Phytotechnology for eutrophic waters: ecological approach to increase benefits. A review

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Abstract. Phytotechnology utilizes plants as a strategic tool for resolving various environmental problems. One major problem of the lake in Indonesia is floating cage aquaculture practices that produce organic contamination which leads to water eutrophication. As a producer, plants play a central role in material and energy transfer in ecosystems, utilizing solar energy to perform photosynthesis and converting nutrients into biomass, which can be very useful for any purpose. A suitable plant can play phytoremediation function, while at the same time could produce biomass for feeding. Research by Research Centre for Limnology (RCL), Indonesian Institute of Sciences, using eutrophic lake water to grow minute duckweed (Lemna perpusilla Torr) has shown that the plant was able to grow while absorbing nutrients from the water. At the same time, cultivating the plant in an enclosed recirculated water pond enhanced double functions of water phytoremediation and biomass production for feed. It is also environmentally sound, as it could save water as much as 85% as well as producing oxygen and uptake carbon dioxide, while the produced biomass can be used for additional feed to increase the pond productivity and efficiency. This study showed that phytotechnology is a reliable tool to remediate lake water eutrophication.

Key words: phytoremediation, eutrophic water, biomass, feed

1. Introduction
Since it was introduced in the 1980’s, floating cage fishery activities in Indonesian lakes have been boomed exceeding the carrying capacity [1]. As reported in cascade manmade lake of Citarum River, which consisted of 3 main reservoirs, Saguling, Cirata, and Jatiluhur, those reservoirs currently occupied by 6,980, 49,985, and 15,810 unit of floating cage fisheries (FCF), respectively, while their carrying capacity has been pointed out as much as 3,261, 7.037, and 6.692 units respectively [2]. The same situation has also been reported in 2008 in Lake Maninjau, West Sumatra, which there was occupied by more than 15,000 units of FCF while the carrying capacity is 1,500 units [3].

Those FCF activities have given large organic and nutrient contamination on lake water. As reported by Garno [4], contamination from floating cage fishery aquaculture in Saguling reservoir were 10,952 ton organic/year, 478 ton N/year, and 68 ton P/year, and along with contamination input...
from Citarum stream leads to water eutrophication. The reservoir has been reported to contain 0.684 – 3.460 mg/L total nitrogen (TN) and 0.067 – 0.364 mg/L total phosphorus (TP), while the chlorophyll content was as high as 5.364 – 71.126 mg/m³ [5][6].

Lake Maninjau has also been in eutrophic condition due to high FCF activities, in which the water TP content was ranged 0.027-0.65 mg/L, the TN was 0.366 - 7.429 mg/L, and chlorophyll-a ranged 0.236-0.285 µg/L [7][8]. The water was reported to be highly degraded, unsuitable for swimming or bathing and affected ourism development in the area. There was an urgency to recover the lake water quality, particularly by reducing floating cage fishery activities, but the implementation in the field was hindered by lack of a better alternative for environmentally sound activities to earn a living. At the same time, efforts for employing some remedial technologies have also faced the obstacle of unaffordable high investment as well as maintenance and operational cost. A breakthrough resolution to overcome lake water quality problem is needed, since the problem is naturally complex, particularly in association with the socio-economic aspect.

Phytotechnology is a scientific approach to solve an environmental problem by utilizing plants as a major tool [9]. It is based on the general concept that plants through the photosynthetic capability adsorb nutrients and convert it into biomass which can be used for many purposes [10]. A wide variety of plants are able to remediate water and their biomass can be further utilized for various purposes. In this regard, plant selection to play an effective role in remediating the wastewater, and at the same time providing a good source of biomass should be considered.

2. Phytotechnology

Using plants for resolving an environmental problem is not a brand new concept. For instance, the strategy for abatement of the greenhouse effect at the global scale has been directed to manage forest vegetation. Scientists have brought phytotechnology to emphasize plants as an integral part of an ecosystem and utilize its function in an accountable manner to control the ecological processes in order to enhance any proposed functions. Phytotechnology is a part of ecotechnology [9], which is a scientific concept developed from consideration that ecosystem is an integral system of life being called superorganism that reacts and adapts spontaneously to every change.

This scientific concept comes from works of ecological modeling that showed the existence of adaptation capability through complex structural changes of an ecosystem in response to both internal and external changes. This adaptation capability is then considered as a self-design capability and becomes a major principal to develop ecotechnology [11]. Ecological modelling helps to understand and quantify functional interactions among components of an ecosystem as well as pointing out the most strategic factor that control a certain function and how this function responds to the environmental changes. Accordingly, the most efficient factor with minimal risk for intervention could be selected to obtain an expected function [11].

Ecotechnology, where phytotechnology is a part of it, is believed to answer the challenge of environmental management, including water resources. Mitsch & Jorgensen [12] emphasized two advantages of ecotechnology application: firstly; as it is based on the ecosystem in which the energy source comes from solar system (solar-driven system), it does not require large energy investment. Secondly, entire tools and materials involved in the management process are the internal ecosystem components so that the application automatically goes along with the ecosystem conservation, including the biodiversity and abiotic environment.

Phytotechnology progressed along with the ecotechnology development at narrower scope, which focussed more on the management of plant components, even though the faced challenges are not less simple. UNEP [9] stated that phytotechnology is principally an in-situ approach that has to give priorities on the utilization of local species and has to carefully consider the specific local conditions as well as the ecological interaction inside. Attention has also to be directed on the risk of invasive species or other harmful species which potentially give larger damage than the benefit obtained. The success of phytotechnology application mostly depends on the ecological process and adaptation knowledge on the employed system, as well as the implementation monitoring to collect feedback for
the system improvement.

3. Aquatic Plants

The primary entity of plant is its taxonomy, where the species name is identified according to some specific properties. Pancho & Surjani [13] noted there are around 250 species of aquatic plants distributed in the South East Asian region, consisted of 6 families of cryptogamae and 35 families of phanerogamae. These plants have diverse morphology and physiology to adapt to the water zones (figure 1). Some species grow well in humid land of the riparian zone; others have their root penetrate into the bottom while forming long shaft out of the water surface to meet solar radiation, which particularly colonized inshore and shallow water area, called emergent plants. In the deeper zone, some species anchor their roots into the bottom and form long stem to connect with the leave on the surface (floating leaf plants), such as lotus. Besides those, there are plants live in the sub-surface water called submerged vegetation, and those grow free-floating on water surface called floating vegetation. This diversity in places and habitats enable the selection of a particular species for supporting certain required functions as well as in terms of phytotechnological design according to the available space.

![Aquatic vegetation](image)

**Figure 1.** Aquatic vegetation consisted of plant groups adapted to various water zones [14].

Other important plant entities related to phytotechnology development are growth rate and biomass productivity. Although it is also associated with the taxonomic, plant growth rate is mostly influenced by the environmental condition. Factors which influence plant growth are called growth factor, and pattern of respond on a single growth factor called respond curve (figure 2). The plant respond curve is generally in terms of hyperbolic curve model, consisted of a deficient level where the plant grows sub-optimally, and resource addition will accelerate the growth up to the level of saturation where the resource is in a suitable amount to support the maximum growth. Over this saturation level, the resource addition comes into a toxic level which will inhibit the growth. Ideally, plant growth is maintained at a level just before the saturation point to obtain maximum growth.
Among various growth factors, plant growth is limited by the most scarce factor, known as Leibigh law of minimum [15][16]. It is then called as growth-limiting factor which can be identified and resolved by serial steps of experiments to find out the highest growth rate that can be obtained. The first limiting factor supports growth up to a certain level, and if this is able to be resolved, the growth rate will be further speed up exponentially up to the maximum level controlled by the other limiting factor (figure 3) [17]. Accordingly, identification and control of limiting factors are very important in utilizing plants for various functions.

Figure 2. Plant respond curve to the growth factors [15].

![Graph showing growth rate vs growth factors with Deficient, Adequate, and Toxic levels marked]

Figure 3. Enhancing growth by elimination of limiting factors in microalgal Phaeodactylum tricornutum culture [17]; LL low light, HL high light, HHL double light, HHHL triple light, HHHHL quadruple light, + CO₂ addition.
Plant biomass productivity is a function of the growth rate and density [10]. Therefore, the phytotechnology application has to obtain the optimum density which gives the highest biomass productivity. Control of population density can be rather complex. The growth rate is also influenced by population density, due to the internal competition on resource factors. Plant population density can be controlled by means of regular harvesting (figure 4). Under no limiting factor condition, the plant population grows exponentially and controlled by space availability and internal competition. Regular harvest can maintain the growth rate at the exponential phase.

![Figure 4](image.png)

**Figure 4.** Regular harvest maintained continual growth in an outdoor minute duckweed (*Lemna perpusilla*) culture (left); Under homogen substrat condition the plant growth was largely controlled by the weather while the growth rate strongly regulated the biomass productivity; after [18].

Plant biomass productivity is related to their body size. As shown in table 1, larger species has a higher biomass productivity and has to become an important consideration in selecting plant for carrying out any function. This is because any functions expected from the plants are related to biological processes in which the capacity is proportional to the size of the biomass.

| Species          | SGR (%/day) | Maximum Density (kg/m²) | Productivity (ton/ha/year) | Uptake Rate (g/m²/day) |
|------------------|-------------|-------------------------|---------------------------|------------------------|
| *Lemna perpusilla* | 15-40       | 0.45                    | 258                       | 0.20                   |
| *Spirodella polyrhiza* | 15-30     | 0.45                    | 238                       | 0.18                   |
| *Pistia stratiotes*    | 5-25       | 2.01                    | 1.353                     | 1.07                   |
| *Eichhornia crassipes* | 4-9        | 15                      | 3.834                     | 3.03                   |

There have been evidences showing that aquatic plants can grow on eutrophic water, such as the outbreak of water hyacinth in some eutrophic lakes. It has been reported that aquatic vegetation have the highest biomass productivity among another type of plants, including rain forest (table 2) [19]. In terms of phytotechnology application, however, there are still plenty of questions have to be answered, including selection of the most beneficial plants, growth and population control, harvesting, and utilization of the biomass. One lake management, for instance, have to find out the
most adaptive as well as controllable plants so as to grow well in the lake whilst keeping the population under control/ manageable density level.

4. Eutrophic Water as Source of Nutrients

Eutrophic water is a condition occurs in an aquatic body such as river and lakes, that suffer from the high level of nutrients, particularly N and P. Those nutrients mostly come from insufficient sewage disposal systems, both industrial and domestic, agricultural leaching fertilizer, and in lakes and reservoirs from floating cage aquaculture activities. In general, limnologists have divided open water into some trophic conditions based on N and P concentrations and the chlorophyll-\(a\) content to represent the extent impact of nutrient on the water biomass productivity. Table 2 shows an example of water trophic classification which is mostly used in Indonesia.

Table 2. Water trophic classification [20].

| Trophic Status Index (TSI) | Chlorophyll-\(a\) \(\mu g/L\) | TP \(\mu g/L\) | Secchi depth \(m\) | Trophic Status |
|---------------------------|-------------------------------|--------------|-----------------|---------------|
| <30 - 40                  | 0 - 2.6                       | 0 - 12       | 8 - 4           | Oligotrophic  |
| 40 - 50                   | 2.6 - 20                      | 12 - 24      | 4 - 2           | Mesotrophic   |
| 50 - 70                   | 20 - 56                       | 24 - 96      | 2 - 0.5         | Eutrophic     |
| 70 - >100                 | 56 - >155                     | 96 - >384    | 0.5 - <0.25     | Hypereutrophic|

Table 3 gives an illustration of the nutrient conditions in some eutrophic lakes in Indonesia. Lake Limboto in Gorontalo Province, for example, has total nitrogen content ranged 0.89-1.66 mg/L, total phosphorus content ranged 0.12-0.64 mg/L, and chlorophyll-\(a\) content ranged 18.43-42.18 mg/L has been considered as a eutrophic lake [21].

It has been a large number of reports stated the worst impacts of water eutrophication, such as destruction of raw drinking water, mass fish killing, blue-green algal and macrophytic bloom, faster siltation, etc. Under eutrophic condition for instance, Lake Limboto is currently facing problems of water hyacinth outbreak and fast sedimentation rate.

Apart from those negative values, however, eutrophic water can be considered as available media for growing aquatic plants. The outbreak of macrophytes population can be an indication of huge potential of eutrophic water to grow aquatic plants. It just needs a selection on the plants to be grown to obtain beneficial values. In this case, growing the aquatic plants can become an integral part of water eutrophication abatement programs, as the aquatic plants naturally absorb nutrients from water and convert it into biomass through photosynthesis, while the biomass production with the beneficial values can give incentive for the eutrophication abatement effort.

Table 3. Nutrient content of some eutrophic lakes in Indonesia.

| Lakes     | TN (mg/L) | TP (mg/L) | Chlor-\(a\) (\(\mu g/L\)) | References |
|-----------|-----------|-----------|---------------------------|------------|
| Limboto   | 0.89-1.66 | 0.12-0.64 | 18.43-42.18               | [21]       |
| Maninjau  | 0.37-7.43 | 0.02-0.65 | 0.236-0.285               | [7][8]     |
| Saguling  | 0.68 – 3.46 | 0.07 – 0.36 | 5.36 – 71.13 | [5][6][22] |

The range of N and P concentrations suitable for growing Lemnaceae plants was at 0.02-10.00 mg/L N and 0.003-2.000 mg/L P, which significantly lower than that formulated for the synthetic growth media (Hoagland growth media formulation of UTCC) which contains 35 mg/L N and 17 g/L P [23]. Chrismadha & Mardiati [22] reported that minute duckweed (\textit{Lemma perpusilla}) grow well for a short period in eutrophic Saguling Reservoir water that contain 1.289 mg/L NO\(_3\)-N and 0.047 mg/L PO\(_4\)-P. The growth rate as high as 24 \%/day was obtained, while the biomass productivity was accounted as much as 161.11 g fresh weight/m\(^2\)/day, equal to 31.9 ton dry weight/ha/year.
Significant growth and productivity was also reported for the same species in Lake Maninjau that contains a lower nutrient concentration of 0.119 – 0.183 mg/L total inorganic nitrogen (TIN) and 0.050 - 0.065 mg/L PO₄-P although it was considered to be lower than in Saguling water [24]. This short growing period is attributed to limited availability of nutrients, particularly N in the eutrophic lake water. It can be compensated by constant supply by means of continuous culture system, in which the water media is channeled continuously at an appropriate flow rate to the growing containers or ponds, to maintain the suitable nutrients to support plant growth.

5. Phytoremedial Function

Efforts to utilize aquatic plants for water quality phytoremediation purpose have been executed worldwide. For example, various duckweed species have been used to treat domestic and industrial wastewater [25][26][27][28][29][30][31]. Cedergen and Madsen [30] reported the ability of Lemna minor to absorb NH₄ and NO₃ through root and leaf. In vitro measurement measured the uptake rate of this plant on NH₄ and NO₃ up to 3.36 g/m²/day and 0.2 g/ m²/day, respectively, while in the field the uptake rates were 2.11 g/ m²/day and 0.59 g/ m²/day, respectively. In addition, Lemna gibba has been reported by El Kheir et al [26] to be able to eliminate various water quality parameters, including TSS, BOD, COD, NO₃, NH₄, PO₄, Cu, Pb, Zn, and Cd as much as 96.6%, 90.6%, 89.0%, 100%, 82.0%, 64.4%, 100%, 93.6%, and 66.7%, respectively. Alaert et al [29] observed that duckweed removed 74% total Kjeldahl nitrogen (TKN) and 77% TP in a wastewater treatment pond with 21 days of water retention time, resulted in relatively clean water output containing 2.7 mg/L TKN and 0.4 mg/L TP. Chrismadha & Mardiayati [22] have also reported the potential of Lemna perpusilla to carry out phytoremediation function in contaminated Saguling Reservoir water.

In accordance with the above information, some other floating aquatic plants have also been studied to undertake water quality phytoremedial function. Water lettuce (Pistya stratiotes), for instance, has been observed to remove 190-329 kg N/ha/year and 25-34 kg P/ha/year, respectively, and also showed a potential for the elimination of heavy metals and other water quality parameters, including COD, BOD, TSS and nutrients [32][33]. It is the case of water hyacinth (Eichhornia crassipes) which has been reported to be able to improve river water quality, control wastewater from the palm oil industry, and also removal of various heavy metals [36][37]. Satya et al [38] also reported the ability of water hyacinth to control water quality of a closed recirculation system of catfish culture pond. Meanwhile, an experiment on Saguling Reservoir water revealed the uptake rate of N and P by water hyacinth was as high as 320-1120 mg N/ m²/day and 40-170 mg P/ m²/day, respectively, and water lettuce of 130-1130 mg N/ m²/day and 30-200 mg P/ m²/day, respectively (table 4).

**Table 4. Growth and N and P uptake of water hyacinth and water lettuce at phytoremediation trial in Cililin, Bandung, West Java [39].**
6. Biomass Utilization

As aquatic plant growth, they produce biomass which can be used for many purposes, such as food, feed, fertilizer, energy, medicine, and handy crafts. Some aquatic plants have been traditionally used for food such as water spinach (Ipomea aquatica), yellow bur-head (Limnochris flava), Spirulina, etc., and even for herbal medicine, such as Spirodella polyrhiza. In the meantime, some potential use has also been studied. Naswir et al. [40], for instance, reported that biogas was produced by processing water hyacinth biomass. This plant can also be used as raw material to produce organic fertilizer or compost.

In addition, Chrismadha et al. [41][42] have observed high protein content up to 38% of minute duckweed biomass grown in catfish culture waste. A further experiment in 2018 showed that the fresh minute duckweed biomass can be suitable for feed in nile tilapia fish, promoting the fish growth > 2% /day [43]. Tavarez et al. [44] showed that duckweed biomass can be dried and replaced commercial feed for nile tilapia up to 50% without any harmful effect on the fish growth. A preliminary trial at Research Center for Limnology, Indonesian Institute of Sciences also shown that dried biomass of minute duckweed can be used directly as fertilizer in the cultivation of long bean (Vigna unguiculata). The plant growth was equivalent to that enriched with NPK. Besides those, aquatic plants also have aesthetic means that can beautify the aquatic bodies for recreational activities.

7. Potential Benefits

The aforementioned explanations emphasize the potential benefits of using aquatic plants for water resource management. An effort to resolve lake water eutrophication caused by floating cage fishery activities is by employing the plant biomass for fisheries feed. As currently being studied in the Research Center for Limnology of Indonesian Institute of Sciences, a nutritionally superior aquatic plant is used to combat water nutrient contamination while using the biomass to feed fish. The study on the phytoremedial aspect has shown the ability of aquatic plants to remove nutrients from the water column, even though some required conditions to enhance the expected results have also been pointed out [22][24][41][46].

Particular attention has been paid to minute duckweed, as the plant can grow stable from 2013 up to now in a closed water recirculation ponds, in which the water is circulated through a series of catfish cultivation ponds and minute duckweed ponds continuously (figure 5). In this integrated cultivation system the plant takes advantage of fertile water from the fish pond to support the growth, while the fish obtain two advantages at once, which are cleaner water as the duckweed does phytoremediation, and additional natural feed from the duckweed biomass production. Ten months of observation in 2017 showed that the average biomass productivity was more than 100 g/m²/day or equivalent to 328 ton/ha/year, which is enough to feed nile tilapia fish as much as 13 – 17 tons [47].
The duckweed biomass can replace as much as 75% of the total feed requirement that significantly reduces the fish production cost [47]. In line with this, the duckweed biomass can even be fed to nile tilapia fish for a total replacement of the commercial feed, although the fish growth is slightly slowing down [43]. Therefore, it is suggested to employ phytotechnology with this particular plant for resolving the FCF outbreak in open water, such as in Lake Maninjau. The ideal scheme is by growing the plant on the eutrophic lake water as the media, and use the biomass to replace commercial feed in the FCF activities. It will recirculate the nutrient in the internal lake ecosystem and reduce organic contamination from the feed.

It also can be applied in inland aquaculture practices, in which the use of plant as feed can reduce the production cost and might encourage the removal of FCF practices to inland ponds around the lake. The aquatic plant can also utilize as phytoremedial agent to be applied in water closed recirculation system which then gives an advantage of significant lower water requirement, and make the aquaculture activity become more efficient and environmentally sound.

8. Challenges

Despite those potential benefits aforementioned, there are still some obstacles that hinder the application in the field. It is mainly due to the fact that those mentioned benefits are new things so that it has to be able to compete with the existing developed markets as well as to manage business cultural changes among the stakeholders. Development of plant biomass utilization has to involve some business segments, at least it has to consist of growing, harvesting, processing, and marketing; each with its own expertise and management system. Skilicorn et al [48] suggested that integration between common duckweed (Lemna minor) production and utilization of the biomass for feeding fish is the most simple system that might be developed, as both activities are carried out in the same environment and easy to interact with each other. There is a need for an organization that involves appropriate competence to make coordination among the stakeholders, managing their commitment and arranging socio-economic benefits for incentives. In lake water quality management, involvement

Figure 5. Growth and biomass productivity of minute duckweed (Lemna perpusilla) in an integrated cat fish cultivation pond [47].
of stakeholders of the environmental affair will be necessary, that consider water quality value as an incentive for this development.

Furthermore, aquatic plants grow dynamically in response to the environmental conditions, particularly weather. Therefore, there is an element of uncertainty in terms of production rate and quality which further hardens the effort to establish any standard procedure of production. It has particularly occurred in the growing stage which has to take place in an open space. This fluctuated biomass availability has to have an effective resolution, as it will make the business calculation difficult and further become a disincentive for participation in the development programs. Otherwise, it is suggested to develop a business scheme that includes contingency plans involving broader stakeholders and region, so that under unsuitable biomass production there would be commercial feed supply available to buffer the fish production system.

9. Conclusion
Phytotechnology utilize aquatic plants to rehabilitate open water, including lakes. The plant biodiversity offer various advantages that can be explored and through appropriate techniques. It is not only to solve lake environmental problems but also gives additional benefits that can become incentives for the execution of the rehabilitation programs. Such an effort that involve plants for lake water eutrophication abatement, besides eliminating nutrients from the water, the produced biomass can function as natural feed which replaces the commercial feed. Providing institutional scheme to organize all the potential benefits while encouraging all the stakeholders commitments are very important for the success of the phytotechnological implementation.

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