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Breeding Technology as a Tool for Sustainable Aquaculture Production and Ecosystem Services

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Aquaculture is the aquatic equivalent of agriculture. While agriculture is predominantly based on the use of freshwater to grow crops, aquaculture utilizes freshwater (i.e. inland waters) and brackish water/seawater (i.e. coastal waters) to culture fish, plants, shellfish (bivalve, abalone, sea urchins and sea cucumbers), macro and microalgae. The increasing scarcity of captive aquatic fisheries resources has led to the regenerative farming practices of aquaculture. Aquaculture is the fastest-growing food sector in the world and about the most important means of providing sustainable food production currently. Among the several aquaculture techniques used, breeding technology has been exploited to improve food production. Beyond captive production, breeding technology has also been exploited for restocking programs of many aquatic ecosystems (i.e. rivers, lakes, sea, estuaries, etc.), hence, contributing positively to their management and ecosystem services. This comment, therefore, highlights some breeding technology as regards to their ability to improve sustainable captive production and aquatic ecosystem services.

Keywords: aquaculture, food production, food security, shellfish, stock enhancement

INTRODUCTION

Agriculture and Aquaculture play an important role in sustainable food production. As the world population continues to increase with a 10 billion projection for 2100 (UN, 2019), the need for sustainable food production cannot be overstated. This has implications for land use; hence, commercial agriculture activities could be limited by the non-availability of arable land for the cultivation of crops. Aquaculture activities, however, can be done in both inland (i.e. land-based, or different freshwater ecosystems) and coastal areas/waters (mostly brackish water, oceans and deep sea waters). Consequently, the increasing scarcity of limited natural resources (such as freshwater, land, capital, etc.) has placed aquaculture in a unique state to be considered as a regenerative farming practice (Bawden, 2020). Given the various challenges facing the inland aquaculture production and system (i.e., competitive use of freshwater with humans and other industries, effluent discharge and eutrophication problems), there is an increasing need to facilitate coastal aquaculture activities to accelerate the production of seafood (Jerneck and Olsson, 2014). The sustainable production of aquaculture products (i.e., production of healthy aquatic food without causing environmental degradation), therefore, is key to sufficient food production and efficient deliveries of ecosystem services as we aim to alleviate hunger and ensure food security (Costello et al., 2020; Mah et al., 2020).

FAO had defined ecosystem services [1]as the direct and indirect contributions of ecosystems to human wellbeing. Previous studies had shown that food production could be negatively (i.e. not always linear) or positively correlated with the ecosystem services (Firbank, 2009; Firbank, 2012). Generally, aquaculture production provides different ecosystem services, namely: i) provisional services (production of seafood), ii) habitat and supporting services (maintaining/enhancing population diversity) and iii) cultural services (recreational fishing or employment) (Gentry et al., 2020). Costanza et al. (2014) had shown that the ecosystem services provided by the marine environments and other related coastal activities amount to USD 50 trillion per year. Thus, incorporating various aquaculture technologies, (such as breeding technology) in the achievement of sustainable seafood production and improvement of ecosystem services should be a top priority for scientists, farmers, and aquaculture entrepreneurs.

Improvement of breeding technology is essential to promoting sustainable food production and contributing to ecosystem services. In this perspective, we summarise how the application of breeding technology could lead to sustainable seafood production without detrimental environmental implications but result in improved biodiversity and mitigating species extinction which further jeopardizes food security. We describe herein a few important breeding technologies that are considered relevant to ensuring sustainable aquatic production and improvement of ecosystem services of seafood.

THE ROLE OF BREEDING TECHNOLOGY IN AQUACULTURE

Improving seafood production to meet the health needs and ensure the sustainability of production will require significant improvement in breeding technology. FAO defines breeding [2]as the process of sexual reproduction (i.e. attaining maturity) and production of offspring (i.e. juvenile/seed). Technology[3], on the other hand, is defined as the practical application of scientific knowledge. Thus, breeding technology can be defined as technological innovation (i.e. practical knowledge) of culturing an animal with an intent of enhancing its reproduction (i.e. sexual maturity) and increased production (i.e. number of seeds produce). The goal of breeding aquatic species has gone beyond the mere objective of just increasing food production and quality, to providing sustainable, productive, and more environmentally friendly approaches. Traditional breeding techniques (such as inbreeding practices, selective breeding etc.) could take years to become established depending on the species' fundamental biology and culture technologies (Miller and Atanda, 2011). Thus, advances in currently used breeding technologies could be attributed to the rapid development of aquaculture production. There are several ways breeding technology significantly contributes to sustainable aquaculture production and ecosystem services. We searched the available literatures at the newly updated version of the Web of Science (WOS) Core Collection database[4], to identify the impact of breeding technology on aquaculture production and ecosystem services.

Our finding shows that most of the breeding technologies (in about 40% of the literatures on WOS) that have significantly impacted aquaculture production in the last decade had focused on genetic improvement. Breeding technologies leading to genetic improvement are advanced concepts that describe several activities aimed at transferring the superior genetic variability from parents on to the next generations. These techniques include genomic selection, marker-assisted selection, crossbreeding, hybridization, sex reversal, chromosome set manipulation, stem cell technologies, sperm cryopreservation transgenesis among others (FAO, 2018a). Most domesticated cultured aquatic species (such as salmond, crabs, oysters, shrimps, prawns etc.), have been genetically improved using breeding technology compared to other land animals or plants (Duarte et al., 2007). Thus, advances in genetic breeding are promising in ensuring sustainable seafood production of many aquaculture species.

To meet the increasing demand for seafood both for the national or international markets, there should be renewed interest to improve marine aquaculture production and productivity. Thus, through the adaptation of artificial breeding (i.e. artificial propagation of aquatic species through hypophysation), seafood production can be improved. The establishment of induced breeding (i.e. artificial reproduction) practices for seed production has been developed for various fish/shellfish species either as new aquaculture candidates or for well-established aquatic species already cultured on a large scale (Ranjan et al., 2018; Szabó et al., 2019). This is made possible by the administration of natural or synthetic hormones which speed up the processes of gonadal maturation (Muhd-Farouk et al., 2016). Inducing the maturation of cultured species can significantly affect the reproduction status of the animals, thus reducing the maturation time. Hence, any cultural practice aimed at sustaining seafood production through the application of artificial breeding techniques is truly encouraged for use in most aquaculture or aquatic species.

The common breeding technology used for aquatic species is the captive breeding (i.e., all forms of artificial intervention aimed at influencing and manipulating fish's brood stocks to breed and produce larvae under captive condition). Generally, seafood progenies can be obtained through captive breeding (i.e. in the hatcheries) or collection from the wild. While the culture of some shellfish still rely heavily on wild spat for stocking, it is important to state that these places pressure on wild stocks and contribute to over-exploitation of these species. Hence, the development of

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[1] Definition of the term available at: http://www.fao.org/faoterm/en.

[2] Definition of the term available at: http://www.fao.org/faoterm/en.

[3] Official definition are provided by the Oxford Advanced Learner's Dictionary available at: https://www.oxfordlearnersdictionaries.com.

[4] Newly updated version referred at: https://clarivate.com/webofsciencegroup/release-notes/wos/.

captive breeding protocol of these wild species can help improve productivity and sustainable exploitation. These also includes examination of their adaptability in various production systems, behavioural changes and performance under manipulated environmental conditions, and different feed management. Therefore, through captive breeding, it is possible that the reproductive biology of cultured animals are controlled and enhanced by the manipulation of various factors such as culture systems or environmental conditions (Moorhead and Zeng, 2010; Bricknell et al., 2021). This is currently the focus of much research in a bid to improve production characteristics, diversification of the aquaculture species, and ensure food security in the long run.

ADVANTAGES OF AQUACULTURE FOR SUSTAINABLE FOOD PRODUCTION

Aquaculture is one of the fastest-growing food production sectors in the world (FAO Fisheries Department et al., 2019; Tacon, 2020), hence has the prospect of becoming one of the main sources of several future foods. This is evident in the annual increase in global food fish consumption (3.2%) which has outpaced population growth (1.6%) and exceeded that of meat from all terrestrial animals combined (2.8%) (FAO 2018b). More so, there are many advantages of this sector over the others; which includes i) higher nutritional benefits, ii) better source of income, iii) direct employment opportunities and in the value chain, iv) some aquatic product are cheaper source of animal protein than red meat, v) possibility of sustainable exploitation, vi) production is yearly on an increase, vii) availability of advanced culture techniques for many fish species cultured around the world and viii) Health related-benefits of their consumption. Despite these advantages, sustainable aquaculture production would require biological knowledge of the animals, the environmental requirement for culture, a good policy framework for aquaculture practices, and availability of a large market to drive the production for supply of the cultured species (Broitman et al., 2017; Weitzman, 2019; Boyd et al., 2020; van der Schatte Olivier et al., 2020). It was estimated some decades ago that a large percentage of the food consumed by man will originate from the sea (Rothschild, 1981). However, even though aquaculture currently accounts for about half of the world's fish supply (with projection for future growth), a higher percentage of the current production is from the freshwater ecosystem (Edwards, 2015; Naylor et al., 2021). Hence, with the abundance of the marine ecosystem and the dwindling of freshwater resources, marine aquatic production would be a key sector in the supply of high-quality protein for the global population in the future.

DEVELOPMENT OF BREEDING TECHNOLOGY FOR FOOD PRODUCTION AND ECOSYSTEM SERVICES

With the total number of aquaculture species reaching about 600 (FAO, 2018b), the establishment of advanced breeding technologies for these species could positively impact their sustainable production. In the same vein, ecosystem services from aquaculture can contribute significantly to food provision (farmed seafood), habitat protection and support (genetic diversity for protected species) as well as cultural services (recreational fishing or employment) (Hattam et al., 2015; Alleway et al., 2019). Thus, this segment explores the positive ecosystem services benefits provided through breeding technology and highlights some of it potential negative impacts too.

Optimization of the selective breeding protocol could enhance the progeny quality of the cultured species, consequently, it increases the growth rate among other factors (i.e., disease resistance, fillet yield, colour, hardiness etc.) (Costa et al., 2020). Fast-growing cultured species are very important for aquaculture activities, as they contribute to reducing the production time. Consequently, the supporting services are improved through the availability of a genetic population with high-quality performance that can bring a high economic return to the farmers. Furthermore, genetic improvement through well-designed production traits and advancement in sequencing/bioinformatics tools could expedite the domestication process of wild species. Artificial propagation is used for seed production under captive conditions, hence, one of the ecosystem services that is derived from this is helping to mitigate the extinction of wild species which has been exploited beyond the maximum sustainable yield (Kitada et al., 2019). In addition, since the response to selection for higher genetic variance is better in aquatic species compared to terrestrial animals (Dunham et al., 2000), it could then be right to infer that the former has the potential to contribute more to sustainable food development than the later. A notable example of such success story is with Tilapia where different strain of selective breeds such as GIFT (Genetic Improvement of Farmed Tilapias) GET-EXCEL Tilapia, FaSTilapia, GST (GenoMar Supreme Tilapia), and Hainan Progift Tilapia are now commercially sold around the world (Trong, 2013). However, the drawback of this breeding technology (i.e. selective breeding) is the time taken (i.e. 5-15 years) for improvement to be achieved (Hulata, 2001). This age long practice is currently been replaced by more sophisticated breeding technology such as transgenesis which improves the trait of interest within a relatively short time. This is made possible by transferring foreign gene of interest into the developing embryo of the target species and monitoring it expression over time.

One of the ecosystem services of improved breeding technology is the ease of controlled spawning and larval rearing at the convenience of the fish farmer (Dominguez-Godino and Gonzalez-Wanguemert, 2018). This contrasts with aquaculture species in the wild where the environmental factors frequently fluctuate, hence, affecting the reproduction and productivity of the fish or shellfish. Thus, the brood stock produced, maintained, and spawn in captive condition using improved breeding technologies ensures all-year-round hatchery production. It could indirectly mitigate the loss in biodiversity of certain aquatic species. Through captive breeding, overexploited fish species could be restored to the level of sustainable exploitation. This is not to say there are no debates around how some breeding technologies negatively affect ecosystem services. For instance, some genetically improved marine aquaculture species (such as salmon, crabs etc.) have been said to possess potential negative impacts on wild fish populations during escapes from the aquaculture facility. Polyploids and transgenic progenies in particular may negatively affect the wild habitat and biodiversity services of marine systems. Hence, measures to mitigate this and safeguard the wild ecosystem is, therefore, of great research importance.

CONCLUSION AND RECOMMENDATIONS

Breeding technology is one of the most used tools for sustainable seafood production as it contributes to the conservation efforts for most aquatic species. Genetic improvement induces breeding and captive breeding are some of the identified breeding strategies that have been exploited to boost the production of aquatic organisms in coastal communities and other aquatic environments. It also provides better ecosystem services by improving biodiversity and mitigating species extinction through the improvement of breeding practices. More research is needed to elucidate other breeding techniques with a view of understanding their advantages and disadvantages following their application to different commercial aquatic species.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

MA wrote the first draft of the manuscript. VO wrote the revised version of the manuscript. MI contributed to the conception and design of the study. All authors contributed to manuscript revision and approved the submitted version.

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