

# Bioresources and diversity of snakehead, *Channa striata* (Bloch 1793): a proposed model for optimal and sustainable utilization of freshwater fish

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**Abstract.** Among freshwater fishes in Indonesia, snakehead is an essential and valuable fish bioresources for a long time. Although breeding snakehead just started in the last decade, direct consumption, raw material for food industry and pharmacy/albumin source have already been developed earlier. This study outlines snakehead biological resources and their diversity, production trends and challenges, and understanding for strategic planning for its optimal and sustainable use. Of the 10 snakehead species in Indonesia, *Channa striata* is the most popular species. Although Indonesia's snakehead production contributes significantly to global production, the production of this species in the last three decades still depends on inland fisheries around 73-97%, and the rest comes from aquaculture. Therefore, the decline in snakehead production occurs because of over-exploitation, seasonal influence and high vulnerability of the species to climate change. Bioresource flow model (BRFM) is proposed to optimize the use of snakehead to provide strategic planning for further development. This model includes a domestication program for aquaculture and conservation, hatchery production, an alternative understanding of snakehead aquaculture production systems, biotechnological improvement processing for albumin production, and wastewater treatment management.

## 1. Introduction

Indonesia is a rich country in freshwater fish bioresources based on the existing genetic resources and its diversity. To preserve bioresources richness, it needs optimal and sustainable use of the available fish genetic resources through proper management and appropriate approach [1]. Most freshwater fishes are protein resource for the people in the country with a demand that increases year by year, about 55.95 kg/cap in 2019 [2]. In term of freshwater fish bioresources, tilapia is an excellent example of success for cultivated freshwater species not only for direct consumption, but also for fillet and other products [3-5]. Among freshwater fishes in Indonesia, snakehead, with ten species in the group, is an essential and valuable species for a long time [6]. The exploitation of snakehead was commercially started in 1990 but breeding snakehead has established in the last decade. Snakehead production was mainly collected from inland fisheries around 92.8%, and the remaining was from aquaculture [7]. Thus, if this situation is still going on, the wild bioresources of snakehead will be threatened due to over-exploitation. The snakehead aquaculture has not optimally developed as the spawning activity of brood stock was very much influenced by the seasonal condition. Thus, the seeds could not be produced out of spawning season in contrast to tilapia or catfish aquaculture which are able to produce seeds all year round.

The essential value of bioresources for society is to provide nutrition, but it commonly involves specific processes releasing harvest residues, by-products and wastes [8]. Similarly, in snakehead aquaculture, the use of commercial feed as the main input to accelerate fish growth can release organic waste, uneaten feed, and nutrients to the aquatic ecosystem. Snakehead bioresources are not only utilized for fish food consumption [9] and ornamental fish [10], but also pharmaceutical materials, such as Albumin and Striatin [11]. Concerning the essential substances of snakehead, it is urgently needed to propose the optimal and sustainable utilization of this excellent bioresources. The application of bio-resource flow model (BRFM) has been widely implemented in integrated agriculture and aquaculture



systems to improve sustainable utilization of bioresources [12,13]. A bioresource flow model presents interactions of the essential components and enterprises through the integrated system considering biological, economic and environmental aspects [14]. This model was also successfully implemented in algae-based biofuels [15], and municipal wastewater sludge [16]. To support implementation the BRFM in snakehead aquaculture, investigation of bioresources and diversity of the snakehead were explored as well as its production and challenges. Thus, this paper discusses snakehead bioresource and diversity, existing production, and strategies for optimal and sustainable utilization of snakehead.

## 2. Diversity and potential bioresources of snakehead

Snakehead species belong to the family Channidae, a lineage of freshwater fishes that is characterized by usually having air-breathing ability given the presence of the supra-branchial organs. The snakehead family has general characteristics including elongated body, protruding lower jaw, dorsal and anal fins with many rays, abdominal fin having 6 soft spines, no hard spines on fins, and ctenoid or cycloid scales [17]. There are two genera of snakehead including *Channa* with 39 species distributed in Asia, and *Parachanna* with three species can be found in Africa [18]. In Indonesia, snakehead was first documented by Weber and Beaufort [19] with 11 species. Saanin [20] reported that there are only ten species of snakehead found in Indonesia. This finding was supported by Kottelat *et al.* [21] that also found ten species of snakehead with revised names from previous documentation (Table 1). Seven of the ten species in Indonesia, namely *C. bankanensis*, *C. gachua*, *C. lucius*, *C. maruloides*, *C. micropeltes*, *C. pleurophthalmus*, and *C. striata*, are molecularly separated based on the study by Xia *et al* [22]. Eight of the ten species, namely *C. bankanensis*, *C. gachua*, *C. lucius*, *C. maruloides*, *C. melanopterus*, *C. melasoma*, *C. micropeltes*, *C. pleurophthalmus*, and *C. striata*, are already have barcode for identification [23].

**Table 1.** Species diversity of snakehead distributed in Indonesia.

| No | Species                                     | Common name                         | Distribution   |
|----|---|-------------------------------------|--|
| 1  | <i>Channa bankanensis</i> (Bleeker 1853)    | Bangka snakehead                    | Indonesia (Kalimantan and Sumatra) and Malaysia                                  |
| 2  | <i>Channa cyanospilos</i> (Bleeker 1853)    | Bluespotted snakehead               | Indonesia (Sumatra) dan Malaysia   |
| 3  | <i>Channa gachua</i> (Hamilton 1822)        | Dwarf snakehead                     | Indonesia, Malaysia, South East Asia, China, Southern Asia, Afganistan, and Iran |
| 4  | <i>Channa lucius</i> (Cuvier 1831)          | Splendid snakehead                  | Indonesia, Malaysia, and Indo-China  |
| 5  | <i>Channa maruloides</i> (Bleeker 1851)     | Emperor snakehead                   | Indonesia (Sumatra and Kalimantan), Malaysia, and Southern Thailand              |
| 6  | <i>Channa melanoptera</i> (Bleeker 1855)    | Blackfinned snakehead               | Indonesia (Sumatra and Kalimantan).  |
| 7  | <i>Channa melasoma</i> (Bleeker 1851)       | Black snakehead                     | Indonesia (Sumatra, Kalimantan) Malaysia, Thailand, and Kamboja                  |
| 8  | <i>Channa micropeltes</i> (Cuvier 1831)     | Giant snakehead                     | Indonesia (Kalimantan and Sumatra), Malaysia, and Indochina.                     |
| 9  | <i>Channa pleurophthalma</i> (Bleeker 1851) | Ocellated snakehead                 | Indonesia (Kalimantan and Sumatra)   |
| 10 | <i>Channa striata</i> (Bloch 1793)          | Chevron snakehead/Striped snakehead | South-East Asia to Southern Asia   |

References: Froese and Pauly [18], Courtenay and Williams [24], Benzinger [25]

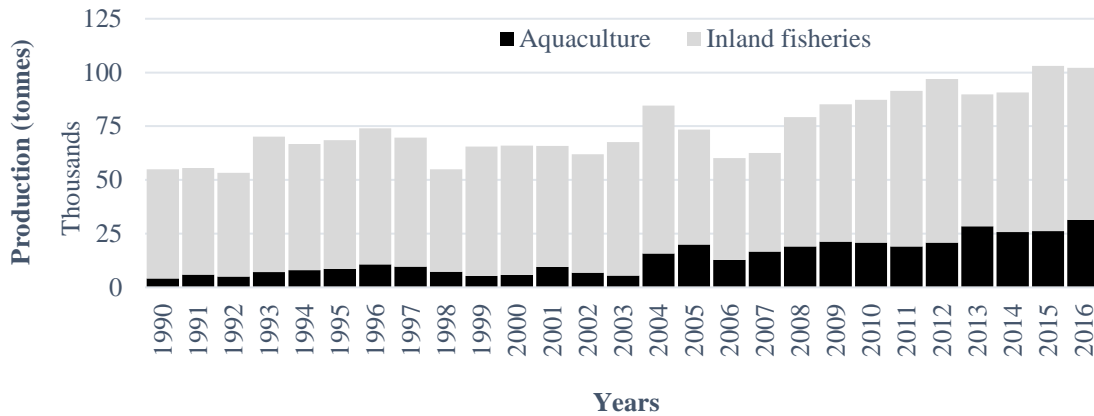
Some species of snakehead are relatively moderate-sized with adults usually about 17cm in length, while other species are large-sized and can reach up to 1.8m [24]. All snakehead species are carnivorous and predators that primarily feed on other freshwater fishes. Some species of snakehead have beautiful coloration, so they are more popular as ornamental fishes. In Asia, snakehead is one of economically important fishes both in capture fisheries and aquaculture.

Comparing among ten snakehead species in terms of their potential bioresource (table 1), *Channa striata*, locally known as 'gabus' or 'haruan', is the most popular species of the genus *Channa* as this species has been commonly consumed in Indonesia. This species also widely distributed in other Asian countries including Malaysia, Philippines, Thailand, Vietnam, Cambodia, India and Bangladesh [26]. *Channa striata* is a commercially important fish, fast-growing, and highly potential for aquaculture development [27]. Thus, research of this species is more frequently conducted in some countries to establish hatchery production and aquaculture development. Research of *C. striata* was first reported by Wee [28] and followed by Boonyaratpalin *et al.* [29]. Investigation of snakehead aquaculture development was published by Muntaziana *et al.* [30] in Malaysia, Truong *et al.* [31] in Vietnam, and Kusmini *et al.* [9] in Indonesia. In the last decade, snakehead aquaculture has started to grow, especially for commercial-scale hatchery production and grow-out farming for fish food consumption. In addition, the higher nutritional and pharmaceutical value of the fish has increased market demand of the species. Mustafa [32] reported that the snakehead extract from Indonesia contains  $2.17 \pm 0.14$  g albumin/100mL that is beneficial for hypoalbuminemia, post-surgical patients, and growing children. This species also is known as the resource of striatin containing 10 essential and 7 non-essential amino acids, fatty acids, vitamins A and B6, and other essential substances that are potential for wound healing and improving albumin level [33].

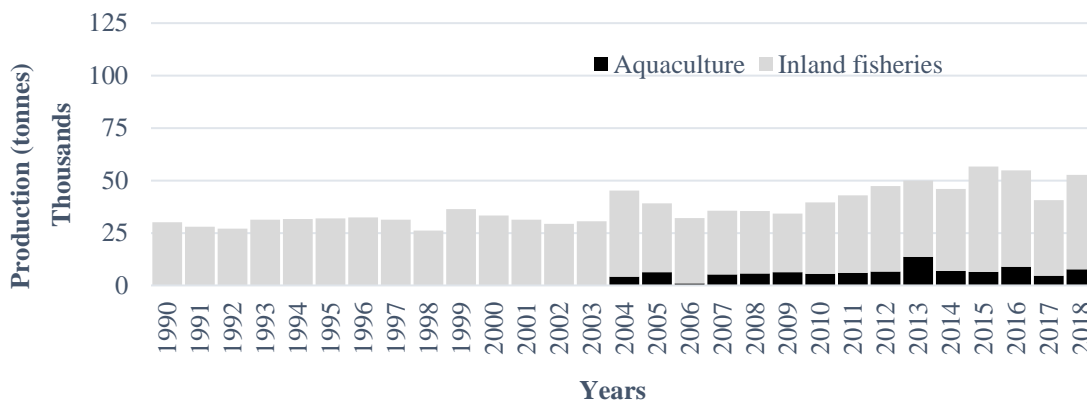
The second most popular species of snakehead in Indonesia is the giant snakehead *Channa micropeltes*, locally known as Toman, distributed in inland freshwater habitats in Sumatra and Kalimantan. This species is potential to be developed for aquaculture as it is more fast-growing species than *Channa striata*, economically valuable and has a prospective market for fish consumption and ornamental fish [6]. Albumin content of the giant snakehead is an essential factor for prospecting the species to be used for pharmaceutical industries [34]. Moreover, Sharif *et al.* [35] reported that the giant snakehead has potentially used for the source of enzyme for insecticides detection. Apart from *C. striata* and *C. micropeltes*, the other species of snakehead have been commonly utilized for ornamental fish commodities such as *C. gachua* and *C. pleurothalma*. Thus, further investigation is needed to reveal the potential bioresources of snakehead for sustainable utilization.

### 3. Trend of snakehead production from inland fisheries and aquaculture

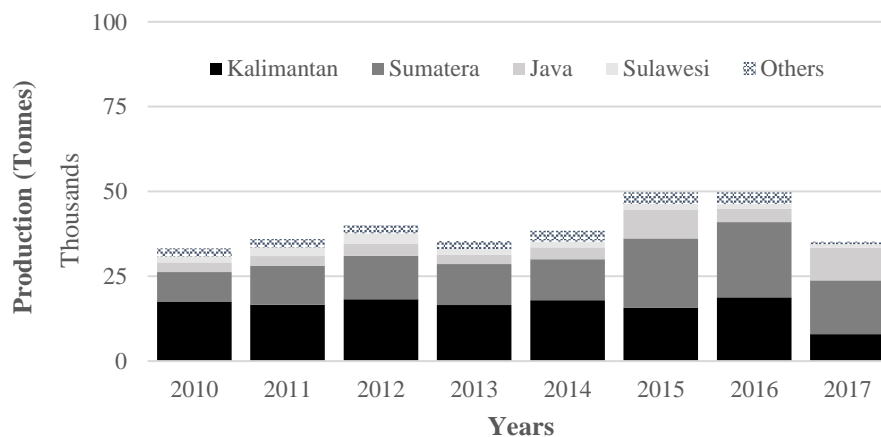
Based on Food Agricultural Organization statistic, global production of snakehead in the last decades increased from 54.942 tons to 102.166 tons during a 1990-2016 period which the largest production was contributed by inland fisheries (figure 1). Inland fisheries production was reported by four countries including Indonesia, Thailand, Philippine, and Tajikistan, while aquaculture production was contributed by 11 countries including Indonesia, Thailand, Philippine, Malaysia, Singapore, Bangladesh, Cambodia, Sri Lanka, Hongkong, Kazakhstan and Uzbekistan. In Indonesia, snakehead includes in the 10 most common freshwater species that significantly contributed to freshwater fish production [7]. Snakehead production from Indonesia provides a significantly important contribution to global production increased from 30.155 ton to 52.638 tons during a 1990-2018 period (figure 2). This indicates that Indonesia is one of the largest producers of snakehead contributed around 33-55% of the global snakehead production. However, Indonesian snakehead production was mainly dominated by inland fisheries around 73-97%, and the remaining was from aquaculture. Aquaculture production for this species was first reported in 2004 as the farmers commonly reared the natural seeds from wild habitat (ranching).



**Figure 1.** Comparison of global inland fisheries and aquaculture production for snakehead (*Channa striata* and *Channa spp*) reported to FAO from 1990 to 2016



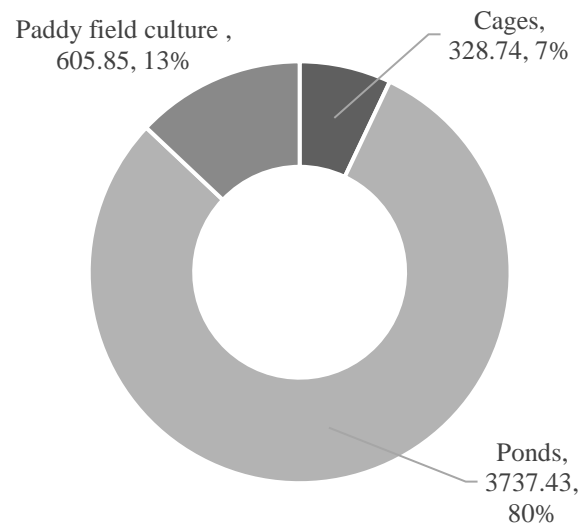
**Figure 2.** Comparison of Indonesian inland fisheries and aquaculture production for snakehead (*Channa striata* and *Channa spp*) reported to FAO from 1990 to 2018 (Source: FAO fishstat and MMAF statistic).



**Figure 3.** Comparison of snakehead production in inland fisheries based on regions from 2010 to 2017.

Kalimantan is the largest producer of snakehead followed by Sumatera and Java regions (figure 3). The snakehead production from these regions was reported around 86-95% of total production from 2010 to 2017. Snakehead can reach high productivity in farming practice and can be cultured with

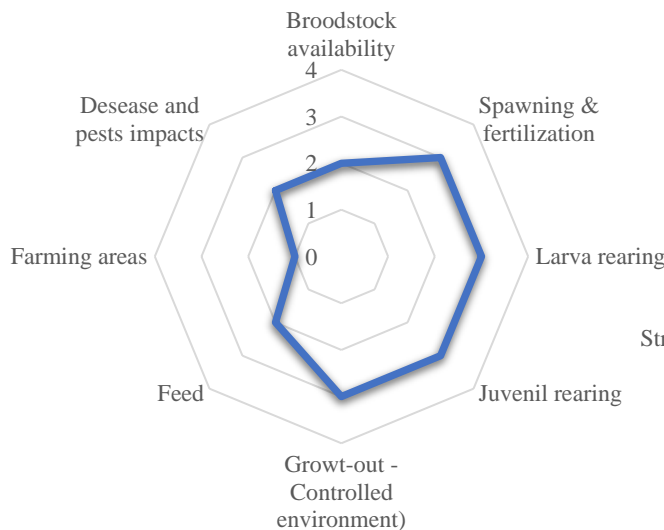
different systems, including the earthen pond, cage, ditch, and paddy field culture systems. Cultured snakehead reared in the ponds (80%) is the highest production, followed by paddy fields (13%) and cage culture systems (7%) (figure 4).



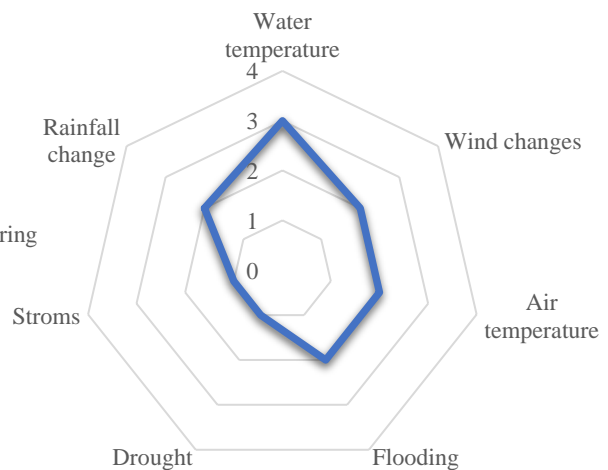
**Figure 4.** Snakehead production based on the different culture systems in 2017.

#### 4. Challenges of snakehead production

Although hatchery production has already established in some regions, the production of snakehead is much influenced by the season. In Indonesia, the peak season for snakehead spawning commonly occurs once in a year between July and January [36,37]. Moreover, it was more challenging as climate change impacts the regular condition by causing a high fluctuation of temperature and extreme seasons, which eventually impact the biological aspects resulting in unpredicted patterns of reproduction and spawning seasons [38]. Climate change also affects on rainfall pattern, droughts, water and air temperature fluctuation, low growth rate, disease outbreak and low survival rate of fish [39]. As these situations occurred, farmers need to change seed production period, delayed seed harvest and selling periods and used high-quality brood-stock [40]. To deal with this issue, Gustiano *et al.* [38] suggested the use of hormone induction out the spawning season to control maturation on snakehead reproduction to enhance brood-stocks maturation as in the spawning season. Investigation using vulnerability assessment on climate change revealed that snakehead performed the highest vulnerability on climate change as compared with tilapia and African catfish [41]. Aquaculture attributes used to assess the risk level of climate change on aquaculture shown in figure 5. In snakehead capture production, seven factors impact on production including water temperature, rainfall change, wind change, air temperatures, flooding, drought, and storms (figure 6).



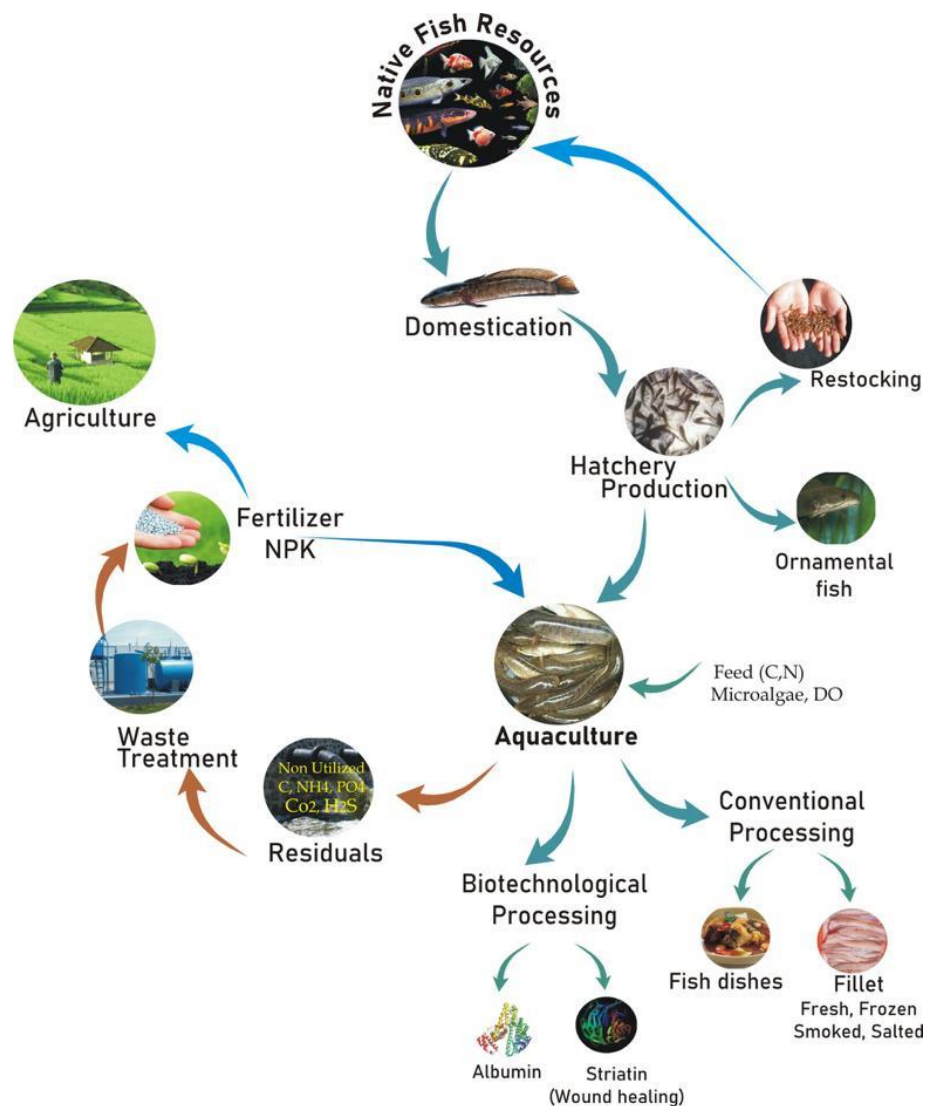
**Figure 5.** Vulnerability assessment of snakehead aquaculture due to climate change calculated based on Doubleday *et al* [42]. The value of 1: low sensitivity level, 2: medium sensitivity level and 3: high sensitivity level.



**Figure 6.** Vulnerability assessment of snakehead collected from capture fisheries due to climate change based on Huong and Trinh [43]. The value of 1: low sensitivity level, 2: medium sensitivity level and 3: high sensitivity level.

### 5. Bioresources flow model for optimal and sustainable utilization

Freshwater bioresources comprise various species which inhabit naturally in the inland water environment and include the fish species cultured in the outdoor or indoor facilities. Utilization of bioresources by harvesting native freshwater fish in natural habitat commonly decreases populations of species. This condition has been deteriorated with water pollution, habitat degradation and fragmentation, invasive species, and climate change that also threat fish biodiversity of inland waters [44]. Therefore, aquaculture plays an important role to incorporate breeding and growing aquatic organisms for better production. Here, we propose a strategic investigation for improving sustainable utilization of snakehead based on a bioresource flow model (figure 7). The utilization program includes improving domestication program, hatchery production, aquaculture production system, biotechnological processing, and wastewater treatment. The target of this program is to gradually convert captured fisheries production of snakehead to sustainable aquaculture production.



**Figure 7.** Bioresources flow model of the snakehead *Channa striata*.

### 5.1 Domestication program for aquaculture and conservation

Considerable growth of aquaculture production has significantly relied on the success of fish domestication [45]. Domestication provides an adaptation of wild fish to the captive environment that consistently controlled from brood-stock maintenance, reproduction, larva rearing and growth [46, 47]. The selected fish for domestication program commonly relies on growth, survival rate and flesh colouration [48]. Moreover, recently, fish selection has been developed to the exploration of new bioresources that possibly contain potential raw materials for pharmaceutical, supplement and nutritional values. The snakehead *Channa striata*, for instance, has been recognized not only as one of potential aquaculture species but also it contains albumin and striatin for pharmaceutical raw materials [33,49]. In addition, other snakehead species has been known as ornamental fish and used for restocking in its natural habitat for conservation programs. However, restocking of snakehead to the natural habitats has been recommended only for native snakehead species, which are known to previously inhabit the natural habitats in the pertinent area to be restocked where these species each serve a role as a predator. The domestication program of snakehead in Indonesia has been successfully conducted for *Channa striata* to improve brood-stock performance in the captive environment [50,51]. To explore benefits of

other snakehead bioresources, it is important to conduct the domestication program for nine remaining members of snakehead.

### 5.2. *Establishing hatchery production*

Establishing hatchery production is one of essential factors in the success of snakehead production. A hatchery is commonly designed based on annual target production of fingerlings which impact on the hatchery size, technical design and investment plan. Main facilities in the hatchery include quarantine tanks, broodstock tanks, spawning tanks, larval rearing tanks and live food tanks while supporting facilities are laboratories, and manpower rooms [52]. Hatchery business is classified in three levels, including small, medium and large scales differentiated based on biological aspects, cost and income variables [53]. A small scale hatchery is mainly concerned on larval rearing and nursery aspect to grow larva to fingerlings, while medium and large scale hatcheries involve in holding broodstock, spawning and hatching eggs, growing seeds from larva to fingerling [54]. Hatchery technology mainly is correlated with water treatment technology, spawning technics, and feeding technology. Most medium-scale hatcheries implement recirculating aquaculture system (RAS) to hold broodstock, to incubate eggs, to grow larva and fingerlings. In the hatchery, snakehead can be spawn naturally to produce seeds, then the seeds were collected and separately reared. A broodstock can produce 1,000-1,500 seeds and they commonly reach the weight of 1 kg (Feed Conversion Rate/FCR about 2.0) in a year reared in the pond fed with commercial feed (protein 30%) [6].

Improving snakehead hatchery production through artificial breeding has been done by many researchers. Hormonal treatments to accelerate brood stock maturation were implemented in snakehead for better hatchery production [51,55]. Quality of snakehead seeds is an essential factor for rearing process of cultured fish in the aquaculture production system. To improve growth performance of snakehead, investigations were carried out to evaluate effects of water hyacinths and probiotics [56], larvae rearing in green water systems [57] and water quality and biological performances [58]. The fingerlings produced in the hatchery can be distributed to the aquaculture production system, ornamental fish or restocking to the natural habitat.

### 5.3 *Alternative aquaculture production systems for improvement of snakehead production*

Snakehead commonly was cultivated in earthen ponds, plastic ponds, or cages. In this conventional culture, the fish generally was harvested over 4 to 6 months culture period with the size 5-8 fish/kg [6]. Various aquaculture production systems basically can be implemented for snakehead aquaculture, including cages, tanks, and raceways. To improve the production of snakehead, ponds and tanks cultured systems can be combined with bio-flock technology, aquaponic, or recirculating aquaculture system (RAS), while cage systems are combined with integrated multitrophic aquaculture (IMTA). Bio-flock technology, consists of heterotroph microorganism, has been recommended in aquaculture to improve sustainable production of the cultured fish [59]. It has been implemented well in aquaculture production to create economic and environmental benefits through the high quality of live feed supply, minimal water use, effluent discharges, and improved biosecurity [60]. Shrimp farming industries in Belize, Indonesia, and Malaysia are examples of the success of bio-flock implementation commercially [61]. The application of bio-flock technology has also successfully developed in catfish and tilapia aquacultures [62,63]. Snakehead potentially can be cultured in the aquaponic system as this species is recognized as more tolerant in different water quality levels. Catfish is one of cultured species successfully cultivated in aquaponic system in various level of ammonia and dissolved oxygen as well as at high stocking density [64]. However, snakehead reared in high stocking density must be combined with shelters with enough feed overtime as this species has cannibalistic behaviour and a predator. Aquaponics is an integrated production system to produce fish and plants in a closed system combining recirculating water and hydroponics systems [65]. Aquaponic is environmentally sustainable technology to improve aquaculture production as it can reduce land and water uses. In addition, optimal biomass production from fish and plants meets the nutrient requirement in the system [64]. An alternative culture system for snakehead is the implantation of Recirculating Aquaculture Systems (RAS). RAS has been



widely implemented in the intensive aquaculture production system, both indoor and outdoor areas [66]. The system optimizes fish production with concern on environmental sustainability as the technology only needs less water and land usage and reduces significantly waste to water environment [67, 68]. This system can be implemented in different stages of aquaculture production from breeding, fingerling, to growing fish. Some commercially cultured fish species, both marine and freshwater including Gilthead sea bream, Rainbow trout, Barramundi, Tilapia, and African catfish have been successfully cultured in this system [67]. The other technology recommended for snakehead aquaculture is integrated multitrophic aquaculture (IMTA). The system has been mainly implemented in marine and freshwater cages aquaculture. IMTA minimizes disposal waste from fish culture to the environment as the remained waste are consumed by alga and shellfish. The sustainability of aquaculture based IMTA found significantly increase through recycling of waste nutrients from higher-trophic-level species into the production of lower trophic-level [69].

In addition, beside various aquaculture production systems used for sustainable production of the fish, water quality management based probiotic application are simple and reasonable methods for improvement snakehead production. Probiotics enhance growth, nonspecific immune responses, disease resistance, and fish survival [70]. The use of probiotics mixed in commercial feed or directly added to water of the pond stabilize water quality, enhance growth and immune response of the fish [71]. This method has been implemented well in catfish aquaculture as the probiotics containing *Bacillus subtilis* and *Streptococcus lentus* able to decrease the population of *Aeromonas hydrophila*, increase survival rate and immune response of catfish [72]. Catfish production based probiotic application presents excellent production indicated by fast growth, uniform size, no muddy smell as well as short cultivation days [73].

#### 5.4 Wastewater treatment management

The intensification of aquaculture has provided viable solutions for increasing aquaculture production system. However, it generates increasing inputs on the ponds such as artificial feed, organic and anorganic fertilizers. The impact of aquaculture waste has increased public concern and threatened natural habitat and its biodiversity. Similarly, in a fish processing field, wastewater management also has a great concern public interests [74]. Thus, methods of waste management in different culture systems need to established for sustainable aquaculture production [75]. Stevenson *et al* [76] recommends the implementation of integrative aquaculture and agriculture systems (IAAS) to reuse water and nutrients to promote sustainability of fish production. IAAS refers to production, integrated management and comprehensive use of aquaculture, agriculture and livestock including rice/fish, poultry/fish or polyculture farms to reduce external inputs and improve cultured fish production [77]. Based on bioresources flow model approach (figure 7), fish waste or residuals can be used as sustainable organic fertilizer for agriculture purposes. The evaluation of compost from fish waste to horticultural plants is save, mature, and stable in the growth of ice lettuce (*L. sativa*) and it presents essential impacts on increasing contents of nitrogen, phosphorus, potassium, sodium, calcium, and magnesium in leaves [78]. The other study reported that application of fish waste on Spinach (*Spinacia oleracea*) can reduce the cost from commercial N fertilizer in both conventional and organic farming [79].

#### 5.5 Improvement biotechnological processing for albumin production

The next process of improving optimal utilization of snakehead production is conventional and biotechnological processing. Conventional processing of snakehead has been already established as fresh, fillet [80], smoked [81] and salted products [82]. Conventional fish processing commonly was conducted based on reducing water content of products to inhibit the growth of microorganisms which extent shelf life of fish products [83]. On the other hand, application of biotechnological processing on snakehead in albumin production has started to be developed recently. This method was conducted to investigate albumin and nutrient contents of snakehead such as fatty acids, total protein, yield, and dry basis water concentration. Asfar *et al* [84] suggested that the use of extraction method using HCl 0,1 M solvent with heating at temperature of 50-60°C implemented in snakehead produced the highest albumin

around 20,80% of the flesh. This method is better than the treatments using variation of solvents, including distilled water, HCl 0.1M, and NaCl 0.9 % that created the highest albumin, around 7.65 % [85]. Investigation of albumin content of native, cultured and reared Indonesian snakehead *C. striata* was  $70.10 \pm 18.03$  mg/g to  $107.28 \pm 3.20$  mg/g; and  $66.74 \pm 3.76$  mg/g to  $63.44 \pm 9.33$  mg/g, respectively [86]. These studies indicated that processing technology used in albumin production needs to be improved for optimal utilization of snakehead.

## 6. Conclusion and recommendation

As an economically important species, *Channa striata* is a very productive commodity for aquaculture. The superiority of *C. striata* is the variety of products. In the future, we must take over the supply of this species from fisheries activity to cultivation to reduce relying on wild-caught snakeheads from natural habitats. Through appropriate breeding technology and a good strategic breeding plan, it is possible to increase seed production from hatcheries to supply enlargement activities and to restocking natural populations. The synergy of the two activities is expected to be able to maintain a sustainable production flow. Advances in cultivation technology must be implemented immediately to increase productivity and profits not only improvement in breeding technology, but also in fish feed management, fish health and wastewater treatment management. Intensification and integration of snakehead aquaculture with other sectors for environmentally friendly purposes are highly recommended for development. In terms of biopharmaca products, albumin, its competitiveness must be enhanced by a new biotechnology approach and finding new prospective candidates that are more prospective in the *Channa* group.

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