract. Urban lakes are an important component in urban areas because they can provide a variety of ecosystem services needed by urban dwellers. The high population in urban areas has an impact on increasing the community's need for various resources such as water, agricultural products, and fish. The sustainability of freshwater fisheries in urban areas is increasingly threatened due to the degradation of lake ecosystems. This study aims to examine the relationship between the various ecosystem services provided by three lakes in Jakarta (Situ Babakan Lake, Srengseng Urban Forest Lake, and South Sunter Lake) and the fisheries sustainability at these locations. From the analysis results, the status of most of the ecosystem services have not demonstrated the sustainability of lake fisheries. Urban lake ecological conditions have an important role in creating harmony and sustainability of ecosystem services provision. Srengseng Urban Forest Lake, the location with the lowest human intervention role in ecosystem alteration, was predicted to have the highest fisheries' sustainability among other locations. To reduce conflicts and trade-offs between ecosystem services' users, comprehensive multi-stakeholder lake management is required, focusing on various aspects and ecosystem services.
Key Words: fish, ecosystem services, urban lakes, urban blue space, sustainability.

Introduction. According to Ho & Goethals (2019), lakes around the world have functions which meet various human needs such as water sources, tourist attractions, animal habitats, and air temperature reducers. Lakes do not only have an ecological value that supports environmental sustainability but also have economic and social functions to meet the needs of the surrounding community. Various lakes in rural areas, especially in Asia, function as a supplier of fishery resources (Makwinja et al 2022). Fishing activities in various lakes in urban areas not only fulfill the people's recreational and hobby needs but also support the people's food needs through the supply of freshwater fish. Urban environmental degradation indirectly affects freshwater ecosystems through increased impermeable land cover and runoff and pollutant flows into water bodies (Cardoso et al 2021). High urban activity consisting of domestic, industrial, and agricultural activities affects water quality in various freshwater ecosystems including lakes. Deteriorating water quality conditions can affect the performance of lake ecosystems in supporting aquatic life (Sutapa et al 2021). Joosse et al (2021) stated that deterioration of this aquatic ecosystem can affect the balance of the food chain, recreational benefits, to the feasibility of consuming fish originating from freshwater lakes.

The ability of fresh waters to provide fishery-related ecosystem services in urban areas decreases over time. Various inhibiting factors such as water pollution, overfishing, habitat destruction, and economic growth are some of the factors driving the decline in fish supply (Nikolaus et al 2021). The low quality status of the aquatic ecosystem can also be a main factor in fish provisioning services degradation. On the other hand, people in urban areas who live far from the coast need a source of protein to support their lives without depending on other areas. The need for fishery resources will continue to increase every year since it is predicted that in 2050, more than 70% of the world's population will live in urban areas (Teurlincx et al 2019).

Jakarta is one of the megacities in Indonesia which has a large urban lake potential (Henny & Meutia 2014). In recent years, the water quality in several lakes in Jakarta has decreased due to high levels of pollutants entering the water bodies. On the other hand, the lake has an important function as a recreation area for the people of Jakarta. Several popular lakes in Jakarta do not charge entry fees for visitors and allow visitors to utilize fish resources for recreational and consumption needs. The low water quality in many lakes threatens the suitability of fish for consumption (Hashim et al 2014). Not only water quality, but also other factors related to the lake ecosystems management greatly affect the fisheries sustainability.

Fisheries sustainability is a term that refers to the utilization of fish resources by considering the 3 pillars of sustainability (social, economic, and environmental). Although the sustainability assessment sounds very subjective, by neglecting one of the sustainability pillars in fish resource utilization, sustainability will not be achieved (Hilborn et al 2015). This analysis was conducted by examining the relationship between fisheries sustainablity and various ecosystem services such as the water quality regulation, fish provisioning, cultural services, flood regulation, and biodiversity supporting.

Material and Method

Description of the study sites. This research was conducted in the period January-March 2023 at three urban lakes in Jakarta which are frequently visited for recreational activities including Situ Babakan Lake (SBL) in South Jakarta, Srengseng Urban Forest Lake (SUFL) in West Jakarta, and South Sunter Lake (SSL) in North Jakarta. These three locations were chosen because of their different surrounding landscape conditions, related to the traditional community villages, urban forests, and commercial areas. The three lakes have a high number of tourist visits and are considered as fishing spots by the local community. Some visitors visit the three lakes to do fishing activities for recreation and sometimes bring their catch for daily fish consumption. The high interest in fishing does not only benefit tourists but also local people who trade fishing tools around the lake. The high potential for fishing activities has made residents sell bait, string, buoys, weights, fishing lines, and rods to meet the needs of recreational visitors.

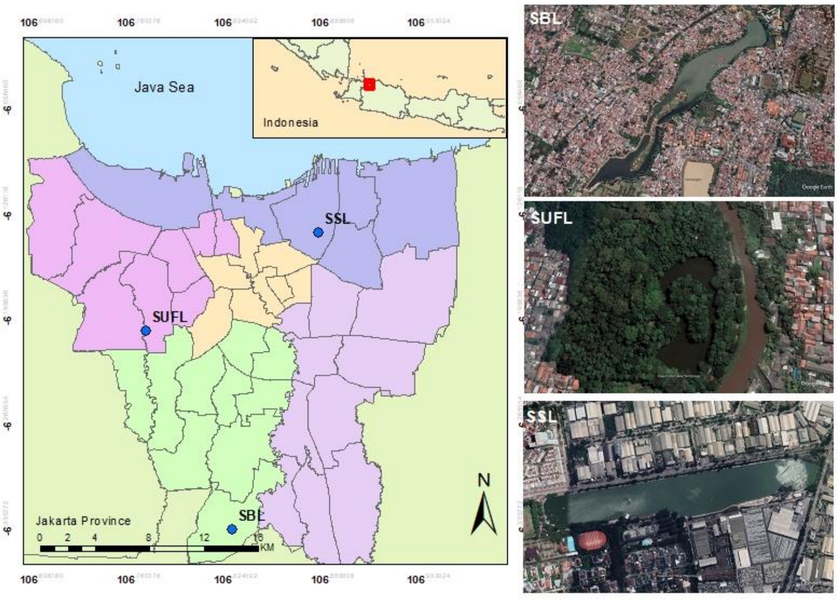

Figure 1. Study locations.

Data collection. Secondary data were obtained from various sources and institutions, such as the provincial environmental service for water quality registers, the provincial cultural service for recreational fishing activities register, the provincial water resources service for flood prevention and fish stocking programs, as well as literature studies related to the tree species diversity index of riparian zones (Table 1).

Table 1

Data collection

Ecosystem services	*Data type*	*Parameters*
Water quality regulating	Secondary, Primary	Temperature, TSS, TDS, pH, DO, TP, BOD, COD, Total coliforms, Fecal coliforms, Hg, Cd, Ni, Pb
Fish provisioning	Secondary	Fish species, fish provisioning management
Cultural	Secondary, Primary	Lake visitors, type of angling activities, type of water recreation
Flood regulating	Secondary	Flood prevention methods
Biodiversity supporting	Secondary, primary	Tree diversity index, greenspace cover percentage

Water quality data in 2022 included parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and total phosphorus (TP). These parameters are important factors that determine the presence of biota in the limnic ecosystem (Fan et al 2020; Li et al 2018). In addition, the utilization of fish in freshwater ecosystems needs to consider several parameters of heavy metals such as mercury (Hg), lead (Pb), nickel (Ni), and cadmium (Cd) based on water class standards for fisheries (Hashim et al 2014; Koniyo 2020). Primary water quality data was also taken using the CTD Profiler tools for the chlorophyll-a parameter.

Primary data collection through ground surveys at the three research locations was conducted to determine the percentage of the total number of anglers out of all lake visitors, the type of fishing gear used, as well as the provision of water recreation facilities at the three locations that have the potential to influence fisheries' sustainability. A ground survey was also conducted to see the condition of land cover, which has been analyzed using GIS. Vegetation surveys were also conducted to measure the tree diversity index.

Data analysis. Water quality parameter data at the three study locations was compared descriptively with class 3 water quality standards according to the Government Regulation number 22 of 2021, to determine the water suitability for aquaculture. Water quality that exceeds government quality standards risks to have a reduced fish productivity. The high content of pollutants has a stress impact on the biota of water. On the other hand, the high concentrations of heavy metals can reduce the feasibility of fishing for human consumption. Data related to other ecosystem services such as fish provisioning, cultural services, flood regulation, and biodiversity support were analyzed descriptively.

To support biodiversity data, a land cover analysis was carried out using ArcGIS 10.8 to determine the percentage of greenspace cover in riparian areas (50 m from the highest littoral zones). Based on the study of Sari et al (2022), tree diversity index could be calculated using the Shannon-Wiener diversity index formula (Table 2). After all the analysis has been carried out, the data was formatted in a tabular presentation to see the correlation of the ecosystem services' status with the fisheries' sustainability. A negative relationship suggests a lower potential of the fisheries for sustainability at the study site, in the future.

$$H' = \sum_{i=1}^{n} \left[\frac{ni}{N}\right] \ln \left[\frac{ni}{N}\right]$$

Where:
H' - Shannon-Wiener diversity index;
Ni - number of individuals of tree species *i*;
N - total number of tree samples.

Table 2

Diversity index categories

H′ value	*Category*
>3	High diversity
2-3	Medium diversity
<2	Low diversity

Results and Discussion

Water quality regulating service. Based on the results of the water quality analysis, some water quality parameters related to oxygen depletion, coli bacteria, and heavy metals at the three study locations did not meet the criteria for aquaculture (Table 3). The high intensity development in urban areas generates a flow of pollutants originating from domestic and industrial waste into the water bodies and increases organic pollutants such as BOD and COD in fresh waters (Gwimbi et al 2019). This condition can trigger oxygen depletion which affects the life of aquatic biota. The high level of organic pollutants and low dissolved oxygen in water triggers the risk of fish mortality, thereby affecting the fisheries sustainability (Boyd et al 2018).

Table 3

Comparison of water quality with class 3 quality standards

Parameters	*Unit*	*Water quality standard*	*SBL*	*SUFL*	*SSL*
Temperature[a]	°C	Dev. 3	30.67	28.62	29.99
TSS[a]	mg L^{-1}	100	33.00	13.67	31.00
TDS[a]	mg L^{-1}	1,000	143.38	216.65	339.83
pH[a]	-	6-9	7.70	7.14	8.71
DO[a]	mg L^{-1}	3	5.17	2.18*	6.01
Chl-a[b]	mg L^{-1}	100	3.31	6.35	5.54
TP[a]	mg L^{-1}	0.1	0.02	0.02	0.03
BOD[a]	mg L^{-1}	6	7.26*	7.85*	16.45*
COD[a]	mg L^{-1}	40	24.05	39.67	66.05*
Total coliforms[a]	MPN 100 mL^{-1}	10,000	136,166.67*	145,750.00*	88,883.33*
Fecal coliforms[a]	MPN 100 mL^{-1}	2,000	16,000.00*	48,116.67*	16,750.17*
Hg[a]	mg L^{-1}	0.002	0.008*	0.009*	0.023*
Cd[a]	mg L^{-1}	0.01	0.005	0.005	0.005
Ni[a]	mg L^{-1}	0.05	0.04	0.03	0.03
Pb[a]	mg L^{-1}	0.03	0.05*	0.01	0.02

[a]Jakarta Provincial Environmental Service; [b]Data Measurement using CTD Profiler tool; *Exceeds the quality standards, except for DO (below the quality standard).

The high levels of biological pollutants from *Escherichia coli* and heavy metals also contribute to the quality of fish catches. Even though low water quality does not trigger fish death, contamination with harmful substances can reduce fish quality and affect human health when consumed (Singkran et al 2019). Heavy metal accumulation can cause bioaccumulation in the environment so that it enters the food chain and causes serious damage to human, animal, and plant health (Vasistha & Ganguly 2020). To ensure the heavy metal content in fish, further research is needed.

Fish provisioning service. The fisheries sustainability is inseparable from how fish provisioning services are managed by various stakeholders. Management of fish provisioning that only focuses on resource aspects and utilization will meet current economic needs without regarding future needs and environmental aspects. In general, fish in Jakarta fresh waters consist of various species such as Pangas Catfish (*Pangasius* sp.), Bonylip barb (*Osteochilus hasselti*), carp (*Cyprinus carpio*), silver barb (*Puntius javanicus*), spotted barb (*Puntius binotatus*), three spot gourami (*Tricogaster tricopterus*), tilapia (*Oreochromis niloticus*), striped snakehead (*Channa striata*), Mozambique tilapia (*Oreochromis mossambicus*), and catfish (*Clarias batracus*). The number of this species has decreased drastically at this time and is dominated by tilapia, three spot gourami, striped snakehead, and pleco (*Hiposarcus pardalis*) (Jakarta Provincial Environmental Service 2019). To meet the need for fish supply services, local stakeholders carry out a fish seed stocking program annually. A total of 36,000 tilapia seeds were stocked in SBL and 10,000 catfish were stocked in SSL. Information regarding seed stocking at SUFL was not obtained so the location was considered free from human introduction of fish species. Apart from the economic benefits obtained by anglers, introduced fish species such as Tilapia and Catfish are invasive species that can threaten native fish life (Vasconcelos et al 2018). If invasive fish introductions continue, the extinction of native species may occur dramatically affecting the food chain at all the research locations. To support sustainability, it is necessary to prevent the introduction of non-native and invasive species into lake waters (Haubrock et al 2021).

Cultural service. Cultural services are ecosystem services related to recreational provision and spiritual activities. The number of anglers, fishing methods, and types of tourism activities are some factors that can affect the sustainability of lake fisheries (Teurlincx et al 2019). Based on data for the last 2 years, the number of daily visitors to SBL, SUFL, and SSL is 101, 74, and 21 respectively. This numbers are not too high, due to the Covid-19 pandemic in the last 3 years. However, the affluence could increase in the coming years, after the government stopped the pandemic emergency state at the end of 2022. About 50% of tourist visitors engage in fishing activities. The fishing method uses a hook. The local government has imposed a ban on the use of nets and other hazardous materials for the utilization of fish resources. The low number of visitors and the ban on the use of dangerous tools reduce the risk of overfishing at the three study locations. Water recreation activities are only available at 2 research locations, such as paddling boats and dragon boats at SBL and SSL. The dragon boat on SBL and SSL has a different type. In SBL, the dragon boat is propelled using oars by passengers, while in SSL the dragon boat is larger and uses a boat engine. Besides having a function as a place of recreation, SSL also has a function as a place for water sports such as speedboats for military training purposes. The existence of boating activities has an impact on fish behavior. Running a small boat with an internal combustion engine affects the behavior of certain fish species in the lake (Jacobsen et al 2014). This behavior change was highly significant and involved increased swimming speed during all disturbance hours, with a steep increase during the first hour and immediate reactions every time the engine was turned. This shows that the provision of boats with engines can affect the sustainability of fish resources in lake waters.

Flood regulating service. The high sedimentation in lakes of urban areas occurs due to high runoff that carries sediment into water bodies. High rainfall and built-up areas also trigger an increase in runoff that enters water bodies (Yao et al 2015). Sedimentation in lake ecosystems increases the risk of turbidity, oxygen depletion, and decreases the volume of water storage due to sedimentation at the lake bottoms (Fashae et al 2019). This condition could increase the risk of flooding in the area around the lake. To increase the volume capacity of water in urban lakes, the government through the provincial water resources service regularly does sediment dredging. Sediment dredging programs have a positive impact on flood regulating services and a negative impact on water quality regulating and fish provisioning services. After dredging is conducted, the water quality condition will worsen, which is marked by an increase in TSS and turbidity (Kjelland et al 2015). This can have an impact on oxygen depletion or hypoxia in the water. Oxygen depletion and hypoxia have a major impact on the survival of aquatic biota including fish (Sula et al 2020). Exposure to high sediment was also reported as being able to change fish behavior patterns due to decreased sensory abilities and migratory patterns. The ability of fish to find prey also decreases due to high turbidity which can affect eating patterns. In the long term, the effect of sediment exposure on fish can affect mating patterns and populations.

Biodiversity supporting service. Riparian areas are important zones in supporting the sustainability of lake and reservoir ecosystems. The availability of greenspace in this area can support the function of floods and microclimate regulation in urban areas (Olokeogun & Kumar 2020). Riparian areas also have important consequences for fish abundance, habitat structure, water clarity, and food web structure. The coarse organic matter originated from the riparian zone contributed to the aquatic environment by influencing the lake habitats and biodiversity, in particular the fish reproduction and predation (Nikolaus et al 2022). The terrestrial matter is also consumed directly by fish and may be a very important source of energy. Interactions between fish and riparian systems are critical to the efforts to rehabilitate degraded limnic environments and to prevent further declines in freshwater fish populations. Land cover analysis showed that SUFL has the highest percentage of greenspace cover while SSL has the lowest one (Table 4). The SSL riparian conditions, which are dominated by pavement and impermeable land cover, make this location a reduced infiltration area (due to the impervious surfaces) dominated by man-made ecosystems. The value of the biodiversity index as measured using the Shannon-Wiener also has a low value (1.85). This situation can also harm fish abundance. The man-made lakeshore area with a low diversity of riparian vegetation has a negative correlation with the high abundance of small and large fish in the lake ecosystem (Nikolaus et al 2021). This shows that fish supply services require a high vegetation cover and diversity index.

Table 4

Greenspace cover and tree species diversity index in riparian zones

Location	*Greenspace cover (%)*	*Diversity index*
SBL	59.7%	4.23[a]
SUFL	86.71%	2.81[b]
SSL	35.81%	1.85

[a]Reswari et al (2021); [b]Sari et al (2022).

Based on the data from Table 5, almost all ecosystem services' status is altered and reduces the fisheries' sustainability at the three study locations. This shows that the evaluation of the ecosystem services is still focused on immediate benefits, without considering the potentially negative impacts. Provisioning and regulating ecosystem services are two types of ecosystem services that generally experience conflicts and trade-offs (Schröter et al 2017). However, the negative impact received by an ecosystem service can be minimized through a comprehensive management carried out by various stakeholders. The existence of a complex and mutually influencing relationship between ecosystem services and the pillars of sustainability indicates that ecosystem management needs to be carried out thoroughly and not to be focused on a particular area (Deng et al 2016).

Table 5

Relationship between ecosystem services and fisheries' sustainability

Ecosystem services	*Fisheries' sustainability*		
	SBL	*SUFL*	*SSL*
Fish provisioning	-	+	-
Water quality regulation	-	-	-
Cultural	+	+	-
Flood regulation	-	-	-
Biodiversity support	+	+	-

SSL has a negative relationship with all ecosystem services and fisheries sustainability while SUFL has the best condition, with 3 positive values. This indicates that the ecological quality of the lake ecosystem can support the fisheries' sustainability. SUFL has natural landscape conditions with the least human interventions altering the ecosystem, compared to the other 2 ecosystems. Good ecological conditions have a positive correlation with the condition of ecosystem services (Grizzetti et al 2019). If supported by comprehensive management, this ecological status can support the ecosystem sustainability in the future.

Conclusions. Based on the analysis, poor management of water quality and flood regulating services results in poor water quality and could lead to fish mortality due to oxygen depletion, pollutants contamination, and heavy metals exposure. Management of fish provisioning services has not been carried out sustainably at 2 locations due to the introduction of invasive fish species by stakeholders. The choice of water recreation vehicles and riparian zone pavement has the risk of harming fish behavior in SSL. Flood prevention program through sediment dredging provides risks of increasing TSS and turbidity which has a high potential to change fish behavior. The low diversity of tree species accompanied by impervious surfaces that dominate the lakeshore has the potential of reducing the fish abundance in water bodies. The high level of conflict between ecosystem services and fisheries' sustainability indicated a poor coordination between various stakeholders and implemented programs. In managing ecosystems, a harmonious cooperation is needed in creating ideal ecological conditions for ecosystems. The ecological condition of an ecosystem is an important driving factor that can affect sustainability. Maintaining the current ecological condition of aquatic ecosystems can guarantee the perennity of ecosystem services in the future. The good condition of an ecosystem service can be a positive stimulus for other ecosystem services, since they are interconnected.

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