Environmental Science

http://www.aimspress.com/journal/environmental

AIMS Environmental Science, 9(1): 1–15.
DOI: 10.3934/environsci.2022001
Received: 08 October 2021
Revised: 18 December 2021
Accepted: 22 December 2021
Published: 18 January 2022

*Research article*

# Floating cage aquaculture production in Indonesia: Assessment of opportunities and challenges in Lake Maninjau

**Junaidi[1,*], Hafrijal Syandri[2], Azrita[3], Abdullah Munzir[1]**

[1] Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, Universitas Bung Hatta Padang, West Sumatera, 25133
[2] Department of Aquaculture, Faculty of Fisheries and Marine Science, Bung Hatta University, Padang, Indonesia
[3] Department of Biology Education, Faculty of Education, Bung Hatta University, Padang, Indonesia.

* **Correspondence:** Email: junaidi@bunghatta. ac. id, Tel +627517051678.

**Abstract:** Aquaculture in floating cages in Lake Maninjau has recorded significant growth, even as the largest contributor to total annual aquacultural production in West Sumatra Province. In this study, we assessed the output of floating net cages in Lake Maninjau, Indonesia. We analyzed the characteristics of fish farming, fish fry, feed supply, and production, and the challenges and opportunities for increasing aquacultural production in the future. We used purposive sampling in this study with an interview questionnaire to obtain information from 80 fish-cultivating households in Lake Maninjau. We then used descriptive statistical methods of data analysis. The results showed that in 2018, there were 17596 floating net cages. The majority (n = 33, 41.25%) of fish farmers have 20 to 40 floating net cages per household, and 67.5% (n = 54) are used for tilapia cultivation. We recorded that 77.5% (n = 62) of fingerlings were sourced from private hatcheries. Six companies supply commercial feed pellets in an amount of 2000 tons per month for aquaculture activities. Japfa Comfeed Indonesia Ltd. provides 35% of the feed. The fish species cultivated were Nile tilapia, common carp, giant gourami, Clarias catfish, and pangasius catfish, with gross yields (kg/$m^3$/cycle) of 12, 11.5, 10.4, 7.88, and 8.89, respectively. Fish farmers face challenging conditions: poor water quality, mass mortality of tilapia, high fish feed prices and low fish sale prices, and noncash payments. We recommend ensuring the development of floating net cages in Lake Maninjau for a more sustainable future. Therefore, it is necessary to operate as many as 6000 nets to meet guidelines for carrying capacity and cultivation based on the Regional Regulation of Agam Regency Number 5 of 2014 concerning the management of Maninjau Lake, which is accessible proportionally by eight villages. Giant gourami is prioritized for cultivation because it is resistant to poor water quality and high market prices.

**Keywords:** aquaculture; lake fisheries; cage; ecosystem health; challenges

## 1. Introduction

Aquaculture is responsible for a supply of fish for human consumption; for this reason, aquaculture continues to grow faster than other major food production sectors [1]. Indonesia is rich in natural water resources that can be utilized for aquaculture development in the future [2–4]. In 2016, aquaculture in Indonesia occupied 1201275 ha in total, consisting of 250640 ha (20.86%) of inland area, 674135 ha (56.12%) of coastal area, and 276500 ha (23.02%) of marine area [5]. These data show that the aquaculture sector plays an important economic role in Indonesia [4,6,7]. Recently, the freshwater aquaculture commodities developed in Indonesia include Clarias catfish, Pangasius catfish, common carp, and Nile tilapia [8]. These species have contributed as much as 14.0%, 11.0%, 13.4%, and 22.7% to Indonesian aquaculture production, respectively [2], and are derived from ponds, floating net cages, and paddy fish integrated farming [5].

Aquaculture activities in floating net cages in Lake Maninjau date back to 1992, when Yulinus Farm Limited successfully harvested fish from floating net cages constructed for their farm. At that time, the fish species being cultured was common carp (*Cyprinus carpio*). Nile tilapia was more dominant in the last ten years, and other species, such as giant gourami and Clarias pangasius were also farmed [9,10]. In 2015, in Lake Maninjau, as many as 16608 floating net cages were recorded, compared to only 16 nets recorded in 1992 [11]. However, the number of floating net cages and other supporting industries is increasing in Lake Maninjau. Therefore, a strategy is required to guide investment based on “sustainability”, i.e., the practice of cultivating floating net cages to grow sustainably. At the same time, negative environmental impacts must be reduced significantly [12,13].

Previously, we did not have recorded information on the characteristics of floating net cages, sociodemographic indicators, or the number of floating net cages in each village in Lake Maninjau. Our study includes the fish cultivated, fingerling sources, and activities related to commercial feed provision and feed supply companies. Therefore, this study evaluates the characteristics and sociodemographic indicators of farms, such as the number of cages in each village, species of fish cultivated, feed supply companies, and harvested production. Apart from these data, we also analyzed the opportunities for and challenges of floating net cages in Lake Maninjau. These data are fundamental to future sustainable fish farming activities with floating net cages.

## 2. Methods

### *2.1. Study area*

This study was conducted in Lake Maninjau, Tanjung Raya subdistrict, Agam District, West Sumatera Province, Indonesia. This lake is categorized as teptovolcanic. It is located at longitudes of E: 0012'26.63"– S: 0025'02.80" and E: 100007'43.74"– E: 100016'22.48", at an altitude of 461.50 m above sea level, approximately 150 km southwest of Padang City. The biophysical characteristics of Lake Maninjau are presented in Table 1. The Tanjung Raya subdistrict has a population of 35309 [14]; the community's main activities in Lake Maninjau are floating net cage fish farming and tilapia hatcheries on the lake border.

**Table 1**. Biophysical characteristics of Lake Maninjau.

| Biophysical characteristics | units | value |
|---|---|---|
| Surface area | $km^2$ | 99.7 |
| Length of coastline | km | 52.7 |
| Maximum length | km | 16.46 |
| Maximum width | km | 7.5 |
| Maximum depth | m | 168 |
| Average depth | m | 118 |
| Relative depth, Zr | % | 1.51 |
| Volume of water | $km^3$ | 10.4 |
| Water retention time | year | 25 |
| Catchment area | $km^2$ | 132.6 |

Data sources: [15].

### *2.2. Study design*

In this study, we used the purposive sampling method. Interviews were conducted by questionnaire to obtain information on 80 fish farmers' households characteristics (10 households per village) from 850 fish farmer households in eight villages in the Tanjung Raya subdistrict [16]. The eight vilages were Koto Malintang, Tanjungsani, Sungai Batang, Maninjau, Bayur, Dou Koto, Koto Kaciek, and Anam Koto. We conducted this survey in the Tanjung Raya District of Danau Maninjau from March–July 2018. Primary data collection included the total number of floating cages in each village, the number of operators of floating net cages, fish feed supply, fish fingerling availability, and harvested production. Then, we analyzed the challenges faced by fish farmers working with floating net cages. We obtained additional relevant information about fish farming activities in floating net cages from the managers of the feed companies, and from field observations.

Before we collected primary data, a questionnaire was designed, and a pretest was run with several floating net cage farmers in each village. Changes in the questionnaire form were made according to the data requirements. The final questionnaires were improved, rearranged, and modified based on responses from the pretested questionnaires. In addition to primary data, we also collected secondary data, including a dataset of the number of floating net cages from 2001 to 2018 from the Department of Fisheries, Agam District, West Sumatera Province. Mapping involved georeferencing the number of floating net cages in each village based on GPS locations established for floating net cages in Lake Maninjau using ArcGIS 10.0 (Esri Canada).

### *2.3. Data analysis*

The data collected were organized into charts, tables, and graphs in Microsoft Excel and then all answers were coded and transferred to the Statistical Package for Social Scientists (SPSS) version 17.0.

## 3. Results and discussion

### *3.1. Characteristics and sociodemographic indicators*

Fish farming households in Lake Maninjau have practiced production methods and the single floating net cage system for economic reasons. A production unit consists of an iron frame coated with anti-rust material (iron paint) supporting four floating net cages of 75 $m^3$ (5 x 5 x 3 m) constructed of 10 mm mesh. The units are used in combination with other equipment (i.e., a float, feeding station, and cage pathway). Floats are plastic drums of a double ring type, with a body diameter of 58 cm, a total height of 93 cm, a product weight of 8.6 kg, and a full volume of 200 L. In contrast, in Lake Victoria, Kenya, fish farmers used cages ranging from 8 to 125 $m^3$, and the sizes of the pens were related to differences in financial resources [17].

The number of floating net cages increased exponentially between 2001 and 2018 and increased by 90.14% in the last five years (Figure 1) [14]. Interest is growing for the floating net cage business. Table 2 shows the number of floating net cages in each village around Lake Maninjau. Tanjung Sani village had the highest number of floating net cages (n = 4364, 24.80%) out of a total of 17596 cages in Lake Maninjau. Koto Gadang village and Duo Koto had the lowest numbers of floating net cages ($n$ = 660, 3.75% and $n$ = 653, 3.71%, respectively). The difference in the number of floating net cages in each village was mainly due to the length of coastline owned by each village.

For example, floating net cages in Bayur Village are shown in Figure 2. Most of the floating net cages (n = 45, 56.26%) were located 300 m from the shore. Farmers prefer that zone due to its better water quality and protection from potentially damaging winds and currents. However, mapping showed that there were also floating net cages placed around the weir zone of the hydroelectric power plant. Several areas (<100 m) of each village were "Rasau Rindu Wisata" zones that function as fish breeding zones and are protected from fishing, thereby affecting natural fish populations.

This survey involved 80 fish farmers' households from a sample of 850 fish cultivating households. Overall, we recorded 2274 floating net cages from 80 respondents. The respondents were classified as full-time fish farmers ($n$ = 54, 67.5%), part-time fish farmers ($n$ = 10, 12.5%), fisherman and fish farmers ($n$ = 13, 16.25%) or other ($n$ = 3, 3.75%). In this case, other referred to persons who owned cages but were neither full-time fish farmers, nor part-time fish farmers, nor fishermen. These individuals could have been village office clerks, teachers, shopkeepers, or individuals earning civil servant pensions. The average income of respondent's household was USD 172.41 per month, with the majority of respondents living in the Maninjau Lake area (n = 75, 93.75%). This income is lower than the income of cage fish farmers in Lake Victoria, Kenya (USD 2832 per month). At the same time, 82% of those fish farmers live in rural areas of the Lake Victoria region [13].

The majority of floating net cages were individually owned ($n$ = 60, 75%), while other cages were owned by feed traders ($n$ = 15, 18.75%), and fish traders ($n$ = 5, 6.25%) (Figure 3). The number of floating net cages in each fish farmer's household ranged from 4 to 60 nets. The majority ($n$ = 33, 41.25%) of the fish farmers' households had 20 to 40 floating net cages, while other households had 41 to 60 nets ($n$ = 22, 27.08%), 8 to 20 nets ($n$ = 18, 23.33%), or 4 to 8 nets ($n$ = 7, 8.33%) (Figure 4).

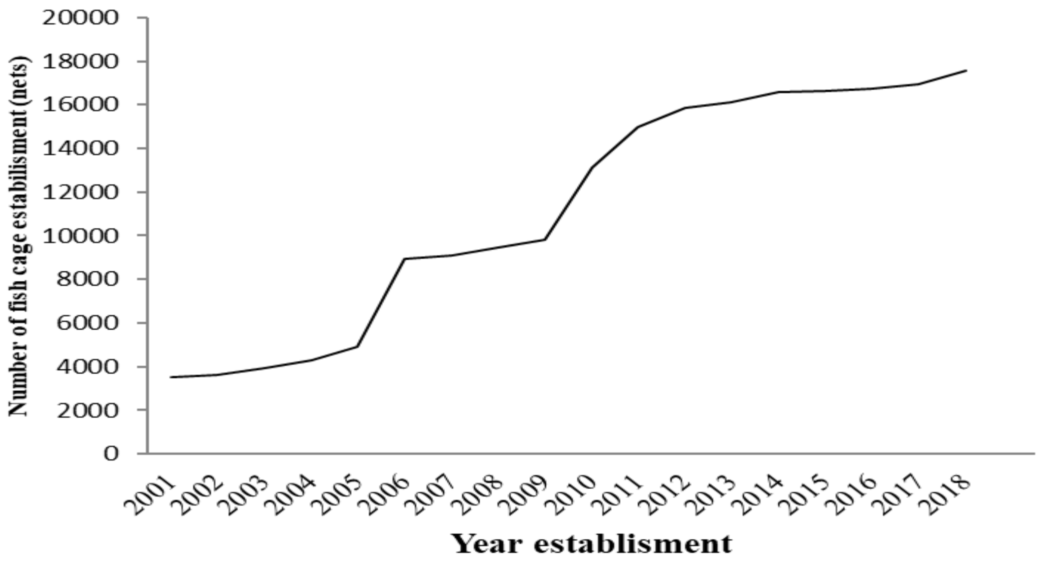


**Figure 1.** The number of fish cages established between 2001 and 2018 in Lake Maninjau, Indonesia.

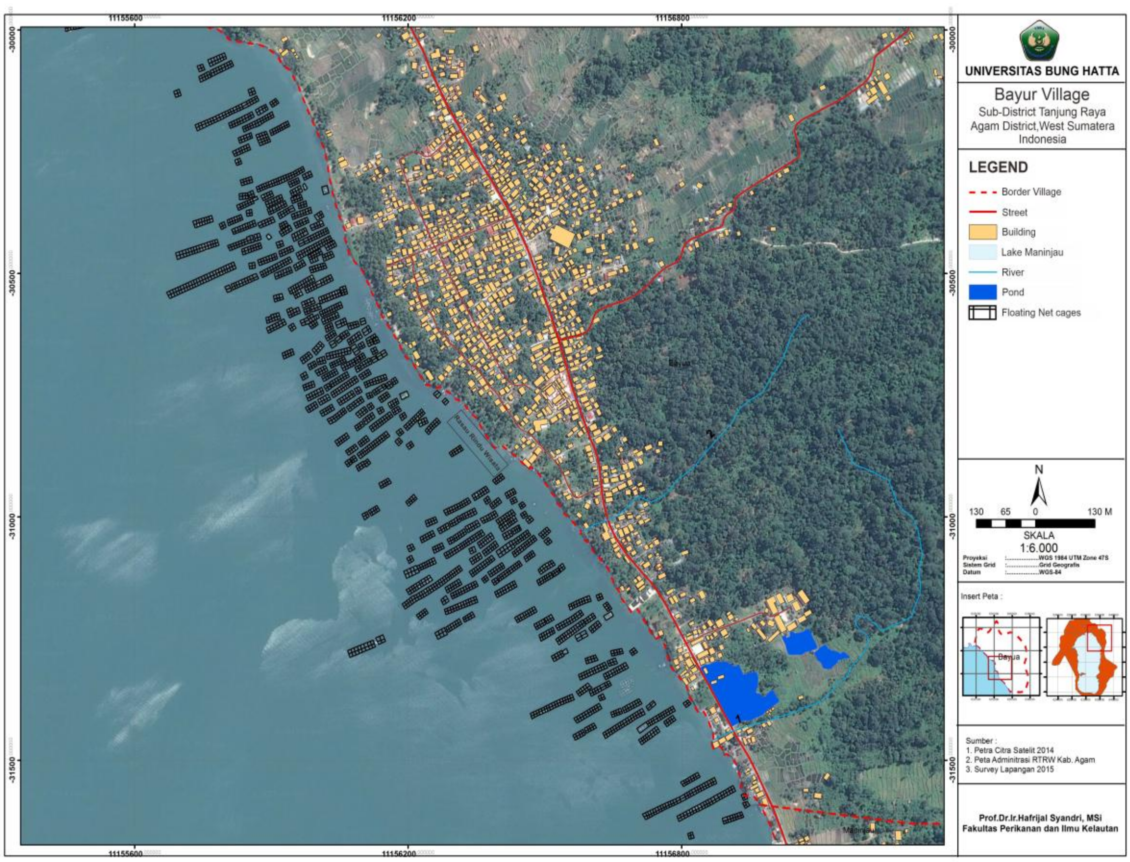


**Figure 2.** Map of floating net cage locations in Bayur Village, Lake Maninjau, Indonesia.

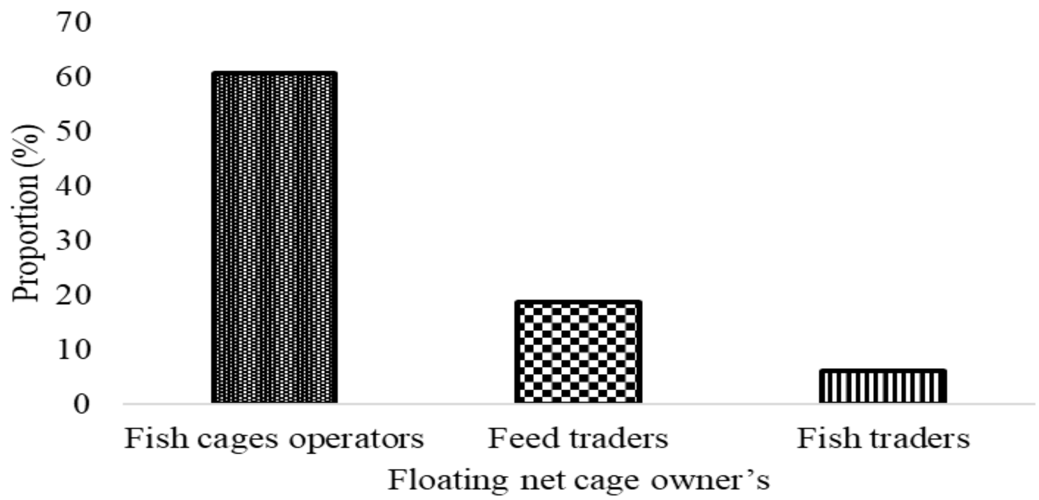


**Figure 3.** Owners of floating net cages in Lake Maninjau.

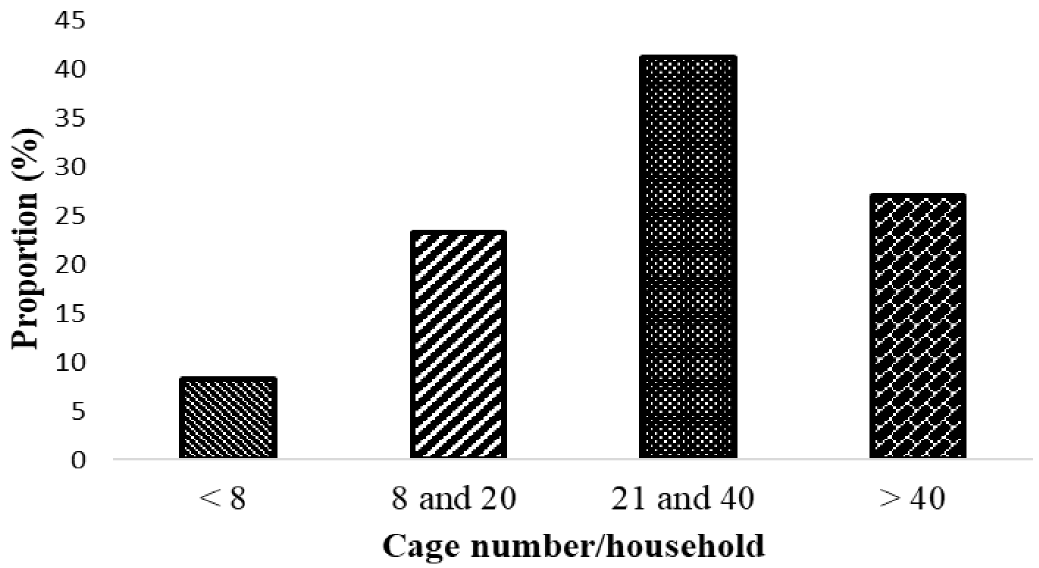


**Figure 4.** Ownership of floating cages per fish farmer household in Lake Maninjau.

**Table 2.** Distribution of floating net cages in eight villages in Lake Maninjau, Indonesia.

| | Floating net cage location | Number of floating net cages | Proportion (%) |
|---|---|---|---|
| 1 | Maninjau | 1332 | 7.57 |
| 2 | Bayua | 3354 | 19.06 |
| 3 | Duo Koto | 653 | 3.71 |
| 4 | Koto Kocik | 1265 | 7.19 |
| 5 | Koto Gadang VI Koto | 660 | 3.75 |
| 6 | Koto Malintang | 3459 | 19.66 |
| 7 | Tanjung Sani | 4364 | 24.80 |
| 8 | Sungai Batang | 2509 | 14.26 |
| | Total | 17596 | 100 |

Data source**:** Based on the GIS mapping, 2018.

### 3.2. Species cultured and stocking densities

The fish species cultured were Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus carpio*), Clarias catfish (*Clarias sp*), Pangasius catfish (*Pangasius hypophthalmus*), and giant gourami (*Osphronemus goramy*). Other researchers have reported that Nile tilapia is the predominant species cultured in cages [13,18,19]. In this study, the majority (67.5%) of the floating net cages were used for cultured Nile tilapia, 18.75% were used for common carp, 5.00% were used for Clarias catfish, 3.75% were used for Pangasius catfish, and 5.0% were used for giant gourami (Figure 5). Clarias catfish and Pangasius catfish are cultured because the production cycle is short. They can be fed feed dead tilapia, which come from the floating net cages in this area, and are resistant to poor water quality. At the same time, although the growth rate of giant gourami is slow, this species is resistant to poor water quality and has a high market price. The average stocking density of Nile tilapia fingerlings was 100 fish/m$^3$ (7500 fish per net), the average stocking density of common carp and giant gourami was 66 fish/m$^3$ (5000 fish per net), and the average stocking density of Clarias catfish and Pangasius catfish was 133 fish/m$^3$ (10000 fish pernet). In this study, tilapia fingerlings for cage culture were sourced from private fish hatcheries and individual hatcheries, and caught in Lake Maninjau (Figure 6). The fingerlings of common carp, Clarias catfish, and giant gourami were obtained from private companies in Luak District, Lima Puluh Kota Regency, West Sumatra Province, which is 75 km from Lake Maninjau. We collected catfish fingerlings from Kampar Regency, Riau Province, 120 km from Lake Maninjau.

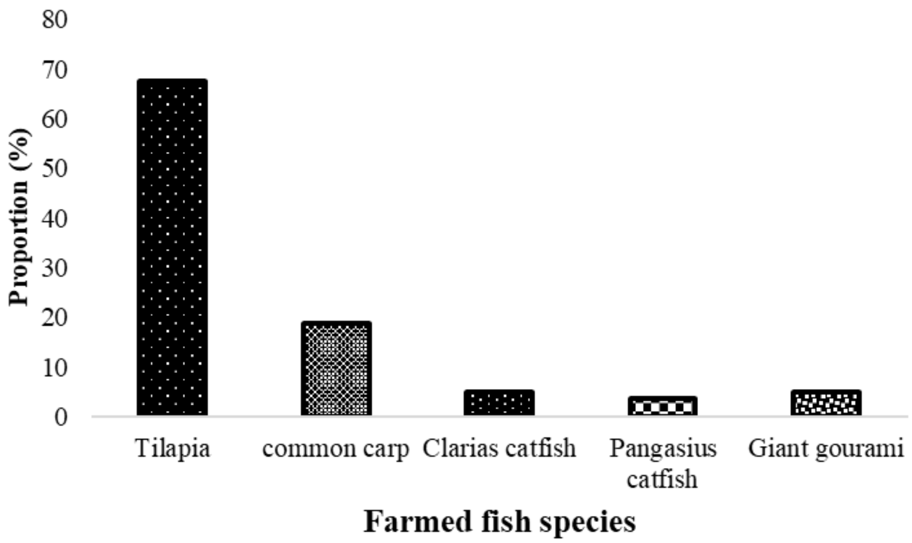


**Figure 5.** The proportion of fish farmers' households by fish species kept in Lake Maninjau.

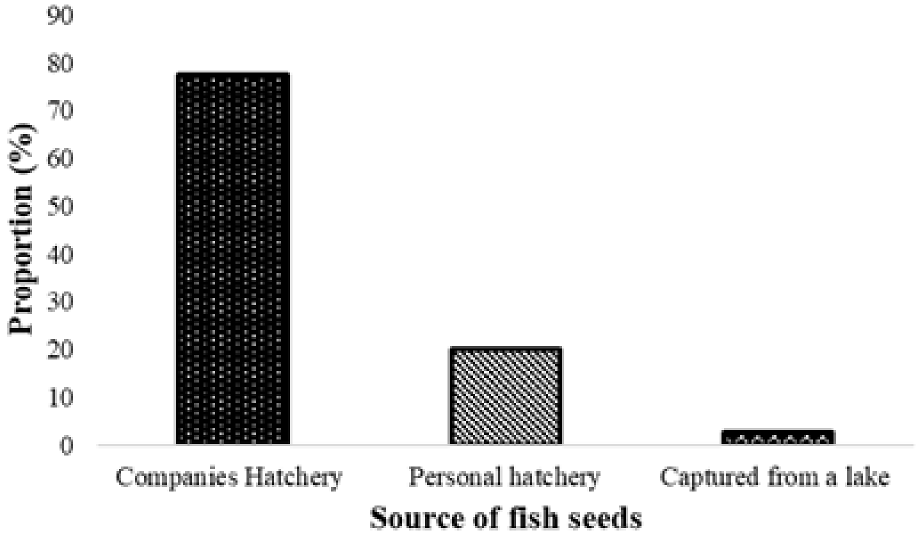


**Figure 6.** Sources of tilapia fingerlings for aquaculture activities.

### *3.3. Fish feed*

This study revealed that fish farmers in Lake Maninjau carried out aquaculture activities for 60 to 180 days per production cycle to achieve market sizes. Most fish farmers fed the fish twice a day, from 09:00 to 10:00 AM and 4:00 to 5:00 PM. Fish were hand-fed at a 3% body weight rate per day until study termination. According to Thongprajukaew et al. [20], tilapia operations with a twice daily feeding (09.00 PM and 6.00 PM) are optimal for feed management. Conversely, feeding fish improperly can be a problem for fish farmers in developing countries [21]. In this study, we noted that the feed used was floating and sinking commercial feed, however, cage fish farmers in Lake Victoria used floating, sinking, slow sinking, and other feed types [13].

In this study, we also noted that the feed used to produce floating net cage fish was supplied from a feed company in North Sumatra Province, Indonesia. Currently, the feed supplied to Lake Maninjau, Tanjung Raya District, averages 2000 tons per month. Commercial feed was supplied by seven companies, namely, Japfa Comfeed Indonesia Ltd., Central Proteina Prima Ltd., Mabar Feed Indonesia Ltd., Malindo Feedmill Ltd., Sinta Prima Feedmill Ltd., Universal Agri Bisnisindo Ltd., and Cargill Feed and Nutrition Ltd. (Figure 7). Feed was transported by truck; the distance from the location of the animal feed company to Lake Maninjau was 650 km. The feed used by fish farmers was 60% best quality feed, 30% good quality feed, and 10% relatively poor-quality feed. In Lake Kariba, Zambia, the feed supplied by two companies ranged between 50 and 100 tons per day [19]. In contrast, Aura et al. [13] stated that cage farmers obtained feed from nine companies in Lake Victoria, Kenya.

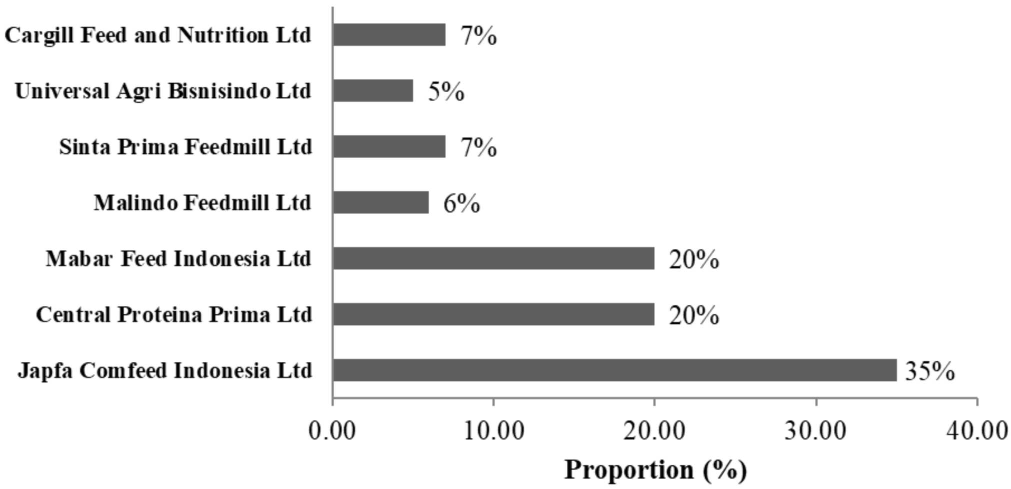


**Figure 7.** Fish feed supplied by each company to Lake Maninjau.

*3.4. Harvested fish*

Based on the records of fish farmers, tilapia and gourami were given commercial feed every day from 09.00 to 10.00 and from 16.00 to 18.00. The amount of feed given ranged between 3% and 5% of body mass. Meanwhile, Clarias and Pangasius catfish were not fed commercial feed but were given dead tilapia from the surrounding cage culture. The tilapia and common carp were reared in floating net cages for each production cycle, with an average of 120 days, whereas giant gourami was reared for 170 days. Conversely, Clarias catfish and pangasius catfish were raised for 60 and 75 days. The average harvested weight of tilapia and giant gourami were 200 and 300 g/fish, respectively, and the gross yield of tilapia was 12 kg/$m^3$/cycle and that of giant gourami was 10.4 kg/$m^3$/cycle. The feed conversion ratio (FCR) for tilapia was 1.68, and that of giant gourami was 1.65. The average harvested weight of Clarias catfish was 125 g/fish, and that of Pangasius catfish was 150 g/fish. The gross yields of Clarias catfish and pangasius catfish ranged from 7.88 to 8.89 kg/$m^3$/cycle, respectively. We did not record the FCR for Clarias and pangasius catfish because these fish are not fed commercial feed by fish farmers.

*3.5. Significant challenges in aquaculture*

3.5.1. First challenge

In this study, we found several challenges in the development of tilapia aquaculture in Lake Maninjau. Most fish farmers face the challenge of mass mortality of fry in the early period of their cultivation activities due to poor water quality. In recent years, the water of Lake Maninjau has been heavily polluted, and the lake has a hypereutrophic status [22]. According to [23], cyanobacteria dominate eutrophic lakes, and cyanobacteria produce cyanotoxins [24,25] reported that mass mortality of fish was associated with toxins from cyanobacteria. Meanwhile, the main challenge for tilapia cultivation worldwide is the disease *Streptococcus agalactiae*, which causes huge losses for tilapia farmers [26,27]. In comparison, Ferguson et al. [28] stated that Tilapia Lake Virus (TiLV) was found together with well-known pathogenic bacteria such as Aeromonas spp., which negatively impacted the survival of tilapia fish. Whether TiLV lives in Lake Maninjau and negatively affects the survival rate of tilapia was not examined in this study. However, TiLV infection can decrease tilapia production and can cause serious socioeconomic impacts [28–32].

### 3.5.2. Second challenge

The price of commercial feed pellets (IDR 12000/kg) is the second challenge for tilapia aquaculture in Lake Maninjau because the selling price of fish is not proportional to the cost of feed. Tilapia is a target species with local market prices of IDR 19000/kg and higher production levels (approximately 85% of total production). The price of common carp is IDR 22000/kg, the price of giant gourami is IDR 40000/kg, the price of Clarias catfish is IDR 15000/kg, and the price of Pangasius catfish is IDR 14000/kg. The cost of feed contributes to approximately 60% of the operating expenses in the aquaculture system in Lake Maninjau. Furthermore, most farmers have experienced challenges in estimating the right amount of feed to provide, so the FCR varies between 1.6 and 1.8. Similar to the findings of Ali et al. [33] and Thongprajukaew et al. [20], who stated that feed was the most significant component of operating costs in an intensive aquaculture system, we found that optimum feeding without waste would determine the system's economic viability. Therefore, feeding fish according to their needs can improve productivity, help to reduce feed loss, and maintain a suitable aquaculture environment [34]. At the same time, other critical challenges in fish farming are theft and predators such as birds and crocodiles [19]. However, in this study, we found that theft and predators did not become a challenge for fish farmers in Lake Maninjau because farmers run their fish farming activity around their residence.

### 3.5.3. Third challence

Based on Agam Regency Government Regulation Number 5, of 2014, concerning the management of Maninjau Lake, the number of floating net cages allowed for cultivation activities, based on carrying capacity, is 6000 nets. In this study, fish farmers did not implement the above government regulations. Most aquaculture producers (58.34%) stated that the law prevented them from increasing their production and reducing their income. Meanwhile, few agricultural activities can be carried out around lakes due to the narrow, hilly, and rocky land areas [16]. However, David et al. [35] stated that water bodies must be used rationally, based on the ecological carrying capacity, to sustain aquaculture production. For example, in Lakes Victoria, Kariba, Malawi, and Taihu, fish farmers have complied with the best regulations to promote sustainable aquaculture [36–38]. In addition, government regulations have been applied along the Norwegian coast to determine the spatial distribution of salmoncages, their size, and the structure of cage ownership [39].

Furthermore, continued water damage is the third challenge for fish farmers wanting to increase fish production. Other researchers found that lake damage was caused by nitrogen and phosphorus in the water bodies [35,40]. According to Syandri et al. [41], the availability of nitrogen, phosphorous and total organic matter in the water was significantly higher after fish mass mortalities harmed the water quality of Lake Maninjau. Releasing nutrients from cage aquaculture in the aquatic environment affects water quality and conflicts with multiple users. However, it also exerts a negative feedback effect on the cage operations themselves [35,40,42,43].

Table 3 shows that poor water quality, fish mass mortality, and uncertainty regarding operational aquaculture law were the main challenges in fish aquaculture activities in Lake Maninjau. On the other hand, biophysical variables such as disease, pollution, and lack of an appropriate environment do not make it challenging for cage fish farmers in Lake Maninjau. In some countries, political and social factors and local community participation are dominant challenges in the development of aquaculture [3,44–46].

**Table 3.** Factors affecting prospects for expanded aquaculture production in Lake Maninjau.

| Constraints | Proportion (%) |
|---|---|
| Fish mass mortality | 87.50 |
| High cost of feed | 83.33 |
| Low sale price of fish | 72.61 |
| Poor water quality | 95.83 |
| Government regulations not in support | 41.66 |
| Legal uncertainty/absence of aquaculture law | 85.33 |
| Noncash payment for the sale of fish | 70.66 |

## 4. Conclusions

Fish farming with floating net cages in Lake Maninjau has represented a significant proportion of aquaculture production for decades and is an economic investment in the region. However, floating net cage fish farming activities in Lake Maninjau have not yet adopted a sustainable model because fish are not cultured based on carrying capacity. At the same time, negative environmental impacts, mainly water quality, are becoming worse. Most fish farmers produce tilapia, which cannot tolerate poor water quality, resulting in mass mortality during the production cycle.

Based on GIS mapping, most cages (n = 45, 56.26%) were located at a distance of 300 m from the shoreline and a depth of less than 50 m. Some of this area (<100 m) is designated "Rasau Rindu Wisata," which serves as a fish breeding zone. In addition, all cage aquaculture operators for tilapia, common carp, and giant gourami use commercial feed. However, the resulting FCR ranged from 1.65 to 1.68, meaning that feed efficiency was very low, ranging between 59% and 60%. In contrast, the waste load released into the lake water ranges between 40% and 41%. Challenges faced by fish farmers include heavily polluted water, mass mortality of tilapia, high feed costs, low selling prices of fish, and unpaid fish sales, in addition to legal uncertainty/absence of floating cage aquaculture regulations that are environmentally friendly.

Considering the challenges above, we recommend that cultured species are resistant to poor water quality, such as giant gourami. This species has a high market price and is an herbivorous fish that can eat various plants, such as sente leaves (*Alocasia macrorrhiza*) and other young plants, and plants can partially substitute for commercial feed. Furthermore, we also recommend that the government of Agam Regency make regulations for environmentally friendly floating net cage fish farming by allocating certain zones for tourism and not placing cages in the weir zone of hydroelectric power plants. This policy would allow for optimal use of Lake Maninjau for various activities, such as floating cage operations, tourism, water use by hydroelectric power plants, and other sustainable aquaculture activities.

## Conflict of interest

The authors have no conflict of interest.

## Acknowledgments

The authors thank the Ministry of Finance, the Republic of Indonesia, for supporting this study through the competitive grants scheme Productive Innovative Research (Policy/Governance) 2019 with contract number PRJ-99/LPDP/2019. Our appreciation goes out to all of the students, fish farmers, and partners who helped the author during data collection in the field.


## References


1. FAO (2018) The state of world fisheries and aquaculture 2018: contributing to food security and nutrition for all, Rome.
2. Tran N, Rodriguez UP, Chan CY, et al. (2017) Indonesian aquaculture futures: An analysis of fish supply and demand in Indonesia to 2030 and role of aquaculture using the Asia Fish model. *Mar Policy* 79: 25–32. https://doi.org/10.1016/j.marpol.2017.02.002
3. Senff P, Partelow S, Indriana LF, et al. (2018) Improving pond aquaculture production on Lombok, Indonesia. *Aquaculture* 497: 64–73. https://doi.org/10.1016/j.aquaculture.2018.07.027
4. Pouil S, Samsudin R, Slembrouck J, et al. (2019) Nutrient budgets in a small-scale freshwater fish pond system in Indonesia. *Aquaculture* 504: 267–274. https://doi.org/10.1016/j.aquaculture.2019.01.067
5. CDSI, Central Data Statistic Indonesia (2016) Ministry of Marine and Fisheries Republic of Indonesia. CSI. *Center for data, statistics and information (CSI)*. Marine and Fisheries in Figures. Ministry of Marine and Fisheries Republic of Indonesia. 2018. https://kkp.go.id/wp-content/uploads/2018/01/KKP-Dirjen-PDSPKP-FMB-Kominfo-19-Januari-2018.pdf
6. Syandri H, Azrita, Junaidi, et al. (2015) Social Status of the fish-farmers of floating-net-cages in Lake Maninjau, Indonesia. *J Aquac Res Dev* 7: 1.
7. Rimmer MA, Sugama, Rakhmawati K, et al. (2013) A review and SWOT analysis of aquaculture development in Indonesia. *Rev Aquac* 5: 255–279. https://doi.org/10.1111/raq.12017
8. Henriksson PJG, Tran N, Mohan CV, et al. (2017) Indonesian aquaculture futures evaluating environmental and socio-economic potentials and limitations. *J Clean Prod* 162: 1482–1490. https://doi.org/10.1016/j.jclepro.2017.06.133
9. Syandri H, Azrita, Mardiah A, et al. (2018) Nitrogen and phosphorus waste production from different fish species cultured at floating net cages in Lake Maninjau, Indonesia. *Asian J Sci Res* 11: 287–294. https://doi.org/10.3923/ajsr.2018.287.294
10. Syandri H, Azrita, Sumiarsih E, et al. (2021) Nutrient loading and farm characteristics of giant gourami fish aquaculture systems in Lake Maninjau, Indonesia: Basic knowledge of production performance. F1000Research, 10: 378. https://doi.org/10.12688/f1000research.52613.1.
11. Syandri H, Azrita, Niagara, et al. (2016) Trophic Status and load capacity of water pollution waste fish culture with floating net cages in Maninjau Lake, Indonesia. *Eco Env Cons* 22: 469–476. http://www.envirobiotechjournals.com/article_abstract.php?aid = 6717&iid = 207&jid = 3
12. Ahmed N, Thompson S (2019) The blue dimensions of aquaculture: A global synthesis. Sci. *Total Environ* 652: 851–861. https://doi.org/10.1016/j.scitotenv.2018.10.163.

13. Aura CM, Musa S, Yongo E, et al. (2017) Integration of mapping and socio-economic status of cage culture: Toward balancing lake-use and culture fisheries in Lake Victoria Kenya. *Aquac Res* 49: 532–545. https://doi.org/10.1111/are.13484
14. CSA, Central Statistics Agency (2018) Agam District, West Sumatera Province, Indonesia. https://agamkab.bps.go.id/
15. Syandri H, Junaidi, Azrita, et al. 2014. State of aquatic resources Maninjau Lake West Sumatra Province, Indonesia. *J Ecol Environ Sci* 1: 109–114.
16. Central Bureau of Statistics (CBS) of Agam Regency. (2017). Agam Regency in Figures 2017.
17. Opiyo MA, Marijani E, Muendo P, et al. (2018) A review of aquaculture production and health management practices of farmed fish in Kenya. *Int J Vet Sci Med* 6: 141–148. https://doi.org/10.1016/j.ijvsm.2018.07.001
18. Mbowa S, Odokonyero T, Munyaho AT, et al. (2017) Harnessing floating cage technology to increase fish production in Uganda, Research Series No. 138.
19. Hasimuna OJ, Maulu S, Monde C, et al. (2019) Cage aquaculture production in Zambia: Assessment of opportunities and challenges on Lake Kariba, Siavonga district. Egypt. *J Aquat Res* 45: 281–285. https://doi.org/10.1016/j.ejar.2019.06.007
20. Thongprajukaew K, Kovitvadhi S, Kovitvadhi U, et al. (2017) Effects of feeding frequency on growth performance and digestive enzyme activity of sex-reversed Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758). *Agric Nat Resources* 51: 292–298. https://doi.org/10.1016/j.anres.2017.04.005
21. Prem R, Tewari VK (2020) Development of human-powered fish feeding machine for freshwater aquaculture farms of developing countries. *Aquac Eng* 88: 102028. https://doi.org/10.1016/j.aquaeng.2019.102028
22. Syandri H, Azrita, Mardiah A, et al. (2020) Water Quality Status and Pollution Waste Load from Floating Net Cages at Maninjau Lake, West Sumatera Indonesia. *IOP Conf Ser Earth Environ Sci* 430: 01203. https://doi.org/10.1088/1755-1315/430/1/012031
23. Ji B, Qin H, Guo S, et al. (2018) Bacterial communities of four adjacent fresh lakes at different trophic status. *Ecotoxicol Environ Saf* 157: 388–394. https://doi.org/10.1016/j.ecoenv.2018.03.086
24. Burgos MJG, Romero JL, Pulido RP, et al. (2018) Analysis of potential risks from the bacterial communities associated with air-contact surfaces from tilapia (*Oreochromis niloticus*) fish farming. *Environ Res* 160: 385-390. https://doi.org/10.1016/j.envres.2017.10.021
25. Zhao M, Xie S, Zhu X, et al. (2006) Effect of dietary cyanobacteria on growth and accumulation of microcystins in Nile tilapia (*Oreochromis niloticus*). *Aquaculture* 261: 960–966. https://doi.org/10.1016/j.aquaculture.2006.08.019
26. de Oliveira TF, Queiroz GA, Teixeira JP, et al. (2018) Recurrent *Streptococcus agalactiae* infection in Nile tilapia (*Oreochromis niloticus*) treated with florfenicol. *Aquaculture* 493: 51–60. https://doi.org/10.1016/j.aquaculture.2018.04.037
27. Nicholson P, Mon-on N, Jaemwimol P, et al. (2019) Co-infection of tilapia lake virus and *Aeromonas hydrophila* synergistically increased mortality and worsened the disease severity in tilapia (*Oreochromis* spp.). *Aquaculture* 520: 734746. https://doi.org/10.1016/j.aquaculture.2019.734746

28. Hounmanou YMG, Mdegela RH, Dougnon TV, et al. (2018) Tilapia lake virus threatens tilapiines farming and food security: Socio-economic challenges and preventive measures in Sub- Saharan Africa. *Aquaculture* 493: 123–129. https://doi.org/10.1016/j.aquaculture.2018.05.001
29. Ferguson HW, Kabuusu R, Beltran S, et al. (2014) Syncytial hepatitis of farmed tilapia, *Oreochromis niloticus* (L.): a case report. *J Fish Dis* 37: 583–589. https://doi.org/10.1111/jfd.12142
30. Tsofack JEK, Zamostiano R, Watted S, et al. (2017) Detection of Tilapia Lake Virus in Clinical Samples by Culturing and Nested Reverse Transcription-PCR. *J Clin Microbiol* 55: 759–767. https://doi.org/10.1128/JCM.01808-16
31. Amal MNA, Koh CB, Nurliyana M, et al. (2018) A case of natural co-infection of Tilapia Lake Virus and *Aeromonas veronii* in a Malaysian red hybrid tilapia (*Oreochromis niloticus* × *O. mossambicus*) farm experiencing high mortality. *Aquaculture* 485: 12–16. https://doi.org/10.1016/j.aquaculture.2017.11.019
32. Mugimba KK, Chengula, AA Wamala S, et al. (2018) Detection of tilapia lake virus (TiLV) infection by PCR in farmed and wild Nile tilapia (*Oreochromis niloticus*) from Lake Victoria. *J Fish Dis* https://doi.org/10.1111/jfd.12790
33. Ali H, Rahman MM, Murshed-e-Jaha K, et al. (2018) Production economics of striped catfish (*Pangasianodon hypophthalmus*, Sauvage, 1878) farming under polyculture system in Bangladesh. *Aquaculture* 491: 281–390. https://doi.org/10.1016/j.aquaculture.2017.12.004
34. Verdegem MCJ, Bosma RH (2009) Water withdrawal for brackish and inland aquaculture and options to produce more fish in ponds with present water use. *Water Policy* 11: 52–68 Supplement 1. https://doi.org/10.2166/wp.2009.003
35. David GS, Carvalho ED, Lemos D, et al. (2015) Ecological carrying capacity for intensive Tilapia (*Oreochromis niloticus*) cage aquaculture in a large hydroelectrical reservoir in Southeastern Brazil. *Aquac Eng* 66: 30–40. https://doi.org/10.1016/j.aquaeng.2015.02.003
36. Musinguzi L, Lugya J, Rwezawula P, et al. (2019) The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters. *J Great Lakes Res* 45: 1340–1347. https://doi.org/10.1016/j.jglr.2019.09.011
37. Jamu D, Banda M, Njaya F, et al. (2011) Challenges to sustainable management of the lakes of Malawi. *J Great Lakes Res* 37: 3–14. https://doi.org/10.1016/j.jglr.2010.11.017
38. Jia P, Zhang W, Liu Q, et al. (2013) Lake fisheries in China: Challenges and opportunities. *Fish Res* 140: 66–72. https://doi.org/10.1016/j.fishres.2012.12.007
39. Asche F, Roll KH, Tveteras R, et al. (2009) Economic inefficiency and environmental impact: An application to aquaculture production. *J Environ Econ Manage* 58: 93–105. https://doi.org/10.1016/j.jeem.2008.10.003
40. Lindim C, Becker A, Grüneberg B, et al. (2015) Modelling the effects of nutrient loads reduction and testing the N and P control paradigm in a German shallow lake. *Aquac Eng* 82: 418–457. https://doi.org/10.1016/j.ecoleng.2015.05.009
41. Syandri H, Azrita, Junaidi, et al. (2017) Levels of available nitrogen-phosphorus before and after fish mass mortality in Maninjau Lake of Indonesia. *J Fish Aquat Sci* 12: 191–196. https://doi.org/10.3923/jfas.2017.191.196

42. Du H, Chen Z, Mao G, et al. (2019) Evaluation of eutrophication in freshwater lakes: A new non-equilibrium statistical approach. *Ecol Indic* 102: 686–692. https://doi.org/10.1016/j.ecolind.2019.03.032
43. Ni Z, Wu X, Li L, et al. (2017) Pollution control and in situ bioremediation for lake aquaculture using an ecological dam. *J Clean Prod* 172: 2256–2265. https://doi.org/10.1016/j.jclepro.2017.11.185
44. Young N, Brattland C, Digiovanni, et al. (2019) Limitations to growth: Social-ecological challenges to aquaculture development in five wealthy nations. *Mar Policy* 104: 216–224. https://doi.org/10.1016/j.marpol.2019.02.022
45. Holden JS, Collicutt B, Covernton G, et al. (2019) Synergies on the coast: Challenges facing shellfish aquaculture development on the central and north coast of British Columbia. *Mar Policy* 101: 108–117. https://doi.org/10.1016/j.marpol.2019.01.001.
46. Weitzman J (2019) Applying the ecosystem services concept to aquaculture: A review of approaches, definitions, and uses. *Ecosyst Serv* 35: 194–206. https://doi.org/10.1016/j.ecoser.2018.12.009.