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Local Perception on the Invasion of Plecos (*Glyptoperichthys gibbiceps*) and Ecosystem-based Management in Tempe Lake, South Sulawesi, Indonesia

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Abstract

Tempe Lake in South Sulawesi, Indonesia, is encountering a global threat on biodiversity and people well-being: the invasive alien species. The invasion of plecos (*Glyptoperichthys gibbiceps*) deteriorates ecosystem conditions at Tempe Lake, including bank erosion and changes in lake ecosystem function. Local communities in Wajo, a district located adjacent to Tempe Lake, implemented several approaches to reduce pleco population e.g., direct killing, sun-drying, and pleco-based food processing. However, these efforts failed due to the lack of economic incentives and social acceptance of the food made from plecos. Local perception towards the pleco invasion and management alternatives needs to be understood. This study examined local perception on the pleco invasion, villager knowledge about the plecos, and ecosystem-based management. A survey-based study was conducted in 17 villages adjacent to Tempe Lake in Wajo during August to November 2022. A semi-administered questionnaire was employed to collect data i.e., household socioeconomics, villager perception and knowledge, and management alternatives. In total, 200 household representatives participated in the questionnaire of which 53.5% are fishermen. Local fishermen recognized drastic declines in their catch due to increasing pleco population, which directly affected fish consumers because they needed to pay for more expensive fish. The fishermen group expressed strongly that the pleco invasion needs to be controlled now. They perceived that current management was ineffective, especially direct killing of the plecos. Local communities expressed an ecosystem-based management with economic incentives for local community participation is the key. Furthermore, a cost-benefit analysis of proposed projects is essential for effective implementation. Local communities, both villagers and local administration, need clear and sufficient information to help them see potential gains and losses from their actions whether they decide to “do no nothing” or “do something about it.”

Keywords : invasive alien species; plecos; Tempe Lake; ecosystem-based management

Introduction

The International Union for Conservation of Nature (IUCN) defines invasive alien species as "*species introduced into places outside their natural range that have negative impacts on native biodiversity.*" There are several vectors for invasive species to colonize in certain environments. Scientists classify these vectors into two groups. The first group is transportation-related vectors, representing economic or social activities when moving from one place to another. Examples of species known to be transported from their native habitats to other places are *Styela clava* and *Botrylloides violaceus* (invasive ascidians) and macroalgae e.g., *Sargassum muticum*, hulled on recreational boats [1]. Secondly, trade and consumption activities [2], including dam construction, sport fishing and aquaculture [3], agricultural expansion, natural resource exploitation, and urbanization [4] are also key vectors of alien species distribution and invasion. Invasive species affect a biomass balance in certain habitats [5], alter ecosystem functions and cause economic losses [6]. Large-scale tree mortalities were caused by gypsy moths (*Lymantria dispar*), hemlock woolly adelgids (*Adelges tsugae*), beech scales (*Cryptococcus fagisuga*), and emerald ash borers (*Agrilus planipennis*) [7]. Moreover, alien species spread over time as global logistic transport grows. Sea or marine-based logistic transport accounts for nearly 90% of global transportation, allowing a large number of species to travel outside their native habitats. The world's emerging shipping network could yield a 3-to-20-fold increase in global invasion risk of alien species by 2050 [8].

Fish have been introduced outside their native habitats throughout the world. For example, the armored catfish or plecos (Loricaridae), native to freshwater habitats of the South and Central America, are recorded outside their native range, including Central America, southern states of the USA, the Pacific Ocean, East and Southeast Asia, since the second half of the 20th century [9]. Plecos spread due to bad practices in aquarium trade and hobbies [10]. Sometimes, they escaped by accidents due to floods. Plecos have demonstrated posing threats to non-native ecosystems because they outcompete native species, alter species composition and induce erosion and siltation [10-13]. They potentially lead to native species reduction or even extinction [14-15].

Tempe Lake is one of the largest freshwater wetlands in South Sulawesi, Indonesia. It is home to great biodiversity, including at least 19 fish species, 21 species of aquatic plants, three species of reptiles, and five migratory bird species [12, 13]. In addition, two fish species are classified as endemic to Tempe Lake, namely the binishi (*Oryzias celebensis*) and the Celebes rainbow (*Telmatherina ladigesi*). Tempe Lake greatly contributes to local livelihoods, including agriculture, aquaculture, transportation, fishery, and water supply [16, 17]. However, Tempe Lake is experiencing substantial changes that alter lake ecosystem conditions such as water pollution, sedimentation, decreases in native fish populations, and invasion of alien species, specifically the plecos (*Glyptoperichthys gibbiceps*, Loricaridae, Figure 1). In 2014, the Indonesian Ministry of Marine Affairs and Fisheries (Regulation Number 41) listed the plecos as an invasive alien species due to wide propagation and aggressive competition with native fish, which led to population declines and damaged local fishery [18]. The pleco invasion deteriorates ecosystem conditions at Tempe Lake, including bank erosion and changes in lake ecosystem function, especially from species composition and interaction alteration [19, 20].

Local communities in Wajo, a district located adjacent to Tempe Lake, had implemented several approaches to reduce pleco population such as direct killing, sun-drying and pleco-based food processing. However, these efforts failed due to the lack of economic incentives and social acceptance of the food made from plecos [18]. Villagers were unfamiliar with the taste so hesitated to eat it. A survey conducted in 2021 revealed that management alternatives need to be affordable and practical at a household-scale for local communities to get involved [19].

Figure 1 A picture of plecos caught by a local fisherman from Tempe Lake. (The photograph was taken by the researcher in 2022)

Given potential threats from the pleco invasion to Tempe Lake, effective management with community participation is needed more urgently than ever. Local perception towards the pleco invasion and management alternatives needs to be understood. This study examined local perception on the pleco invasion in Tempe Lake, villager knowledge on the plecos and their habitats, and ecosystem-based management. Local community participation is one of the key factors necessary for effective management [13], and it depends on villager perception and expectation of benefits accrued from investing their time, labor or money in management activities [21, 22]. Many ecosystem management projects failed due to low community participation [23]. For instance, rural communities in the Kat River valley, located between small agricultural towns of Seymour and Fort Beaufort, South Africa, positively viewed that an increasing number of invasive cacti (*Opuntia ficus-indica*) were beneficial. Villagers could earn additional income from selling the cactus fruit, although scientists and ecosystem managers were trying to eradicate these invaders to protect the native species [18]. Another example is the Yellowstone Cutthroat (*Oncorhynchus clarkii bouvieri*), a native species being threatened due to angler preferences of a native fish over invasive species e.g., predatory lake trout (*Salvelinus namaycush*). To protect native populations from overfishing, while helping reduce invasive species population, Yellowstone lake's managers need to change angler's perception so they can shift from catching only native fish to invasive species [24]. These different perspectives between the locals and project managers resulted in low participation hindering effective management.

Methodology

The study took place in 17 villages, located adjacent to Tempe Lake in Wajo district, South Sulawesi, Indonesia (Figure 2). A semi-administered questionnaire was conducted in August to November 2022 to collect data, including household socioeconomic conditions, villager perception on the lake and pleco invasion, knowledge on the plecos and their habitats, and management alternatives. A sample size was determined using the Taro Yamane's formula [25] with 7% of error. Household representatives from each of the 17 villages were asked if they would be willing to participate in the survey. If they agreed, they would be personally interviewed according to a series of questionnaire questions. Basically, the questions on local perception were structured based on a Likert's scale scoring from 1 to 5 (1 = strongly disagree to 5 = strongly agree). In addition, village leader interviews and onsite observation were conducted to cross check data from the questionnaire. Data analyses were based on descriptive statistics, t-test, and the Chi-square test of Independence. We hypothesized that key household socioeconomic conditions e.g., occupation: fishermen vs non-fishermen, educational levels, age and household income, are likely to influence the samples' perception and willingness to participate in the pleco invasion ecosystem-based management.

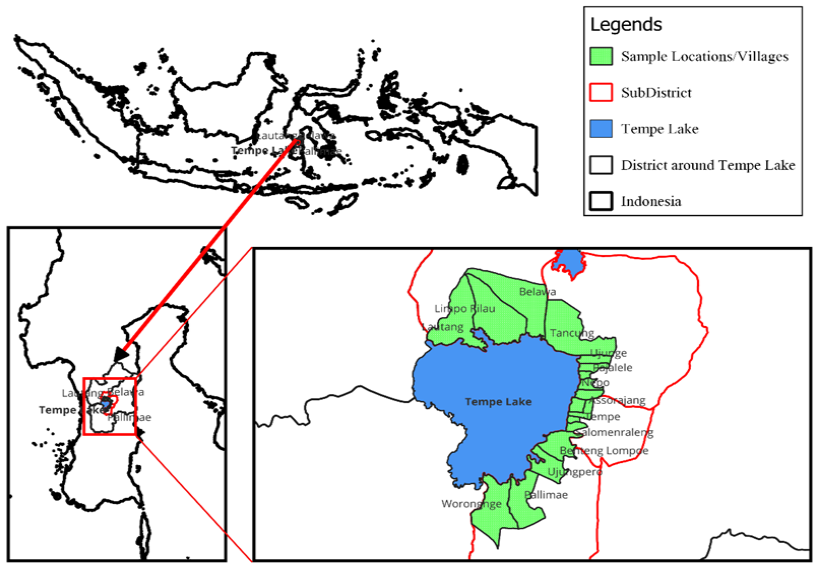

Figure 2 The study site: Tempe Lake and the 17 villages located adjacent to the Lake in Wajo district, South Sulawesi, Indonesia

Results and Discussion

Household socioeconomics

In total, 200 household representatives participated in the questionnaire survey of which 53.5% are fishermen. The rest is a non-fishermen group, consisting of civil servants, business owners, contract employees and farmers. The majority of samples (97.5%) aged between 25-60 years with about 2.5% considered as elderly. The average age is 37 years old, indicating active labors responded to the questionnaire. Basic education within the fishermen group is elementary school (48.6%); some obtained no education (6.5%) and none earned higher education. In contrast, the non-fishermen group mostly obtained high school and higher education (46.2% and 31.8%, respectively). They generally work as civil servants in local government agencies e.g., Wajo local administration, public school, and hospital.

The majority of respondents, especially fishermen, earned income on average of US$90.93 per month, slightly below a national standard for civil servant salary i.e., US$101 up to US$196 monthly (Indonesian Government Declaration Number 15, 2019). Meanwhile, about one fourth of the non-fishermen group were considered as a middle to higher income family, obtaining a monthly salary above US$101. Generally, one household consists of two and four members for the fishermen and non-fishermen groups, respectively. Approximately, 65.5% of the family members are considered active labors, responsible for household income generation. Figure 3 summarizes key socioeconomic conditions of the sampled households.

Local livelihoods and connections between the Wajo people and Tempe Lake

The majority of Wajo residents are the Buginese, the biggest native group of South Sulawesi. Their livelihoods directly depend on Tempe Lake, especially subsistence fishery and seasonal cultivation due to regular flooding in areas near the lake. From May to September, a rainy season, floods usually occur, turning large amounts of land into a shallow lake (Figure 4). Throughout the year, the majority of villagers earn their income from fishery and farming. But during the flooding season, they earn income only from fishery and sometimes wait for the government aid. Crops such as vegetables and rice are usually cultivated in the dry season from October to April when floods recede. During the survey, villagers said that this year they encountered the most severe flooding in the past decade. Floods lasted for nearly three months and water levels reached up to 4 m.

Figure 3 The sampled households' socioeconomic conditions: a) education levels, b) age classes, c) household structure, and d) income levels. Note: The inner doughnut charts depict fishermen's information, while the outer depicts non-fishermen

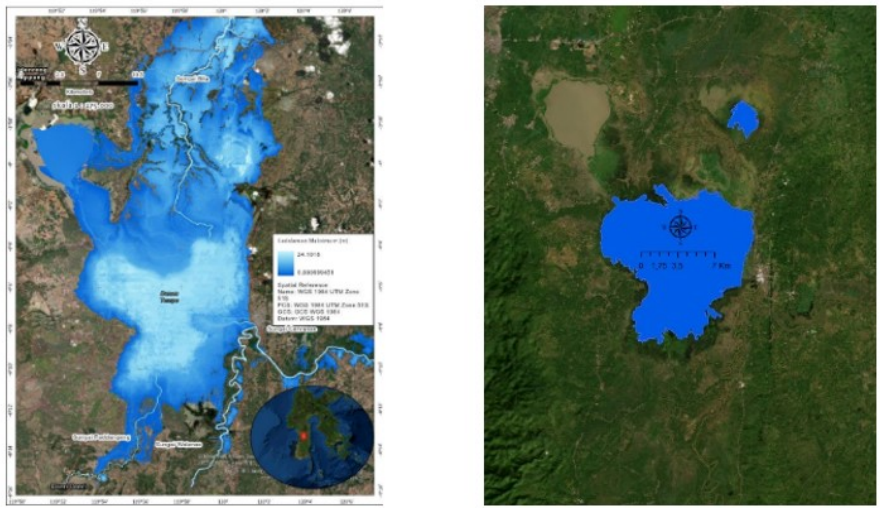

Figure 4 Areas in/around Tempe Lake during: the flooding season (left) and the dry season (right)

The Wajo people adapt to flooding conditions. Nearly all households owned boat(s) either for fishing or commuting during the flood season. The government provided some households, especially those with low income, with a boat so they can use during the flooding (Figure 5). In addition, some families built a floating house on the lake, particularly in villages located at the southern side of Tempe Lake e.g., Tempe and Laelo. This traditional housing style is common among subsistence fishermen families since they can move around following a fishing ground. However, a number of floating houses declined due to changes in lake conditions, land use regulation and socioeconomic development.

Figure 5 Different boat styles provided by the government to some local households since floods occurred regularly: a. big-sized boat, b. small-sized boat and c. square-type boat

Key ecosystem changes at Tempe Lake

Table 1 summarizes key changes at Tempe Lake observed by local villagers. The fishermen group clearly stated that water quality was polluted, followed by more frequent flooding and biodiversity decline. Meanwhile, the non-fishermen group expressed half and half opinions. The majority of them agreed that floods occurred more often, but they were less aware of water quality change and biodiversity loss, including the pleco invasion. Moreover, 18 respondents from the non-fishermen group (~20%) clearly stated "there are no problems" at all. Perhaps, the non-fishermen group did not directly interact with the lake when compared to those fishermen who go out fishing every day. The fishermen observed lake conditions during their fishing trips and recognized changes. They can act as a real-time monitor; thus, their perception and participation are essential for effective management.

Furthermore, local perception of the lake conditions related to village locations. Figure 6 depicts geographic locations of the samples who agreed (red) and disagreed (green) with the given issues as described in Table 1. Basically, those who agreed that flooding and biodiversity loss problems existed lived in villages located north of the Tempe Lake but downstream of the "Bendungan Gerak" Dam. The dam was constructed in 2013 for flood control and water resource management purposes. Areas closer to the dam experienced less flooding because dam operation conveys flood water to flow out of the village zones. Meanwhile, the majority of samples who expressed concerns on lake water quality distributed throughout the study villages. Finally, none of the samples recognized land use conflict in their village area.

Table 1 Key changes observed by local villagers living in/around the Tempe Lake

Items	Fishermen		Non-fishermen	
	A	D	A	D
1. Water quality is polluted.	107	0	45	48
2. Floods occurred more frequently, affecting local people.	76	31	50	43
3. Biodiversity decreased.	74	33	36	57
4. There are land use conflicts in your area.	0	107	0	93
5. The Pleco population increased.	107	0	34	59

Note: A = agreed, D = disagreed. Numeric data represent a number of samples responded to the statements.

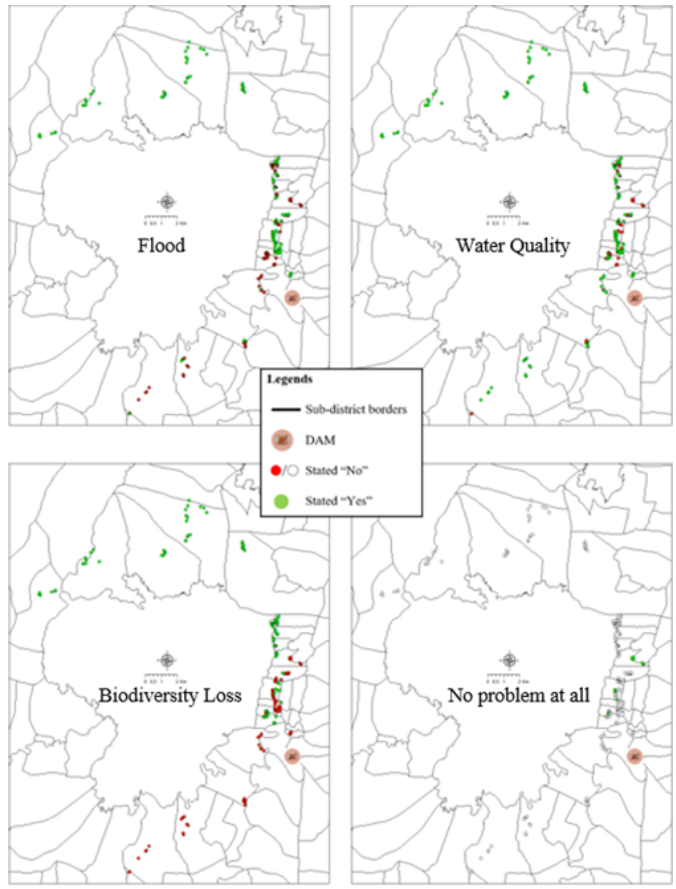

Figure 6 Geographic distribution of the sample responses: Red = agreed that problems existed, and Green = disagreed with such the problems

Local perception and knowledge on the pleco invasion and current management

Local fishermen recognized a drastic decline in their catch due to the increasing pleco population. The pleco invasion caused other fish prices to rise due to decreased amounts of catch, which directly affected fish consumers because they needed to pay for more expensive fish. The fishermen group expressed strongly that the pleco invasion needs to be controlled in a timely manner (Table 2). They disagreed that current management was effective, especially direct killing of the plecos, whereas the non-fishermen group agreed otherwise. Local fishermen reflected that economic incentives are the key. Since the plecos now obtain no market value, nobody wants to invest anything because they cannot see any benefit returns. However, when the two groups were asked if they would like to eat food made from plecos, they gave a neutral response. This is considered a positive signal since they did not reject the idea of turning plecos to human food – the pleco-based food processing. Villagers wanted to try if the project showed them potential profits from doing so. Particularly, the fishermen group would like to give it a try because they want to get rid of plecos.

Moreover, the respondents agreed that they observed decreasing connections between people and the lake, especially among young generations. This poses a great challenge for effective management since youth power and their participation is one of the keys to determine our future toward sustainability [26]. Urbanization brings convenience but also departs people from nature, especially the young because they basically grow up in the more urbanized environment. With loose connections, they may not realize how

important Tempe Lake is to their livelihoods. Some of the interviewed fishermen leaders said that their kids were not interested in fishing due to hard-working perception, high costs but low returns. Many parents actually encouraged their children to go work in cities since better income jobs can be expected. Subsistence fisheries can hardly support household economies. The pleco invasion even worsens this situation. It does not only deteriorate the lake and biodiversity but also shatter the community structure and culture.

Obviously, local people recognized the pleco invasion and its impacts on the lake and livelihoods, especially within the fishermen group. Despite knowing about the invasion, we asked how villagers knew about the plecos, including physical appearance and habitat. All the fishermen could tell what the pleco fish looks like and where its habitat is. In contrast, the non-fishermen group received an average score of 1.63, significantly lower than the mean score of the fishermen group (Table 3). They might recognize or hear some of the invasion problems, but do not pay attention to the fish since their livelihoods depend on other activities rather than fishery.

Community willingness to participate in ecosystem-based management of the plecos

The pleco invasion needs action now, and it needs to be ecosystem-based management where ecological, social, and economic aspects are taken into considerations [27]. We asked what the villagers at Wajo thought about ecosystem-based management to deal with the pleco invasion at Tempe Lake. In doing so, we proposed a project named "the pleco-based Black Soldier Fly (BSF) feedstock production" where plecos will be used to make the BSF feedstock. This will help reduce the pleco population – an *ecological aspect*. Meanwhile, villagers who participate in the project will be able to make additional income from catching the plecos and/or processing the BSF feedstock – an *economic aspect*. Furthermore, this pleco-based BSF feedstock production will add value to fishery and create a new local business, so helps attract villagers to stay in their village instead of moving out – a *social aspect*.

Table 2 Local perceptions on the pleco invasion and current management approaches

Items	Fishermen		Non-fishermen	
	Mean (SD)	A-level	Mean (SD)	A-level
1. Knowing the term "invasive species"*	4.11 (0.57)	SA	2.44 (0.93)	NS
2. Observed plecos in the lake in the past decade*	5.00 (.00)	SA	1.94 (.88)	D
3. The pleco invasion drives up other fish prices*	4.92 (0.27)	SA	2.53 (1.17)	NS
4. Plecos dug holes for nesting caused bank erosion*	3.71 (.96)	A	1.58 (.65)	D
5. Current management is effective*	1.37 (0.78)	D	2.41 (1.13)	NS
6. Direct killing is the most effective method*	1.00 (0.00)	D	3.04 (0.98)	A
7. Will eat pleco-based food	2.54 (1.51)	NS	2.25 (1.33)	NS
8. Less connections between youth and the lake*	4.92 (0.27)	SA	3.94 (0.75)	A

Note: A-level = agreement level, SA = strongly agreed, A = agreed, D = disagreed and NS = not sure. * Indicates a significant difference (t-test, p-value < 0.05) of mean between the fishermen and non-fishermen groups.

Table 3 Villager knowledge about the pleco fish characteristics and habitat

Items	**Fishermen**	**Non-fishermen**
1. Pleco mouth position	1.00(0.00)	0.43(0.50)
2. Scale hardness	1.00(0.00)	0.53(0.51)
3. Moving habit	1.00(0.00)	0.40(0.49)
4. Habitat position	1.00(0.00)	0.28(0.45)
Average total score	4.00(0.00)	1.63(0.49)

Note: a full score is 4.00 where the samples with score 0.00 = very limited knowledge, 1.00-3.00 = obtained some knowledge and 4.00 = well recognized of the pleco. * Indicates a significant difference (t-test, p-value < 0.05) of mean between the fishermen and non-fishermen groups

Approximately, 68.5% of respondents expressed their willingness to participate in the proposed management project, especially the fishermen group, due to the alarming situation of the pleco invasion. All of the interviewed fishermen said "yes" that they would catch and sell plecos to the BSF feedstock production. For the non-fishermen group, we received quite a positive response of their participation (approximately one third of the non-fishermen group said "yes"). However, the majority of respondents who said "yes" stated their confidence level of participating below 50% for the non-fishermen group but between 51-75% for the fishermen group (Table 4). This is considered a big hurdle to cross for management planning and proposal when putting it into practice. Villagers may not see clearly what actions they will take; whether or not they will be able to really get involved even though they might agree with such a proposal. Uncertainty of outcomes and benefit returns lessens villagers' confidence to participate. And it becomes a big challenge for project managers to put the plan into clear and real outcomes to be expected by villagers. Meanwhile, the respondents who said "no" to the proposed project indicated three main reasons for not willing to get involved, including time constraint, infeasible implementation, and ineffective outcome expectation.

Table 4 Villager willingness to participate in the proposed ecosystem-based management of plecos: the BSF feedstock production

Item	Fishermen group (%)	Non-fishermen group (%)
1. Willing to participate in the project		
●Yes	100	32.26
●No	0	67.74
2. A confidence level of participating		
●<50%	4.67	73.33
●=50%	18.69	3.33
●51-75%	42.06	16.67
●>75%	34.57	6.67
3. Reasons of not willing to participate		
●No time to participate	0	71.42
●Didn't think it's feasible to implement the project	0	26.98
●Didn't expect effective outcome from the project	0	1.58
4. If you said "yes", what activity you would likely to participate		
●Catch and sell plecos to the BSF feedstock production	33.64	46.67
●Process plecos into the BSF feed	42.06	26.67
●Both activities: catch, sell and process plecos	24.3	26.66

Conclusions

Tempe Lake in South Sulawesi, Indonesia is encountering one of the global threats on biodiversity and people well-being – the invasive alien species. The invasion of plecos reduced native fish populations, caused erosion, and changed the lake ecosystem functions – *ecological impacts*. Subsequently, decreases in native fish affected fishery production; amounts of catch dropped and lowered fishermen income – *economic effects*. Moreover, fishery is perceived as a hard-working job with low economic returns, especially among young people. A mindset towards other jobs drives them away from fishery and/or other labor-based jobs. Particularly, a civil service position is projected as a job with high respect, stable and secure income even after retirement. It is a way out of poverty. As a result, young people usually look for jobs outside fishery, migrate to big cities, but often end up with daily wage-labor work. This workforce migration leads to changes in family structure from extended to a single-family type, disconnection among family members and slum settlement in big cities – *social impacts* (Figure 7).

Local communities expressed an ecosystem-based management with economic incentives for local community participation is needed in a timely manner. The pleco-based BSF feedstock production is proposed since it offers the alternative to deal with economic, social, and ecological aspects of the problem, especially from the lack of economic incentives that result in no investment and/or low participation. However, the project's implementation directly depends on local perception and their willingness to participate. We received quite positive responses from the local communities in Wajo, especially the fishermen group with the degree of confidence to participate in the management project greater than 50%; but educating the public to recognize problems or impacts from the pleco invasion is still needed to gain people participation. Furthermore, a cost-benefit analysis of the proposed project is essential for effective implementation. Local communities, both villagers and local administration, need clear and sufficient information to help them see potential gains and losses from their actions whether they decide to "do no nothing" or "do something about it."

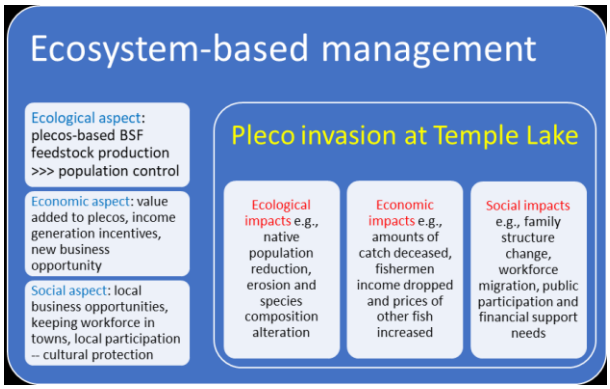

Figure 7 Ecological, economic, social, and public impacts from the pleco invasion

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