Integrated multitrophic aquaculture in Maninjau Lake: converting eutrophic water into fish meal

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Abstract. Maninjau lake has currently been under eutrophic condition and needs urgent efforts to recover it. Integrated multitrophic aquaculture (IMTA) has proposed as one among those pointed measures, by using lake water to perform inland aquaculture activity, in which an aquatic plant was employed to carry out double functions, as water phytoremediator and source of natural feed for fish. This research was focused on the ability of the duckweeds to support growth of Tilapia (*Oreochromis niloticus*), carried out in IMTA ponds located at Nagari Batang, Maninjau Lake, West Sumatra for 40 days (September-October 2018). IMTA systems have been implemented as an effort to utilize lake water for growth media. It consisted of 3 tilapia ponds of 4x6 m² and 12 duckweed ponds (8 ponds of 4x4 m² and 4 ponds of 4x8 m²). The lake water was lifted up into the fish ponds (265 fishes/pond) and then channeled down into the duckweeds ponds, so as the duckweeds grew while absorbing nutrients content of waste fertile water from the fish ponds. The obtained duckweed biomass was then fed up to the fish. The result showed that the fish average SGR was 0.54 (0.31-0.73)%, the survival rate was 95.26 (92.88-98.12)% and the average FCR was 21.03 (14.02-28.29). Proximate analysis of the fish showed the protein content was 45.767 (42.17-50.99)% and lipid was 7.923 (4.42-11.79)% The daily production of duckweed was 48.19 (35.00-72.92) g/m²/day; with SGR 17.57 (3.15-31.43) %, while the protein content of Lemna was 32.896 (29.58-36.22)% and lipid 9.732 (8.47-10.99)% The duckweed was able to convert eutrophic water into useful biomass for fish feed and can be promoted to support development of inland aquaculture activity nearby the Maninjau Lake.

Keywords: duckweed, fish growth, IMTA system, Maninjau Lake, phytotechnology

1. Introduction

Lake Maninjau of 99.5 km² with maximum water depth 165 meters and water volume 10,400 m³, is a large tecto-vulcanic lakes located in Agam Regency, West Sumatra, Indonesia [1]. It has many economic functions, including as a power plant that generates 205 GWH of annual energy, sources of irrigation water, fisheries both in floating cages and capture fisheries, and as a national and international tourism destination. Ecological functions include controlling groundwater balance and microclimate, and habitat for biodiversity [1, 2]. Lake Maninjau currently faces problems of ecosystem degradation, caused by out controlled floating net cages fish farming development that exceeded the lake’s carrying capacity and accelerate eutrophication process in the lake. The last report
stated that Lake Maninjau has a hyper-eutrophic status [1]. Concerning the phytoplankton community
dynamic, Sulastri et al [3] reported a temporal variation in trophical status of the lake, from
mesotrophic, meso-eutrophic, eutrophic and up to hypereutrophic. Accordingly, there is an urgent
need to resuce the lake. One among others is application of technology for reducing nutrient content in
the lake water. The technology applied should not only able to water nutrient reduction, but also to
deliver direct benefits to the community around, so that it would be able to resolve the ecological as
well as the socio-economic problems at once.

IMTA (Integrated Multitrophic Aquaculture) technology is an integrated cultivation technology
utilizing trophic properties of aquatic plants that can absorb nutrients from the water
(phytoremediation) and convert them into biomass which can be used as an alternative source of fish
feed. The technology is very suitable to be applied to overcome eutrophication such as in Lake
Maninjau waters. The aquatic plants can be cultivated utilizing fertile water of the lake and the
produced biomass can be harvested by the community for feeding fish. The results of its cultivation
can be utilized by the community. IMTA application was initiated by Barrington et al [4] and
claimed to be very flexible, because it can be applied to open-water and land-based systems, marine,
as well as freshwater systems. Soto [5] mentioned that integrated aquaculture has been widely practiced
by small households in freshwater environments, mainly in Asia.

Efforts to employ aquatic plants for water pollution control has been widely reported. For
examples, some duckweeds have been employed for domestic and industrial wastewater treatments [6 – 10]. Cedergreen and Madsen [11] reported the ability of Lemna minor to absorb NH₃ and NO₃
through the roots and leaves. Under in vitro condition, the absorption rate of nitrogen and phosphorous
compounds was up to 3.36 g/m²/day and 0.20 g/m²/day, respectively, while in the field the absorption
rate was up to 2.11 g/m²/day and 0.59 g/m²/day [6]. Duckweed (Lemna perpusilla) has the ability as a
phytoremediator, which can absorb pollutants (organic) in water and produce clean water. The results
of Chrismadha and Mardayati [12] research found that Lemna had an absorption capacity of 3.9 mg N-
NO₃ m⁻² day⁻¹ and as much as 6.7 mg P-PO₄ m⁻² day⁻¹ in water media of eutropic Saguling Reservoir,
West Java. Said et al [13] reported that application of minute duckweed (Lemna) in IMTA system in
Enrekang, South Sulawesi, resulted in TP reduction by 35-52% and TN 14.76-15.63%. Amalia et al [14]
research results showed that in 30 days Lemna perpusilla was able to absorb TN from catfish
cultivation water as much as 4.48 ± 0.04 g in the cultivation pond at the initial plant coverage of
44.1%. Following these information, it is proposed to employ minute duckweed (L perpusilla) to carry
out phytoremediation function in Lake Maninjau water.

Besides as wastewater treatment agent, some aquatic plants have also been known to have
high potential for natural feed, such as those of belong to duckweeds [15, 16]. Lemna perpusilla is one
of aquatic plants that can be applied for IMTA system. This plant contains high protein and other
nutrient content [17, 18], so that it can function as a source of fish food. Said et al [19] research results
that the use of L perpusilla as an additional feed in catfish culture in an integrated system (IMTA) able
to decrease feed conversion ratio (pellet) down to only 0.97. Use 25% Lemna as additional feed can
reduce the value of the conversion ratio of tilapia fish (pellet) to 1.48 [20]. Another research (not yet
published) found that nilem (Osteochilus vittatus) can grow well by completely fed on 100% Lemna
perpusilla. A trial in Brazil has shown the potential of dried duckweed biomass for supplemental feed
to replace commercial pellet up to 50% without any harmful effect on the growth [18]. According to
Ilyas [20], Lemna can be given for fish feded in fresh form or formulated in pellet form. These
informations provides confirmation of the potential of Lemna as an alternative feed in fish farming.
The use of Lemna can reduce the cost of feed which further reduce the overall production cost.

In order to involve in effort for Lake Maninjau rehabilitation, a research on the use of minute
duckweed (Lemna perpusilla) for phytoremedial agent combined with feed function under scheme of
IMTA technology was carried out. This report is focused on the aspect of utilization of Lemna
perpusilla biomass as a source of fish feed.
2. Materials and Methods
An Integrated Multitrophic Aquaculture (IMTA) ponds system was built in the village of River Batang on shores of Lake Maninjau (figure 1). The system consisted of 3 fishponds (N1, N2, and N3) measuring 4x6 m² each and 12 ponds for Lemna cultivation, comprised 8 ponds (L1-L8) of 4x4 m² and 4 other ponds (L9-L12) of 4x8 m². All the ponds were overlaid by tarpaulin (plastic) sheet to hinder seepage, while the water distribution system uses was by means of PVC pipes. Water from Lake Maninjau was drawn into the fish ponds using a pump, and further channelled into the L1-L8 ponds, which then distributed separately as follow: water from L1 and L2 flows to L9; water from L3 and L4 flows to L10; water from L5 and L6 flows to L11; and water from L7 and L8 flows to L12. The trial was carried out for 40 days (September-October 2018).

![Figure 1. Sketch of the IMTA System.](image1)

Each fishpond (N1, N2, and N3) was stocked with 267 Tilapia fish seeds, or around 15 kg/ pond. A total of 30 fishes for each pool were sampled to measure the length (cm) and weight (grams), to represent the initial day (T-0). The fish was fed with fresh biomass of *Lemna perpusilla*, that obtained from 12 cultivation ponds. It was harvested, and then dewatered before being weighed and fed to the fish by means of throwing it to the ponds (figure 2). The feeding amount was suited to the daily Lemna production rate from the available 12 ponds, delivered twice a day, in the morning and evening.

![Figure 2. Lemna Ponds, Lemna fresh biomass for feed, and Lemna stocking back to the ponds.](image2)
Several parameters of water quality were measured using Water Quality Checker (WQC) equipment. The temperature (°C), pH, dissolved oxygen/DO (mg/L) was measured using YSI [American]. Observation on the fish growth and survival rate was carried out at day 40 (T=40). As much as 30 fishes were taken from each pond for samples of length and weight measurements, while entire number of populations were lifted out and accounted for Survival Rate (SR) calculation (figure 3).

Evaluation of effect feeding Lemna on Nile tilapia cultivation was carried out in terms of growth, survival rate, and feed conversion ratio parameters, while the water quality data were used for confirmation of suitability growth condition. Calculation of the total weight of fish in each pond by multiplying the number of fish by the mean weight of the fish in each pond. Absolute growth was calculated from the average differences in length, weight, and estimated total weight of fish in each pond during the observation period. Calculation of relative growth (Specific Growth Rate/ SGR) refers to the Sawhney et al [21]. While the Survival Rate (SR) calculation is the value of the number of fish at T (40) divided by the number of fish at the beginning (T0) multiplied by 100%. FCR value is obtained from a comparison between the amount of feed expended for achieved the weight of fish. Calculation of the number of Lemna plants produced by recording all Lemna produced on each day, then the average value is calculated.

To make Lemna biomass available everyday, the lemma cultivation ponds were divided into 4 groups of three ponds each. Each group was then harvested in line every 4 days. All the plant biomass was taken and weighed, as much as 2 kg biomass was stocked back to each ponds and the rest biomass was fed to the fish. Proximate and amino acid content analysis of fish and duckweed was carried out at the Bogor Agriculture University Laboratory. The method for proximate analysis refers to AOAC and SNI [22, 23] while amino acid analysis by HPLC Post-Column derivatization method [24], with reference of 15 amino acids standards. Total nitrogenous (TN) was analysed according to salicylic acid method [25, 26, 27], and total phosphorous (TP) was analysed followed ascorbic acid method [28].

![Figure 3. Preparation of measurement of fish samples, calculation of the number of fish, and fish samples.](image)

### 3. Results and Discussion

This experiment has confirmed the prospect of utilization minute duckweed (*Lemna perpusilla*) biomass for feeding nile tilapia fish. It is particularly indicated by the FCR value of 14.02-28.30 (table 1), even though the fish was observed to have considerable low growth rate of 0.31-0.73 %/ day due to under nourish condition as the minute duckweed biomass production was very limited. Unfortunately, there had been inadequate amount of duckweed biomass obtained from the available ponds, so that the fish SGR was relatively low, which were 0.31-0.73 %/ day. As has been reported by Chrismadha and Mulyana [29], FCR of nile tilapia production fed on minute duckweed biomass at luxurious amount was ranged 20-30, while the daily growth rate was up to 3 %/ day. The remarkably higher nile tilapia growth rate of around 6 %/ day was reported for that was grown in floating cage aquaculture [30]. This experiment showed that under limited amount duckweed biomass gave a comparable FCR value, which means that if there were suitable feed supply was given the fish might had a comparable growth rate as well. Said et al [13] also reported that growth of nile tilapia reared in an integrated system
(IMTA) for 114 days in which 63 days of it fed on minute duckweed reached 2.06-2.60%. In addition, [31] reported that FCR of * Lemma gibba* biomass for feeding Nile tilapia was 1.5, while the specific growth rate was 0.71.

**Table 1.** Growth, SGR (%), Survival Rate (%), FCR of Tilapia of 40 days.

| Date          | Parameter | Pond   | Average |
|---------------|-----------|--------|---------|
| Sep 13th (T-0)| Population| fish a | 267     | 267     | 267     |
|               | R-Length  | cm b   | 15.00   | 15.27   | 14.27   | 14.847  |
|               | R-Weight  | g/fish c| 59.88   | 67.66   | 55.88   | 61.14   |
|               | CF        | g/cm d=c/b | 3.992 | 4.431   | 3.916   | 4.113   |
|               | Total Weight | g e=c*a | 15,987.96 | 18,065.22 | 14,919.96 | 16,324.38 |
| Oct. 24th (T-40)| Population| fish f | 248     | 262     | 253     | 254     |
|               | R-Length  | cm g   | 16.19   | 16.44   | 16.28   | 16.303  |
|               | R-Weight  | g/fish h | 75.42   | 76.56   | 74.87   | 75.617  |
|               | FK        | g/cm i=h/g | 4.658 | 4.657   | 4.599   | 4.638   |
|               | Total Weight | g j=h*f | 18704.16 | 20058.72 | 18942.11 | 19234.997 |
|               | GR-weight | g/day h-c/day | 0.389 | 0.223   | 0.475   | 0.362   |
|               | SR        | % k=j/e*100 | 92.884 | 98.127  | 94.757  | 95.256  |
|               | WG total  | g l=j-e | 2716.2  | 1993.5  | 4022.15 | 2910.617|
|               | WG daily  | g m=l/day | 67.905 | 49.838  | 100.554 | 72.766  |
|               | Total Feed | g n | 56407  | 56407   | 56407   | 56407   |
|               | FCR       | o=n/l | 20.767  | 28.295  | 14.024  | 21.029  |
|               | SGR Nile  | p= ln(h/c)/day | 0.577 | 0.309   | 0.731   | 0.539   |

At the same time, high value of SR > 90% indicated a suitable condition of the experimental ponds for the fish. As shown in Table 2, the range of water temperature was 26.2-28.6 °C, and pH 7.33-8.22, which both vaporable for the fish growth. Although the DO concentration of 2.95-5.64 mg/L can be considered as sub-optimal condition [32] but it is still under tolerance of the fish [29, 33]. The SR value is comparable to bonylip barb (*Osteochilus vitatus*) [34] that had SR of 89.29% during 12 weeks cultivation fed on minute duckweed as the single diet. In consistence with it, Ilyas et al [35] also reported that SR value of 88.3% of Nile tilapia fish grown on minute duckweed.

**Table 2.** Conditions of Some Water Quality Parameters in Nile Tilapia Ponds.

| Pond | September 14th, 2018, start at 12.10 WIB (T-0) | October 24th, 2018, start at 09.20 WIB (T-40) |
|------|---------------------------------------------|---------------------------------------------|
|      | Temperature (°C) | pH | DO (mg/L) | Temperature (°C) | pH | DO (mg/L) |
| N1   | 28.4 | 7.98 | 2.95 | 26.2 | 8.09 | 3.47 |
| N2   | 28.6 | 7.83 | 4.68 | 27.0 | 8.22 | 4.07 |
| N3   | 28.5 | 7.73 | 5.64 | 26.9 | 7.99 | 4.11 |

**Table 3.** Proximate of Nile Tilapia in IMTA System.
Results of proximate analysis (% wet weight) showed that protein content of the Nile tilapia was 10.653 ± 0.973%, with fat content of 1.843 ± 0.719%, ash content of 5.423 ± 0.240%, and moisture was 76.733±0.510%. This protein content was considerably lower than that reported by Ramlah et al [36] on natural grown Nile tilapia from Lake Mawang and Lake Unhas, South Sulawesi, Indonesia in which the protein values was 12.94% and 16.79%, respectively. So as [37] on five species of Tilapia. This difference can be attributed to living conditions, where natural fish had more variation sources of feed compared to that cultivated fish with only obtain a single type of feed. Widjyanti et al [38] also reported that catfish meal had protein content of 13.68% wet weight. The fat content of tilapia, however, is considerably lower than that of catfish meal which was 4.77%. Meanwhile, the ash content of the Nile tilapia is slightly higher than that of the catfish which was 3.19% [38]. Calculations based on the dry weight revealed that the Nile tilapia has high protein content of 45.767 ± 3.863%, and low fat of 7.923 ± 3.094% (table 3), indicates that feeding minute duckweed promotes higher fish protein content and lower fat content.

Nile tilapia fish was observed to contain all the 15 examined amino acids, which totally made up 19.95 (19.13-20.76)% w/w, consisted of 9 essential amino acids and 6 non essential amino acids (table 4). Previous reports mentioned more number of amino acids in this fish, such as Oluwaniyi et al [39] that reported the occurrence of 17 amino acids, while Pinandoyo et al [40] reported the observation of tryptophan in the fish meal. This composition resembles a previously reported Gouramy fish amino acid composition, but the total content in the Nile tilapia was higher compared to that in fresh gouramy which made up only 17.81 mg/g [41]. The most important essential amino acid, which is lysine, leucine and iso leucine were observed to made up 1.67, 1.59, and 0.97 %w/w, respectively. At the same time, glutamic acid, an amino acids which largely determine fish meat taste was observed as much as 3.27 (3.18-3.36)%w/ w (table 4), which is slightly higher than that of Gouramy (3.12) and cat fish (2.83) [41, 38]. This result indicates that feeding minute duckweed leads to high amino acid content as well as complete composition of essential amino acids.

Table 4. Amino Acid Content of Nila Tilapia fed by Lemna in the IMTA System.

| Amino Acid Content | Amino Acid (%w/w) Method |
|--------------------|--------------------------|
|                    | Average | Range |                   |
| Aspartic Acid 1    | 2.07    | 2.03-2.11 |                   |
| Glutamic Acid 2    | 3.27    | 3.18-3.36 |                   |
| Serine 3           | 0.915   | 0.88-0.95 |                   |
| Histidine 4        | 0.425   | 0.4-0.45  |                   |
| Glycine 5          | 1.795   | 1.72-1.87 |                   |
| Threonine 6        | 0.825   | 0.79-0.86 |                   |
| Arginine 7         | 1.65    | 1.59-1.71 |                   |
| Alanine 8          | 1.545   | 1.49-1.6  |                   |
| Tyrosine 9         | 0.75    | 0.72-0.78 |                   |
| Methionine 10      | 0.52    | 0.5-0.54  |                   |
| Valine 11          | 1.09    | 1.05-1.13 |                   |
| Phenylalanine 12   | 0.875   | 0.85-0.9  | IK. LP-04.7-LT-1.0 (HPLC) |
| Isoleucine 13      | 0.97    | 0.94-1.0  |                   |
The total duckweed biomass production during 40 experimental days was accounted as much as 9,004,220 g (9,004.22 kg) and stocked back for seed plant as much as 8,835,000 g (8,835 kg). So the total amount of duckweed biomass given to the fish was only 169,220 g (169.22 kg), which distributed in equal amount for each N1, N2, and N3 ponds (table 1). In this research the daily production of duckweed was calculated as much as 48.19 (35.00-72.92) g/ m²/day, while the SGR was 17.57 (3.15-31.43) %/ day. The average growth value obtained is in the range of previous research results that observed growth rate of minute duckweed on Saguling Reservoir water was 12-24 %/day [12], but remarkably lower than that grown on very fertile water of catfish cultivation pond, which made up growth rate more than 35 %/ day [34]. A high growth rate up to 34 %/ day also reported by [42] for common duckweed grown on sewage water system. It means that the Maninjau Lake water was not appropriately support the minute duckweed biomass production, which mainly be attributed to low nutrient content of the water. The experiment was carried out just after the occurrence of algal bloom which might exhausted the water nutrient content so as not longer available for the duckweed growth. As has been reported by Chrismadha et al [43] the lake water contained 0.126-0.141 mg/L N and 0.055-0.065 P which considered to be limited for supporting minute duckweed production. Lukman et al [44] reported temporal variation of the Maninjau Lake water content which could also be associated with this algal bloom phenomenon.

At the same time, this research also confirms the duckweed capability of dauckweed as that was pointed out by Chrismadha et al [43]. Laboratory analysis revealed that average total nitrogenous (TN) and total phosphorous (TP) content of the duckweed biomass were 0.315±0.054 % and 0.062±0.011 % of the fresh weight, respectively, which means that there were as much as 66.24±22.49 g N and 13.12±4.45 g P were eliminated from the water, taken out by the duckweed that was used for feed to produce a kg of fish.

Table 5. Proximate of minute duckweed (Lemna perpusilla) in IMTA System.

| Component | % Wet Weight | % Dry weight | Crude Fiber |
|-----------|--------------|--------------|-------------|
|           | Moisture     | Ash | Fat | Protein | Crude fiber | Ash | Protein | Crude Fiber |
| Average   | 88.20        | 1.80 | 1.14 | 3.86 | 1.025 | 15.323 | 9.732 | 32.896 | 8.747 |
| Sd        | 0.997        | 0.057 | 0.113 | 0.226 | 0.092 | 1.773 | 1.780 | 4.695 | 1.517 |
| Range     | 87.49-        | 1.76- | 1.06- | 3.70- | 0.96- | 14.07- | 8.47- | 29.58- | 7.67- |

Minute duckweed grown on Maninjau Lake water contained as much protein as 3.86 (3.70-4.02)% wet weight. While the moisture content was 88.20 (87.49-88.90)% wet weight. The level of protein and fat relative to the dry weight were 32,896 (29.58-36.22)% and 9,732 (8.47-10.99)% respectively (table 5). This protein content is remarkably lower than those have been reported for the duckweed grown in nutrient rich media, which can achieve 38.86% [17, 18]. Ilyas et al [35] also observed that minute duckweed protein content was 38.10% dry weight. This lower protein content can be attributed to the effect nitrogenous compounds availability in the water which is important for protein synthesis. According to Mayasari et al [45] the totally Amino Acid content of the duckweed was 2.93 %/w/w; that are EAA was 1.48%/w/w or 50.51% while the NEAA was 49.49% respectively. The duckweed has 9 Essential Amino Acid (EAA) that are Histidine, Threonine, Arginine, Methionine, Valine, Phenylalanin, Isoleucine, Leucine, and Lysine and 6 Nonessential amino acid (NEAA): Aspartic Acid,
Glutamic Acid, Sirine, Glycine, Alanine, and Tyrosine. Based on the facts that some duckweed has high protein content, as well as the amino acids composition that closes to animal protein [17]. When the duckweed cultivate under optimal growth condition, it can be sources of various minerals, such as K and P, pigments like carotenes and xanthophyll’s [29].

4. Conclusions
This experimental result shows that minute duckweed was able to grow in Maninjau Lake water, converting the nutrient into biomass which useful for fish feed. The production capacity, however, was not high enough to support entire need of fish feed. Therefore, although the plant is potentially to be involved in effort for phytoremediation of the lake water, it can only partially support the development of Integrated Multiprophic Aquaculture scheme, and the need of artificial feed employment is still there.

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