A sustainable aquaculture model in Indonesia: multi-biotechnical approach in *Clarias* farming

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**Abstract.** *Clarias* catfish is the second rank of Indonesian commodity after tilapia in the production of freshwater aquaculture. It is due to the biotechnical innovations in aquaculture for breeding and grow-out, as well as selective breeding of superior fish. Nowadays, *Clarias* farming is a promising business because of a large market available in line with food security, fish farmers’ welfare, and sustainable aquaculture. The objectives of this paper are to review the latest status of *Clarias* catfish, improvement technologies used, challenges, constraints, and strategies to increase and maintain national production. In terms of seedlings production, the existing technology is relatively well-established with available segmentation in fingerling production. As for grow-out, many innovations such as the use of probiotics, biofloc, aquaponics, RAS, and IMTA provide opportunities for various business scales. The availability of technology based on a biotechnical approach enables to improve and maintain the sustainability of national *Clarias* production. The progress of *Clarias* farming in the last decade should be suggested as a model for other potential species. It is recommended that genetically improved *Clarias* by utilizing the potential of local catfish should be applied to produce specific advantages for development in certain areas and to increase business productivity.

1. **Introduction**

*Clarias* catfish is the number two commodity after tilapia in the production of freshwater aquaculture in Indonesia. *Clarias* farming is developed because these species are easily cultured in the area with limited space and lack of water resources. In addition to the technical aspects, catfish have a broad market for consumption with segmentation in their farming process. From the health aspect, 100 g of catfish flesh contained 19.9 g of protein [1] which is only lower than snakehead with 25.5 g of protein per 100 g of the flesh [2]. The progress of national catfish production has shown significant results from 69,386 tons in 2005 to 1,771,867 tons in 2017. There was a significant increase compared to 2016 (764,797 tons). The biggest increase is in line with biotechnical innovations in aquaculture for breeding and grow-out, as well as catfish selective breeding program to produce superior fish for aquaculture efficiency, increasing profits, and increasing productivity. In addition, the national aquaculture business development program in the community also plays an important role to improve welfare, provide employment, and increase the productivity of *Clarias* farming.

Indonesia’s large population and the government’s effort to increase protein per capita are the market share that strongly supports the catfish production. This production continues to be driven for maintaining national food security and the increase of consumption levels which estimated to be 56.39
kg/capita in 2020 [3]. The objectives of this paper were to review the latest status of *Clarias* catfish, improvement technologies used, challenges, constraints, and strategies to increase and maintain the national production.

2. Material and methods

Literature study has been done in preparing this paper. All data and information used were collected based on available publication relating to the past and present status of *Clarias* farming inside the country and abroad. The data and information obtained were then constructed to synthesize the future prospective of *Clarias* farming in Indonesia. Together with recent advance technologies, an analyses to see feasibility of application was also considered to decide or propose strategies regarding to challenges, constrains, and problems faces.

3. Result and discussion

3.1. Status of *Clarias* catfish

The taxonomy of species originated from Africa has been revised [4], but not for species from Asia. According to Ng [5], nine species are known to be valid in Southeast Asia (Thailand, Vietnam, Cambodia, Malaysia, Philippines, and Indonesia), namely *Clarias anfractus* [5], *C. batrachus* [6], *C. batu* [7], *C. leiacanthus* [8], *C. macrocephalus* [9], *C. meladerma* [10], *C. nieuhoffii* [11], *C. olivaceus* [12], and *C. planiceps* [5]. However, the latest taxonomic study added *C. microstomus* [13], *C. intermedius* [14], *C. pseudonieuhoffii* [15], *C. pseudoleiacanthus* [16], and *C. kapuasensis* [16].

According to Gustiano et al. [17], there are 10 species of *Clarias* in Indonesia consisting of *C. nieuhoffii*, *C. meladerma*, *C. intermedius*, *C. pseudonieuhoffii*, *C. olivaceus*, *C. batrachus*, *C. leiacanthus*, *C. microstomus*, *C. pseudoleiacanthus*, and *C. kapuasensis*. Prior to population genetic studies, taxonomic revisions and phylogeny of catfish in Southeast Asia [18,19,20], the diversity of catfish species in Indonesia is not known. Many types of introduction to Indonesia confuse the people about certain species because the introduced catfish are known by their trade names. Therefore, it is very important to scientifically confirm the validity of catfish species which developed and cultured by the community.

Catfish farming had begun to develop since the mid of 1970s. Initially, fish farmers in Indonesia collected catfish fingerlings from nature, which are then raised in ponds for consumption purposes. Each area may have different cultured catfish species because each region had different species. However, it is believed to be *C. batrachus*.

In general, local catfish species have slow growth and small size. For this reason, some *Clarias* catfishes were introduced from other countries. In 1985, in collaboration with universities, African catfish was imported from the Netherlands. It is believed to have genetic resources from Kenya. Through the private companies, another *Clarias* was also imported under the following commercial names, "Dumbo" from Taiwan in 1985, "Paiton" from Thailand in 1998, and "Masamo" from Thailand in 2010. The government imported catfish from Egypt in 2007 and Kenya in 2011. After a comprehensive study on *Clarias* catfish, Iswanto et al. [21] stated that the introduced catfish ("Dumbo", "Paiton", and "Masamo") was *Clarias gariepinus* (Burchell 1822). The results of molecular genetic characterization of African catfish indicated that this species was still pure species without having any gene introgression from other species [22]. Meanwhile, the *Clarias* catfish from the Netherlands was likely the result of hybridization between *Clarias gariepinus* and *Clarias anguillaris* [23]. The above studies confirm that introduced *Clarias* catfish which has been developed and used for catfish farming in Indonesia is *Clarias gariepinus* (Burchell 1822).

From selective breeding, other efforts were made through the creating of polyploid fish [24,25], superior strains, and disease-resistant hybrids [26]. The national breeding program had been started in 2003. The aim was to improve the performance of cultured catfish that have been decreased due to poor broodstock management and improper farming methods. The product of selective breeding is focused on rejuvenation, hybrids, and new superior strains on growth to increase productivity. Nowadays, some products resulted from hybridization are widely used called as Sangkuriang,
Sangkuriang 2, and Mandalika catfish. Meanwhile, the new strain resulted from the selection is the Mutiare catfish [17].

3.2. Breeding technologies
Most of the tropical fish breed in the rainy season, from October to April. Stimulation arises from the submergence of dry soil by rainwater triggered the matured catfish to spawn. A pair of catfish which are ready for spawning will look for a nest to lay and maintain eggs until it hatches. Then, the fish farmers will collect the juveniles for grow-out.

Clarias catfish production technology had been started with natural spawning. In Indonesia, spawing technology with the new artificial system was carried out in 1988 [27]. The first successful spawning was conducted by using carp pituitary extract. It was dissolved with physiological solution and glycerin by 5-10%. Injections were carried out with a dose of 3, 6, and 9 mg/kg broodstock.

In the 2000s, new spawning technology was carried out by using the stimulation of Luteinizing Hormone-Releasing Hormone (LHRH) analogue combined with anti-dopamine. This reproductive hormone is relatively practical and efficient for the ovulation process. The slightly higher dose is recommended for application in domesticated fish as well as during out-of-season spawning. The stages of catfish hatchery activities are divided into broodstock management, induce breeding, and fingerlings production.

3.2.1. Broodstock management
Broodstock management consists of fish selection, maturation, and broodstock selection for breeding. On the process gonadal maturation, it should be conducted at the pond or container with the temperatures above 20°C [28]. Generally, the ideal size of broodfish for spawning activities is ranged from 500-1000 g or less than three years old. Matured broodfish can be observed morphologically. The matured female has the following characteristics: large belly, wider abdomen, swollen and reddish genital papilla, and ripen oocytes can come out if the stomach is pressed to the direction of the genital papilla. Meanwhile, the matured male has large, long, and reddish to the purplish genital papilla.

3.2.2. Induce breeding
Artificial spawning is carried out by hormone injection to the male and female broodfish in the left and right of the dorsal part. Male broodfish is injected once, while the female is injected twice with a six-hour interval by using Ovaprim with the doses ranging from 0.3 to 0.6 mL/kg. After the second injection, the male and female broodfish are put in a prepared pond for breeding. Artificial spawning can also be conducted with external fertilization by mixing eggs and sperm. Firstly, sperm is collected before the eggs. Contamination of urine and water must be avoided during sperm collection. Sperm of catfish can also be collected by dissection.

Immediately, the stripped egg is artificially fertilized with the prepared sperm solution. Artificial fertilization is carried out by pouring the sperm solution into a dry plastic basin containing eggs. Then, it stirred evenly with dry feathers until the sperm and egg are mixed. Fertilized eggs are washed with clean water and spread out to the tray or palm fibre with a stocking density of 50,000-100,000 eggs/m² (about 100-150 g eggs/m²) [29]. After fertilization, the critical period for egg development is about 8-10 hours. During this period, eggs should not be kept at the temperature less than 25°C. Water flow and aeration system should be provided to maintain the optimal hatching rate. The fertile and fully developed eggs appear to have clear look with the slightly brownish-green and reddish spots in the yolk part during 7-9 hours post-fertilization. Eggs begin to hatch about 18 hours after fertilization at 28-29°C. The larvae from hatched eggs need to be separated from unhatched eggs. The newly-hatched catfish larvae have attachment organs at the bottom of the stomach in the yolk sac, so that larvae are attached to the substrate or stick together with other larvae. Due to the attachment organ, catfish larvae is still placed at the bottom of the hatching tub because of their inability to swim, except if it forced by physical disruption. The newly hatched larvae are negative phototaxis, so that they gather and move into dark areas at the bottom corner of hatching tub. Attachment organ will disappear after the larvae
are two days old. At this time, the larvae are able to swim, the yolk-sac is almost fully absorbed, and the feed is required.

3.2.2. Fingerlings production
Post larva rearing can be conducted in an outdoor system by using fibre tanks, concrete ponds, and tarpaulin ponds, or in an indoor system by using aquariums. Juvenile rearing can be divided into four segments based on the harvested size of nursery phases [30]. Nursery I is the juvenile rearing from larval level to the 1-3 cm size. Nursery II carried out the juvenile rearing from 1-3 cm size to 3-5 cm size. Nursery III carried out the juvenile rearing from 3-5 cm size to 5-7 cm size. Lastly, nursery IV carried out the juvenile rearing from 5-7 cm size to 7-9 cm in size.

Before the activities, ponds should be dried, fertilized, and refilled by water. Drying pond aims to kill potential microbes and pests. Fertilization is carried out by using urea + TSP fertilizer with a ratio of 2:1 and a dosage of 40 g/m². Pond refilling is carried out with a gradual water level for optimal growth of natural live feed (rotifers). Prior to starting the rearing activities, the fish should be stocked at the same size, age, and broodfish in order to avoid cannibalism. The length can be classified as 1–2 cm, 2-3 cm, and 3-4 cm. Small size and poor quality of juvenile should be avoided due to slower growth and high feed conversion ratio (FCR). Rearing the same size of fish will simplify feeding management, homogenize growth, minimize cannibalism, minimize food, minimize competition, and make effective and efficient of the harvesting process. The recommended stocking density is presented in Table 1.

| Criteria                      | Unit                  | Nursery I | Nursery II | Nursery III | Nursery IV |
|-------------------------------|-----------------------|-----------|------------|-------------|------------|
| Initial stocking size         | cm                    | 0.5-0.7   | 0.5-0.7    | 1.3         | 1.3        | 3.5        | 3.5        | 5-7        | 5-7        |
| Stocking density              | fish/m²               | 2.000-2.500 | 2.000-2.500 | 1.000-1.500 | 1.000-1.500 | 500-1.000 | 300-500 | 500-1.000 | 300-500    |
| Feeding rate                  | % of biomass          | *)        | 10         | 5-10        | 5-10       | 3-5        | 3-5        | 3          | 3          |
| Feeding frequency             | times/day             | 2         | 2          | 3           | 3          | 3          | 3          | 3          | 3          |
| Survival rate                 | %                    | >75       | >75        | >75         | >75        | >70        | >70        | >80        | >80        |
| Harvested size                | cm                    | 1-3       | 1-3        | 3-5         | 3-5        | 5-7        | 5-7        | 7-9        | 7-9        |
| Uniformity                    | %                    | Min 75%   | Min 75%    | Min 75%     | Min 75%    | Min 75%    | Min 75%    | Min 75%    | Min 75%    |

Note: *) live feed (Tubifex) was given ad-libitum

Higher stocking densities will cause the deterioration of water quality. Technically, it can be handled quickly and easily through siphonization and water replacement. Fish can be fed one day after the stocking. Fish are fed by commercial pellets with 70-80% of satiation. Water quality should be maintained in good condition to support the success of catfish fingerlings production.

3.3. Grow-out
This section presents aquaculture technologies that are widely used in Clarias catfish farming.

3.3.1. Probiotics in Clarias catfish farming
The use of probiotics in Clarias catfish farming is aimed to make the fish grow naturally, healthy, and have a good quality of meat. Probiotics are used to fertilize the pond bottom while maintaining the water quality at the same time. This type of probiotic is applied by simply pouring into the pond water every two weeks in the morning to keep the good water quality and avoid the plankton blooms. The other type is probiotics for stimulating fish growth and increasing disease resistance and poor water quality tolerance through feed application. The good quality of yields is indicated by its excellent growth, uniformity, and free from muddy smell or taste. Clarias catfish farming by using probiotics mixed with feed showed a better feed conversion ratio than that of without probiotics [31].
Additionally, farming period with probiotics will be 10-15 days shorter compared with those of without probiotics (around 60-70 days) [32]. Probiotics application is relatively easy, namely by giving half a glass per day liquid probiotics for 1,500 catfish that are kept in 3 × 4 m tarpaulins [17]. The advantages of using probiotics in catfish farming are shown in Table 2.

| Advantage                        | Description                                                                 |
|----------------------------------|-----------------------------------------------------------------------------|
| Produced higher stocking density | Probiotic keeps the fish growth rate and health at optimal condition even though it is maintained at high stocking density because the feed mixed with probiotics contains high essential amino acids |
| Minimized disease and mortality  | The application of feed mixed with probiotics could reduce fish mortality    |
| Produced higher quality of catfish | Produced the catfish with good flesh quality and without weight loss         |
| Eco-friendly                     | Water pollution can be reduced because the feed source comes from natural sources which can also balance the water pH |

3.3.2. Clarias catfish farming with biofloc

Biofloc is a technology which utilizes the microorganisms’ activity to form flocks. The biofloc was not suddenly formed, but it needs to be formed under certain environmental conditions. These flocks consist of various aquatic microorganisms including bacteria, algae, fungi, protozoa, metazoa, rotifers, nematodes, gastrotricha, and other organisms that suspended with detritus. Biofloc can also be interpreted as a form of bonding by microorganisms in which it depends on the type of microorganism (Figure 1).

![Figure 1. The mechanism of bioflocs [33]](image-url)

Biofloc is widely applied in industrial wastewater treatment and fish farming systems. Biofloc systems can minimize the water changes because of its self-purifier system. Therefore, it will change the uneaten feed, faeces, toxic gases (i.e. ammonia and nitrite) into harmless compounds. Biofloc system is considered effective to boost productivity because more catfish can be farmed in a narrow space. Thus, it can reduce the production costs and rearing period compared with the conventional fish culture. In addition, a biofloc system in aquaculture is odourless and is very good for plant fertilizer.
The results of biofloc application showed improvement on water quality, productivity, feed efficiency, and cost reduction [34, 35]. The differences between biofloc and probiotic systems are in its stability and bacterial composition. Biofloc system is more stable than probiotic system regarding the environmental changes. Additionally, biofloc is mainly comprised of various beneficial microbial communities, but the action of some probiotics it contains is unknown. On the other hand, probiotics are single, known live microbial strains and their actions to the animals are well established. In Indonesia, some examples of biofloc application on *Clarias* catfish production had been performed at laboratory scale [36] and field scale, such as in Banyumas Regency [37], Pekalongan Regency [38], Yogyakarta Province [39], Bali Province [40, 41], Purbalingga Regency [42], Bogor Regency [43], South Lampung Regency [44], Bandung Regency [45], and Majalengka Regency [46]. Generally, those applications showed a positive impact of biofloc systems on *Clarias* production.

3.3.3. *Clarias* catfish farming with the Yumina-Bumina/Aquaponics system

Yumina-Bumina/aquaponics is a technology that utilizes the nutrient flow system from fish culture to grow plants. This technology is able to maintain the aquaculture environment in optimum condition through the mechanism of circulation, filtration, and nutrient utilization for plants [47]. The use of plants in Yumina-Bumina requires suitable plant species. Vegetables and fruits with annual crops are suitable for this system. In Indonesia, suitable and commonly used fish species for this system is tilapia, carp, and *Clarias* catfish. It should be considered that recommended fish feed/pellets for aquaponics system must contain certain fish nutrition requirement. The feeding ratio is a way to balance the components of the aquaponics system and calculate the planting area, fish feed, and fish biomass. Feeding ratio for aquaponics is 40–50 g/day/m² for vegetables and 50–80 g/day/m² for fruits. Cultured fish were fed 1–2% of body weight per day with the recommended stocking density of 10–20 kg/1,000 L of water. In the Yumina-Bumina system, plants were used to absorb nitrogen and phosphorus in waste water from uneaten feed and feces which is harmful for fish (Figure 2).

![Figure 2. Diagram of Yumina-Bumina/Aquaponics system [48]](image)

3.4. Recirculating Aquaculture System (RAS)

Recirculating Aquaculture System (RAS) is a way to intensify and improve efficiency in fish farming by using water recycling technology. Instead of the traditional method of raising fish outdoors (stagnant and running water ponds), this system maintains fish with high density in indoor tanks with a controlled environment. The recirculation system in RAS filters and cleans water for recycling into the rearing media. New water addition to the rearing media is only used to replace water loss due to reduction, evaporation, and disposal of waste material. Fish in the RAS system must be supplied with all of the requirements for their optimal growth and health condition. Fish need a constant supply of clean water at optimal temperature and dissolved oxygen for their growth. A filtration system by
utilizing microorganisms and biofilter is needed to purify water from hazardous waste products and feed residues. Fish must be fed with complete nutrition every day to encourage rapid growth and high survival rate. The benefits of RAS are fully controlled environment for fish, less usage of water, efficient energy use, efficient land use, optimal feeding strategies, easy to sort and harvest the fish, and control of the disease [49].

RAS is almost completely closed (Figure 3). In the RAS, the waste products can be in the form of solid waste, ammonium, and CO₂ which are then discarded or converted to non-toxic products by the system. Then, purified water was saturated with oxygen and returned to the fish tank. By recirculation, water and energy needs can be limited to a minimum. However, it is not possible to design a fully closed recirculation system. Non-degradable waste products must be discarded, whilst the evaporated water must be replaced.

**Figure 3.** The basic principle of RAS [49]

In Indonesia, *Clarias* catfish farming on recirculation system is still classified as new technology. The applied system was named as *Clarias* catfish farming in a tank recirculation system (C-First). This recirculation system makes the oxygen content and nitrification process even better for minimizing toxic compounds that are harmful to catfish. Thus, even if maintained with high stocking densities, the survival rate of catfish will remain high. Zeolites and charcoal as the mechanical filters in this system also help to reduce phosphate level until 0.021 mg/L. Therefore, fish metabolism will not be disrupted by the high content of phosphate. In addition, this system can also reduce the amount of water usage. In terms of productivity, through this recirculation system, farmers can increase productivity 100 times compared with conventional systems [50]. Recently, this technology is developed with the innovation of microbubble technology which can increase productivity by providing a more stable amount of dissolved oxygen in the water.

3.5. **Integrated Multi-Trophic Aquaculture (IMTA)**

Integrated Multi-Trophic Aquaculture (IMTA) is the answer to the main problems faced in the fisheries business, namely high feed requirements, high feed prices, and limited water sources. Those problems can be solved through the aquaculture activities with various types of aquatic biota which integrated based on their trophic level. Thus, the use of space, water, and feed resources will be effective and efficient (Figure 4).
In this IMTA technology, the waste produced from certain species can be an energy source for other species. Hence, in the end, this activity does not produce waste but produces aquaculture commodities that can be harvested as well as good quality of clean water for the environment. As carnivorous fish, *Clarias* need a lot of energy and produce a lot of waste which can be utilized as pond fertilizer. Other species can take advantage of fertile pond processes to increase aquaculture productivity. In terms of *Clarias*, the application of IMTA in Indonesia had been performed between African catfish *Clarias gariepinus* and sludge worm *Tubifex* sp. [52, 53]. In this system, water from catfish culture media flowed into sludge worm culture media. The results from the IMTA system showed improvement of African catfish and sludge worm productivity.

### 3.6. Challenge, constraints, and strategies

The major challenge in the future is how to maintain the catfish farming industry that currently has been developed. As the number one producer of *Clarias* catfish in the world, technological breakthroughs are always needed to increase productivity and profit margins since the fish price is relatively low. Moreover, for Yumina-Bumina/Aquaponics and RAS technology, these systems require a guaranteed and affordable electricity supply for production.

In terms of the strategy, it is important to create a national program for developing catfish farming in an integrated and holistic way. This action will be essential to face challenges and eliminate existing constraints. Technically, continuous efforts should be made to increase productivity through the application and development of existing aquaculture technologies, so that the productivity and profitability will be increased. Biologically, it requires the development of superior types of catfish that can increase productivity and profits in the future. Good farming methods must always be applied and monitored to support a sustainable catfish production system.

### 4. Conclusion

*Clarias* catfish farming is a promising business because of its large market availability to absorb the products. Aquaculture activities are developed with the existence of food security programs to increase fish consumption, increase the farmers’ welfare through business segmentation, and increase the opportunities for various business scales by utilizing diverse technologies. *Clarias* catfish farming with various biotechnical approaches can maintain the sustainability of national catfish production. Only by applying the right technology, the production system will be sustained. Production systems in catfish farming can be used as a model for other aquaculture commodities. It is recommended to find superior catfish by utilizing the potential of local catfish species. Therefore, it can be applied to produce catfish species with specific superiority for development in certain areas and improvement of
business and region productivity. The last, diversification product after harvest should be noted to keep the stability of price and added value on the post-harvest product.

5. References

[1] Doktersehat 2019 *Kandungan Gizi Ikan Lele Dumbo, Lele Segar, dan Lele Goreng* Retrieved from https://doktersehat.com/kandungan-gizi-ikan-lele [in Indonesian].

[2] Solahuddin G 2019 *Kandungan Gizi Ikan Gabus dan Manfaatnya Bagi Pengobatan, Kandungan Proteinnya Lebih Besar dari Daging* [in Indonesian].

[3] Nuraini D 2020 *KKP Bidik Peningkatan Konsumsi Ikan Nasional* Retrieved from https://ekonomi.bisnis.com/read/20200110/99/1188930/kkp-bidik-peningkatan-konsumsi-ikan-nasional [in Indonesian].

[4] Teugels G G 1986 *Annales-Musee Royal de l’Afrique Centrale. Sciences Zoologiques (Belgium)* 247 1-199.

[5] Ng H H 1999 *Raffles Bulletin of Zoology* 47 17-32.

[6] Linnaeus C 1758 *Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis* (Homiae: Laurentia salvii) p 824

[7] Lim K K P and Ng H H 1999 *Raffles Bulletin of Zoology* 47 157-168.

[8] Bleeker P 1851 *Nat. Tijdschr. Nederl.-Ind.* 2 193-208.

[9] Gunther A 1864 *Catalog of the Physostomi containing families Siluridae, Characinidae, Haplochitonidae, Sternoptychidae, Scopelidae in the collection of the British Museum, London* (London: Taylor & Francis) p 455.

[10] Bleeker P 1864 *Nat. Geneesk. Arch. Nederl.-Ind.* 3 284-293.

[11] Cuvier G and Valenciennes A 1840 *Histoire naturelle des poissons. Tome quinzième. Suite du livre dix-septième. Siluroïdes* (Paris & Strasbourg: Ch. Pitois & Ve Levrauld) p 540.

[12] Fowler H W 1904 *J. Acad. Nat. Sci. Phila.*(Ser. 2) 12 495-560.

[13] Ng H H 2001 *Zoological Studies* 40 158-162.

[14] Teugels G G, Sudarto, and Pouyaud L 2001 *Cybium* 25 81-92.

[15] Sudarto, Teugels G G, and Pouyaud L 2004 *Zoological Studies* 43 8-19.

[16] Sudarto, Teugels G G, and Pouyaud L 2003 *Cybium* 27 153-161.

[17] Gustiano R, Prakoso V A, Iswanto B, Radona D, Kusmini I I, and Ath-thar M H F 2020 *Biodiversity, Status, and Trend of Clarias Catfish Farming* (Bogor, Indonesia: IPB Press) p 88 [in Indonesian].

[18] Teugels G G, Gustiano R, Diego R, Legendre M, and Sudarto 1998 *Proceeding of the mid-term workshop of Catfish Asia Project* 41-46.

[19] Pouyaud L, Hadie W, and Sudarto 1998 *Proceeding of the mid-term workshop of Catfish Asia Project* 31-36.

[20] Sudarto and Pouyaud L 2005 *Jurnal Iktiologi Indonesia* 5 39-47 [in Indonesian].

[21] Iswanto B, Imron, Suprapto R, and Marnis H 2019 *Berita Biologi* 18 223-232 [in Indonesian].

[22] Sudarto 1999 *Prosiding Seminar Hasil Penelitian Genetika Ikan* 26-29 [in Indonesian].

[23] Anene N S and Gao T X 2007 *African Journal of Biotechnology* 6 1072-1076.

[24] Taufik P and Gustiano R 2000 *Biosfera* 19 97-100 [in Indonesian].

[25] Taufik P, Gustiano R, and Arifin O Z 2000 *Pros. Simp. Nas. Pengelolaan Pemuliaan dan Plasma Nufah* 577-581 [in Indonesian].

[26] Gustiano R and Taufik P 2003 *Sains Akuatik* 6 87-90.

[27] Zonneveld D, Rustidja, Viveen W J A R, and Mudana W 1988 *Aquaculture* 74 41-47.

[28] De Graaf G J and Janssen J A L 1996 *Artificial reproduction and pond rearing of the African catfish, Clarias gariepinus in sub-Saharan Africa: A handbook* (Rome, Italy: FAO) p 73.

[29] Iswanto B, Suprapto R, Marnis H, and Imron 2015 *Prosiding Forum Inovasi Teknologi Akuakultur* 95-102 [in Indonesian].

[30] Standar Nasional Indonesia 2014 *Produksi Benih Ikan Lele Dumbo* (Jakarta, Indonesia: Badan Standarisasi Nasional) p 6.
6. Acknowledgement

The authors thank I I Kusmini, B Iswanto, and M H F Ath-thar for their help in collecting materials to support the manuscript writing. Prof. G G Teugels, Dr. Sudarto, and Dr. L Pouyaud who worked together in the INCO.DC project “Catfish Asia” financed by the European Commission, for which we owe them a special thanks.