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Article

Sustainable fishery and management of Batur Lake based on ecosystem approach, Bali

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Abstract: Lake Batur is one of the national priorities, as it has economic value, and fish resources are used for food security and improving the local people's welfare. The study examined the applicability of fisheries management status based on the ecosystem approach in lakes. The study was carried out from February to July 2023 using ecosystem approach methods in seven villages around Batur Lake, Bali, Indonesia, Data was collected through observations and interviews with 189 respondents. The success of fisheries management might be shown as a flag model after the composite domain and the total aggregate value of all dominants were rated. The results showed that the managed fish resources and stakeholders were unsatisfactory categories. Generally, social and fishing technology domains were classified as good categories. For that, ecosystem approach applications for sustainable fisheries in Batur Lake needed action under the five common scenario goals (a) reducing non-target fish (red devil) in the lakes by intensive capture and processing into other products of economic value; (b) regulations related to the reserve area as a place for fish to spawn and breed; (c) increasing the synergy of fisheries management policies; (d) increasing the stakeholder capacity; and (e) government support and related stakeholders regarding one regulation for fisheries management.

Keywords: Batur Lake; ecosystem; management lake; status condition; sustainable fishery

1. Introduction

The greatest lake in Bali, Lake Batur, serves a few purposes, including raw resources, clean water, tourism attractions, aquaculture, irrigation for agriculture, environmental purposes, and transportation (Kaban et al., 2023; Lusia et.al., 2023; Nopem et al., 2020). Besides that, inland water is important for suppliers of food and support the livelihoods (FAO, 2014; Nguyen et al., 2023; Smith et al., 2005). Fishing communities that use these aquatic resources typically reside in distant villages; as a result, fisheries' crucial contribution to local food security is sometimes disregarded (Allan et al., 2005; Jia et al., 2013; Novalina, 2019).

In terms of sustainability case studies in inland waters, the policy framework must minimize the effect on fish resources and the environment (Ditya et al., 2022; Funge-Smith et al., 2019; Sass et al., 2017; Stefansson et al., 2019). Lake Batur has been utilized by communities around the lake to fulfill their daily economic needs, including

agriculture, plantations, tourism, and fisheries. The aquaculture that has developed is mainly tilapia fish farming using floating net cages and is generally profitable for fish farmers (Mayasha et al., 2022; Sentosa et al., 2013; Sunaryani et al., 2021). The economics of fish farming with floating net cages are very profitable (positive impact); however, If the state of the waters has exceeded the carrying capacity, it can cause negative environmental and economic impacts (Garno, 2002; Lusia et al., 2023). Degradation of water quality can occur after organic waste from floating net cages directly decomposes in the water and produces nitrogen and phosphorus (Diarta et al., 2016; Garno et al., 2006; Nopem et al., 2020; Sulastika et al., 2019; Wijaya et al., 2012). The results showed that Lake Batur has experienced environmental pressure from being an oligotrophic lake to being eutrophic (Kaban et al., 2023; Laili et al., 2020). Changes in water quality can affect aquatic organisms, especially fish, which is one of the sources of livelihood for fishers. Besides changes in water quality, overfishing and invasive fish can also cause declining catches for target species. Species richness research from fish diversity is critical for predicting future changes in community structure (Amarasinghe and Wellcome, 2002; Boll et al., 2023; Yang et al., 2021). Many introduced fish species have become "invasive species" in various lakes in Indonesia, according to studies (Atmaja et al., 2014; Dina et al., 2022; Herder et al., 2012; Ohee et al., 2018; Syahroma et al., 2019).

Ecosystem-based fisheries management is an integrated approach that seeks to balance a diversity of objectives, both the human and ecological sustainability dimensions (Ditya et al., 2023; Islam et al., 2022). This paper explains the status of Batur Lake based on the environment and people's resources as indicators.

2. Material and methods

2.1. Sampling and data collection

The research was conducted from February to July 2023 in seven villages around in Lake Batur, Bali, Indonesia (**Figure 1**).

The stations are villages that surround Lake Batur and the fishers' groups dependent on the fisheries activity. There are side locations for data collection, such as Trunyan, Abang Songan, Abang Batu Dinding, Buahan, Kedisan, Batur, and Songan villages, using purposive sampling method (**Table 1**). Data was collected through observations and interviews using questionnaires with 189 respondents who utilize and manage the lakes. Utilizing stakeholders here include groups of fishers, fishing collectors in each village, and local governments (marine affairs and fisheries, environment, and forestry).

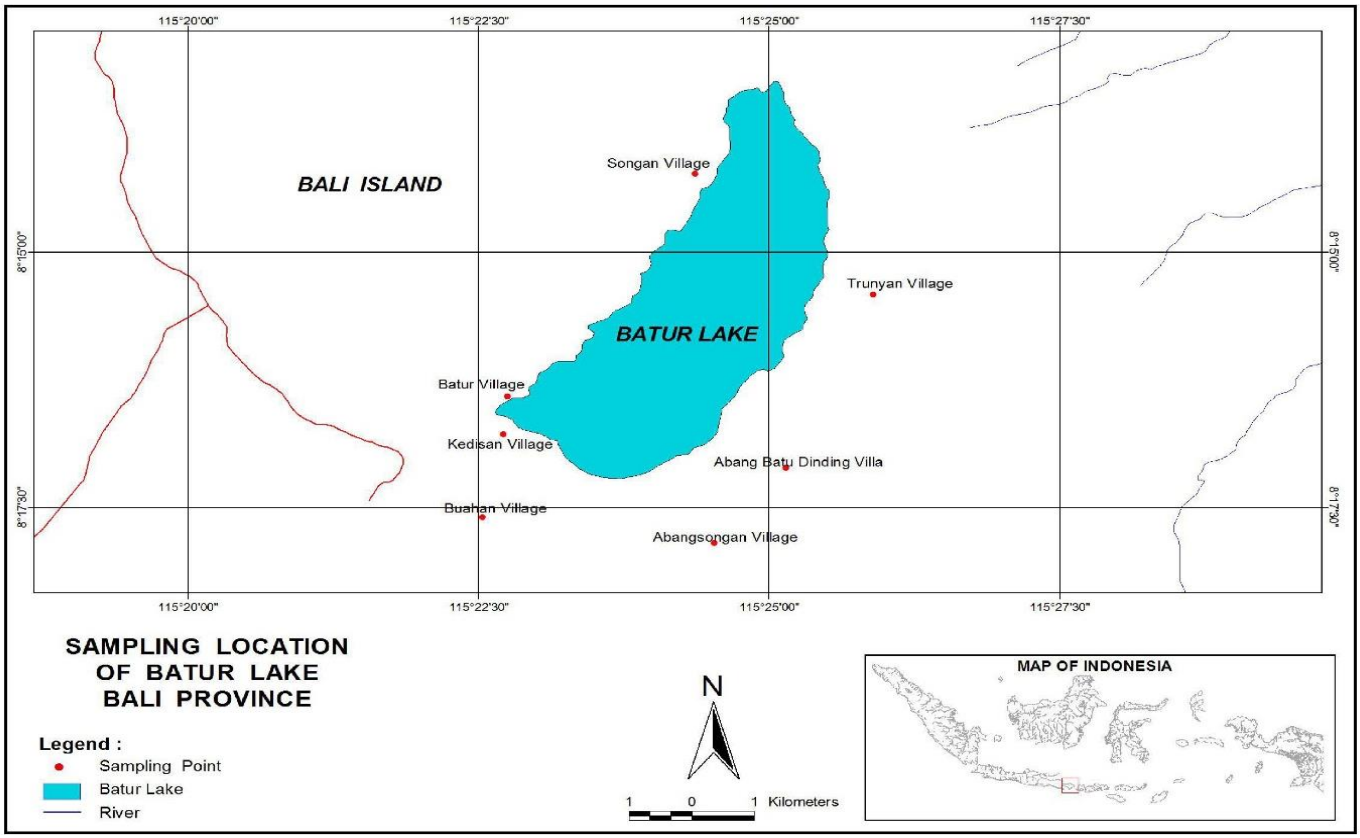

Figure 1. Sampling site in Batur Lake.

Table 1. Description and coordinate of sites location.

No	Sampling site	Coordinate	Remarks
1	Trunyan village	8°15′25″ S 115°25′54″ E	Fisheries activity (capture fishing and aquaculture), more than 40 fishers.
2	Abang Batu Dinding village	8°17′07″ S 115°25′09″ E	Fisheries activity (capture fishing and aquaculture), more than 40 fishers.
3	Abang Songan village	8°17′51″ S 115°24′32″ E	Fisheries activity (capture fishing and aquaculture), more than 6 fishers.
4	Buahan village	8°17′36″ S 115°22′32″ E	Fisheries activity (capture fishing and aquaculture), more than 82 fishers.
5	Kedisan village	8°16′47″ S 115°22′43″ E	Fisheries activity (capture fishing and aquaculture), more than 7 fishers.
6	Batur village	8°16′25″ S 115°22′45″ E	Fisheries activity (capture fishing and aquaculture), more than 6 fishers.
7	Songan village	8°14′14″ S 115°24′22″ E	Fisheries activity (capture fishing and aquaculture), more than 8 fishers.

2.2. Data analysis

The questionnaire contains indicators from seven domains of fisheries management in inland waters (**Table 2**). In determining the order of domain, the fish resource environment domain has the highest value, ranging from 1 to 7, because this indicator is the main factor affecting fish resources.

Table 2. Ecosystems approach fisheries management criteria for indicator using Likert's score.

Domain	Indicators	Scoring
Fish resource environment	(a) Water level fluctuation; (b) Water pollution; (c) Lake bank formation/Litoral area; (d) Protection area; (e) Habitat Modification; (f) Siltation/reduction of the aquatic area; and (g) Spawning area.	1–7
Fishing technology	(a) Destructive fishing gears; (b) Unfriendly fishing gears; (c) Fishing selectivity; (d) Fishing productivity; and (e) Fishing gears modified.	1–5
Social	(a) Stakeholder participation; (b) Fishing conflict; (c) Utilisation of local knowledge in fish resource management; (d) Figure of representation; (e) Education level of fisher; and Fisher experience.	1–5
Economy	(a) Asset ownership; (b) Income; (c) Saving ratio; (d) Consumption level; and (e) Economic dependence.	1–5
Managed fish resources groups	(a) Fish productivity trend; (b) Change in catch size; (c) Juvenile proportion; (d) Catch composition; and (e) Introduced and invasive species.	1–5

For the domain methods, refer to the Directorate of Fish Resources Management (MAAF, 2020). Filling out the questionnaire uses an ordinal-based Likert scale (1, 2, 3), with the highest impact being the first rank, and so on, filled in by respondents regarding opinions or perceptions of the questions or statements in the questionnaire. Furthermore, the results of the indicator assessment were analysed in a simple composite index with the analysis and calculation stages referring to the flag model (Ditya et al., 2022; MAAF, 2020). To evaluate the range of fishery management states in the inland water provided the phases of assessing the composite index as follows:

1) Assign a rank value (*nrij*) for each *x*-th indicator and *z*-domain, which represents the impact of each indicator on the sustainability of the domain, where the highest rank has the most significant impact, and ensure the criterion value (*nkij*) of each indicator in each domain.
2) Assign a weighted rank (*brij*) for each *x*-th indicator and *z*-th domain, which is by dividing the total weighted value (number 100) by the aggregate ranking of all indicators and then multiplying by the ranking value or scale of each indicator.
3) Calculating the composite of each *x*-th and *z*-domain (CIxz) indicator, namely by multiplying the criteria values with rankings and weights.

$$\text{CIxz-1} = nrij \times nkij \times brij \quad (1)$$

4) Calculating the composite index of the *z*-th domain (CDz), which is through the composite or aggregate summation of all indicators from a domain.

$$\text{CDz} = \text{CIxz-1} + \text{CIxz-2} + \text{CIxz-3} + \text{CIxz-4} + \text{CIxz-5} + \text{CIxz-6} + \text{CIxz-7} \quad (2)$$

5) Calculating the average composite index of the entire domain (Average), by averaging the number of composite indexes of all domains

$$\text{CAverage} = \text{Average}\ (\text{CDz-1} + \text{CDz-2} + \text{CDz-3} + \text{CDz-4} + \text{CDz-5} + \text{CDz-6} + \text{CDz-7}) \quad (3)$$

In **Table 3**, showing the form of a simple flag model (Adrianto et al., 2005; MAAF, 2020), it showed that the three quartiles of red (poor), yellow (fair), and green (good) (**Table 4**).

Table 3. Criteria conditions for each domain of lake Batur.

No	Domain	Range of Composite Index		
		Poor	Fair	Good
1.	Fish resources environment	498–830	831–1163	1164–1494
2.	Fishing technology	366–610	611–855	856–1098
3.	Social	366–610	611–855	856–1098
4.	Economic	300–500	501–700	701–900
5.	Managed fish species groups	366–610	611–855	856–1098
6.	Governance	366–610	611–855	856–1098
7.	Stakeholders	233–389	390–546	547–700

Table 4. Category and status of flag ecosystem approach fisheries management.

Category	Flag status	Remarks
Bad		Fishery management in the local ecosystem has not yet applied the principles of sustainable fisheries, so it is necessary to establish a strategic plan to improve or improve the condition of the existing domains and indicators.
Moderate		Fishery management in the local ecosystem has applied the principles of sustainable fisheries. Still, it is not optimal, so it is necessary to set a strategic plan to optimize or improve the existing domains and indicators.
Good		Fisheries management in the local ecosystem has applied the principles of sustainable fisheries optimally, so it is necessary to set a strategic plan to maintain or improve the existing domains and indicators.

Sources: Ditya et al. (2022).

3. Results and discussion

Based on the results of research that has been conducted in 2023 for seven domains, namely the environment/habitat domain, the capture technology domain, the fish resource domain, the social domain, the economic domain, the governance domain, and the stakeholder domain (**Table 5**).

Table 5. Value of composite index domain in Batur Lake.

No	Domain	Composite domain						
		Trunyan	Abang Songan	Abang Batu Dinding	Buahan	Kedisan	Batur	Songan
1.	Fish resources environment	836	836	836	975	975	975	836
2.	Fishing technology	1087	1100	1100	1100	1100	1100	1100
3.	Social	1014	1014	1014	1300	1086	1257	1014
4.	Economy	647	647	647	813	813	647	647
5.	Managed fish species groups	467	440	440	407	407	407	453
6.	Governance	760	760	760	813	813	813	760
7.	Stakeholders	390	550	550	430	430	430	550

The results of scoring the domain composite index values and flag status of the seven domains found that the domain of managed fish species and the stakeholder domain were the main issues and needed effort to implement the principles of ecosystem-based fisheries management in Lake Batur. This was indicated by the composite index value of each location with a red flag status. While the fishing technology domain and the social domain are relatively good in efforts to implement the principles of ecosystem-based fisheries management in Lake Batur, however, it

still needs to be a concern to maintain fisheries in Lake Batur that can be sustainable. The following is a more detailed explanation of the results of interviews and direct surveys of the 7 domains, as follows:

3.1. Fish resources environment domain

The environmental domain indicators, consisting of seven indicators, it was found that the main problems in the environmental domain were the conversion of function and jurisdiction and the absence of fisheries reserves or fishing prohibition areas to support the survival of fish in Lake Batur. In addition, the results of the study showed that Lake Batur had silted up, and there was also no conservation area. The growth of the area around Lake Batur was currently characterized by an increase in the development of physical and non-physical activities, which will certainly cause various impacts, both positive and negative, for the area. Some research activities related to the use of Lake Batur, especially the lake boundary, were still suitable, but there are some inappropriate land uses that can cause damage to the buffer zone (Handayani et al., 2015; Nada et al., 2018; Putri et al., 2023; Sukmawati et al., 2019). Besides that, Lake Batur is a volcanic lake that has experienced moderate environmental pressure, which is classified as moderately polluted due to organic matter pollution, sedimentation, and eutrophic lake status (Kaban et al., 2023; Nada et al., 2019; Nuringtyas et al., 2023; Sukmawati et al., 2019).

3.2. Fishing technology domain

The domain indicators of fishing technology in Lake Batur generally have applicability that can be seen from the application of the principles of environmentally friendly fishing technology. This is characterized by fishing gear used that has a selectivity size and gear capacity that is in accordance with the rules, and there is no placement of fishing gear that is detrimental to the sustainability of fish resources. Fishers in Lake Batur generally catch fish with gill net using boats without engines. The fishers in Lake Batur were fishing mostly using net gear with a size above 3 inches. Prihantoko (2023) inform that the gill net with a mesh size of 3 inches is an environmentally friendly fishing gear for tilapia target species.

3.3. Social domain

In Lake, they applied principles of management and applied the principles of ecosystem-based fisheries management. This is indicated by the absence of fisheries conflicts in Lake Batur and most (>60%) experience as fishers above 10 years, although in some villages the proportion of people with primary education (junior and high school) dominates at >60%. Dominant fishers still have local knowledge related to where and when to set nets according to field conditions to catch fish, and this knowledge is still efficiently applied.

3.4. Economy domain

In this domain, the high role of capture fishing activities in the economic lives of fishing households. The assessment of asset ownership indicators at the location is classified as good, where the ownership of assets commonly owned by fishers other

than houses is a boat, and fishing gear tends to increase every year. The income indicators of fisher households in each zone are different. There is a tendency for the number or value of assets to increase by >30% and a tendency for the proportion of non-food expenditure to be greater than food expenditure. Although the fisher's livelihood varies, which was indicated by the family economy not only from fisheries activities but also from non-fisheries businesses, only <30% of local people work as fishers. The average income of part-time capture fishers in Lake Batur was still below the regional minimum wage of Rp. 835,000/month, with an average fish catch of 2–5 kg/day.

3.5. Managed fish resources groups domain

In this domain, there has been a declining trend in catches with a ratio of >25% and the presence of invasive species, in this case red devil fish. Although the size of the fish caught is still relatively constant, the composition of the catch is quite complete, characterized by the capture of native predatory fish but in decreasing numbers. There were 17 species of fish caught in Lake Batur, which were dominated by the cichlid family including tilapia and Midas cichlid (Gustiano et al., 2023). The growth of red devil fish species in Lake Batur is quite fast, and it is not a target species for fishers, so the fish are more advanced. Because they prey on native species, invasive species can have an impact (Falaschi et al., 2020) hybridization (Duenas et al., 2021; Noella et al., 2021), disease spread (Chalkowski et al., 2018) and competition for available resources (Green and Grosholz, 2021). The natural biodiversity of many countries has been replaced by invading and potentially invasive species (Bax et al., 2003; Franco et al., 2023; Gois et al., 2015; Haubrock et al., 2021; Peh, 2010; Syahroma et al., 2019; Taradipha et al., 2018). To maintain native fish species, *Osteochilus vittatus*, *Barbodes binotatus*, *Barbonymus gonionotus*, *Barbonymus balleroides*, and *Rasbora lateristriata* need concern and rapid action for the government and stakeholders in handling alien fish species (Syah et al., 2023).

3.6. Governance domain

Furthermore, the governance domain indicators, consisting of five indicators and the principles of sustainable fisheries were already well established. This is indicated by the absence of violations and the existence of local wisdom that supports, although not yet fully, the preservation of fish resources and the environment. However, attention needs to be paid to ecosystem-based fisheries management policies because there are no related documents regarding ecosystem-based fisheries management policies in Lake Batur.

3.7. Stakeholders' domain

The indicator of the stakeholder domain showed that the synergy of policies, programs, and activities across sectors has not been optimal. There are many sectors with an interest, but no synergy has been seen. On the other hand, the existing institutional mechanisms at the location are still relatively lacking. The effectiveness of institutional mechanisms is determined by the extent to which decision-making is made and implemented (Adrianto et al., 2014). Fisheries management in each zone

has social institutions at the fisher's level, namely Pokmaswas (Community Supervisory Group). In addition, efforts to increase human resource capacity to support sustainable fisheries management efforts still need to be improved, so it is hoped that local-scale fisheries management institutions can be realized and run effectively

3.8. Strategic option for sustainable fishery management in lake

In this case, the value of the composite index, seven domain ecosystems approach fisheries management in Lake Batur, is shown in **Table 6**. It showed that the types of fish managed, and the stakeholder domain were red flag status. The condition indicated the need for attention in efforts to implement the principles of ecosystem-based fisheries management in Lake Batur. Adopting ecosystem-based fisheries management through establishing appropriate fisheries management mechanisms can be achieved by ensuring the sustainability of fisheries resources and long-term food security. Ecological sustainability and human welfare in fisheries in Lake Batur can also be improved. However, strategies are needed so that fisheries management can run effectively. A possible strategy is activities to increase the capacity of fisherman through training, which will indirectly increase their income. Some of the training in question includes financial management and sharing knowledge about processing harvest products.

Table 6. Action plan in Batur Lake

Domain	Indicators	Reference point	Management action
Ecological aspect			
Water pollution (domestic waste, aquaculture, pesticide)	Eutrophic level	Improvement of habitat and reduction of biodiversity loss.	Manageable aquaculture wastes
Decreasing of catch	no reserved area	Mapping for protected area.	Spatial planning for protected area and fishing zone.
Invasive species	Red devil species	Length maturity (Lm) > Length Capture (Lc).	Should be Lm < Lm, increasing catch of this fish.
Socio-economic			
Low value added	Under regional minimum wage	Total catch 2–5 kg/day	Stocking and restocking for local fish, post-processing.
Low education level	Junior high school	>60% of fishers were junior high school.	Supporting for income-increasing.
Governance			
Lacking fishing data	No data recorded	Catch production is different from the average catch.	Training and extension on sustainable fisheries management given to the local community.
Limited capacity for fisheries management	Low-capacity resources	Conducting participatory-based fisheries management (co-management) across different sectors and regency.	Higher stakeholders' participation resulted in better fisheries management.

4. Conclusion

The main problems in the status of fisheries management in Lake Batur are seen in the domain of managed fish species groups and the stakeholder domain, which is

marked with a red status assessment. The main factors that cause the non-implementation of ecosystem approach fisheries management domain are the reduction of fishing production and the existence of invasive fish species (red devil). Besides that, in terms of habitat, the lake boundary is used for agricultural land and tourism (land use change), and there is also no reserve area in the lake. The implementation of the approach in Lake Batur has not been optimal due to the low role of the government and limited stakeholder synergy. For this reason, several strategic steps can be taken for the sustainability of fisheries in Lake Batur, namely (a) reducing non-target fish (red devil) in the lakes by intensive capture and processing into other products of economic value; (b) regulations related to the reserve area as a place for fish to spawn and breed; (c) increasing the synergy of fisheries management policies; (d) increasing the stakeholder capacity; and (e) government support and related stakeholders regarding one regulation for fisheries management.

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