UDS International Journal of Development [UDSIJD] ISSN: 2026-5336
Volume 11 No. 2, 2024
https://www.udsijd.org

FISHERY RESOURCES AND THE DEVELOPMENT OF AQUACULTURE: INSIGHTS FOR AGRICULTURE HIGHER EDUCATION

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Abstract
An investigation was conducted on the capture fisheries and aquaculture subsectors so as to understand their production outputs and characteristics. Estimates of notable fish resources, total number of species (TNS), effective number of species (ENS), global fish production (GFP), capture fisheries production (CFP) and aquaculture production (AP) for 4-decades were retrieved and analyzed. Capture fisheries and aquaculture were characterized using these criteria: mode of production, place of production, management approaches, motivation/goals, and property regimes. Fishery resources remained fairly constant (1000), TNS increased progressively (157 to 438), ENS fluctuated almost regularly and GFP increased in million metric tonnes (MT) steadily (90.6 to 172.8MT). Contributions to annual GFP by CFP steadily decreased (87.1 to 54.0%) while those of AP increased steadily (12.9 to 46.0%). Capture fisheries and Aquaculture are similar in terms of their contributions to food security through the provision of fish. Contribution of fishery resources to global fish production declines as a result of the steady increases from aquaculture. Aquaculture has developed as a culture-based activity. On the basis of culture-based characteristics, aquaculture can exist as either an independent academic discipline in Agriculture universities or an integral unit of existing livestock-based department.

Keywords: Farming, Fishing, Fish Production, Education Reforms, Universities

Introduction
Advances in aquaculture are among the most remarkable in the twentieth century. The sector is experiencing remarkable changes with new cultured species, hatchery-reared seeds and global spread of fish culture (Cai et al., 2022; Food and Agriculture Organization [FAO], 2022). As aquaculture advances, the contribution of wild-caught fish to society gradually declines despite mechanized fishing and new methods of fishery governance. In this context, the contribution of aquaculture to global food fish, which is now approximately equal to those from capture sources, mirrors the path through which plant/animal resources transit into becoming crops/livestock. Several literature reveal the uniqueness of culture-based production as it gradually replaced the

exploitation of natural resources in response to changes in climatic conditions, distribution pattern of food organisms and human population size while simultaneously encouraging the embrace of sedentary lifestyle, facilitating the growth of trade through exchange of different farm products and freeing some individuals to express other creative abilities such as writing (Uchola, 2016). This transformative effect of agriculture in society, and more recently aquaculture, is evident in tertiary institutions that are dedicated to research and manpower development.

Fisheries and aquaculture are now confronted with new issues related to environment and social change. Most notable are changes in socio-economic variables such as the consolidation in processing and marketing, changing roles of most organizations in the rural sector, new and expensive technologies, consolidation of farms and commercial input suppliers, unpredictable roles of governments and influence of global trade. It was proposed that a new approach to education is required to address these changes in society; an approach that promotes an education that is broad, transdisciplinary and long term (Francis & Gliessman, 2023). Furthermore, rapid expansion of aquaculture production initiates changes in environment such as harmful algae bloom in natural waters, its negative impact on fisheries/ aquaculture and food safety issues (FAO, 2022; Mulchandani et al., 2023). In this situation, fisheries and aquaculture are moving from a narrowly-oriented food production sector to a societal function comprising natural resource conservation, environmental management and social issues. Rapid changes in society appear to call to question the relevance of fisheries and aquaculture, which as academic disciplines include stock assessment studies, fishing pressure regulation, induced spawning under hatchery conditions, selective breeding and large scale fish production. This challenge in emerging societies goes beyond the food fish sector as those societies seek to resolve the questions of access to higher education, funding, governance, gender imbalance, academic freedom, brain drain and capacity building. Academic collaboration will be required to achieving excellence and distinction in Higher Education (Teferra, 2022).

The complex and changing paradigm in agriculture poses a challenge to agriculture universities. With questions such as "how is Agriculture Higher Education to be reformed so that it becomes robust, capable of adapting to changes in society and relevant for training purposes? Many education experts wonder if agriculture educational institutions can make contributions to modern society in ways that are similar to nascent agriculture. Clearly, the issue at stake here is the level of productivity in those institutions; the quality of their service delivery (efficiency) and the extent to which the needs/demands of society are satisfied (effectiveness). As a first step towards addressing the aforementioned question, the present study adopts a sector-based approach by reviewing major fishery resources, advances in the development of aquaculture and their distinct characteristics.

Methodology

Study Themes

The study focuses on the fisheries and aquaculture sub-groups with the major themes as aquatic species/ notable fish resources, cultured species/ total number of species (TNS) and the most evenly spread cultured species/ effective number of species (ENS). Other themes include global fish production, capture fisheries production and aquaculture production within the period 1980-2020. The last theme focuses on the characterization of fisheries and aquaculture as fish production sectors.

Data Retrieval and Presentation

Estimates of aquatic species/ notable fish resources across the globe, cultured species and the most evenly spread cultured species were retrieved from Cai et al. (2022); FAO (2021); Metian et al., (2019). Average annual production output in global fish production, capture fisheries production and aquaculture production (1980-2020) were obtained from FAO 2021 and 2022. The data on cultured species, capture fisheries production and aquaculture production were expressed as percentages of their respective total.

Characterizations of the Major Sub-groups

Some characteristics of captured fisheries and aquaculture production were identified. The sub-groups were further characterized using these criteria: mode of production, place of production, motivation/goals, management approaches and property regimes (Charles, 2009; Serge & Cochrane, 2009).

Results

Table1 shows that the number of fishery resources remains fairly constant within the periods under consideration. The total number of cultured species (TNS) increased progressively from decade to decade over the last four decades with the highest growth rates 43.3% and 44% in 1990 and 2000 respectively. In contrast, the effective number of cultured species (ENS) fluctuates almost regularly during the same period with the highest growth rates 50% and 45.7% recorded in 1990 and 2010 respectively

Table 1: Fishery resources and growth in Aquaculture species

Periods	Fishery resource [1]	Aquaculture Species		Growth rate (%)	
		TNS[2]	ENS	TNS	ENS
1980	1000	157	24	na	na
1990	1000	225	36	43.3	50
2000	1000	324	35	44	-2.8
2010	1000	424	51	30.9	45.7
2020	1000	438	47	3.3	-7.8

Source: *Field survey (2024).*

1 Listed Aquatic Science and Fisheries (ASFIS) species considered to be consistent on global fish production site; includes crustaceans, molluscs, amphibians and reptiles
2 could refer to individual species, hybrids or groups of related species

Table 2 indicates that average annual global fish production increased steadily in the last 4 decades. Capture fisheries production also increased steadily within the same period but its share in the contribution to annual global fish production decreased steadily from 87.1% to 54%. Average annual aquaculture production and its contribution to annual global fish production increased steadily from 12.9% to 46%.

Table 2: Global, capture and aquaculture productions (million tonnes, MT)

Periods	Global MT	Capture	Aqua	Global Prod. (%)	
		MT	MT	Capture	Aqua
1980s	90.6	78.9	11.7	87.1	12.9
1990s	110.7	88.9	21.8	85.4	14.6
2000s	134.3	90.9	43.4	72.8	27.2
2010s	162.6	91.0	71.5	60.1	39.9
2020	172.8	90.3	87.5	54.0	46.0

Source: *Field survey, 2024*

Table 3: Major characteristics of Fisheries and Aquaculture

Criteria	Fisheries	Aquaculture
Place of production	Natural Aquatic systems	Human controlled aquatic systems
Mode of production	Exploitation	Culture
Motivation/	Food security	Food security Sustainable production
Goal	Resource conservation Sustainable livelihood	Culture species diversification Superior product quality
Management-approaches	Traditional Co-management	Sole proprietorship Partnership
Property Rights	Private , public, common, state	Private

Source: *Field survey (2024).*

Table 3 summarizes the distinctions between fisheries and aquaculture in terms of production theatre, production method, motivation/goals, management approaches and property rights. Fisheries production was defined by Natural Aquatic Systems, fish resource exploitation and issues of property rights including those related to governance. In contrast, aquaculture production was defined primarily by human controlled aquatic systems, culture of fish species and privately owned production systems.

Discussion

Fishes are organisms that are endemic to all known water systems and in many instances exhibited extreme differences in body shape, body size, feeding habit and population size as expressed by the large schooling clupeids (e.g Sardine), the bottom-dwelling flatfishes (e.g Soles), the large-sized predators (e.g Sharks), the highly prolific cichlids (e.g Tilapia) and the opportunistic catfishes (e.g Clarias). Some of these fish species become valuable items for food, livestock feedstuff or ornamentals. Once valued for its utility, a fish species is no longer a mere zoological entity within an aquatic ecosystem but a resource. Peruvian anchovy, Alaska pollock, Skipjack tuna, Atlantic herring, Yellowfin tuna, Blue whiting, European pilchard, Pacific chub mackerel, Atlantic cod and Large head hairtail (FAO, 2022) are examples of a fishery resource. Fishing, unlike hunting of terrestrial animals, still remains relevant as a food production system in contemporary society.

The contribution of fishing to global fish production declines with the growth and expansion of aquaculture. Presently, yields from fishing in natural waters are either at their maximum sustainable levels, gradually exceeding the sustainable limits or experiencing overfishing. In fact, stock assessment indicates that 33.3%-86.2% of assessed stocks in different regions of the Pacific and Atlantic oceans were fished within biologically sustainable levels or levels that will produce maximum sustainable yields (FAO, 2022). In particular, 33.3% of stock of the top 10 fish species with the largest landings and 33.3% of principal tuna species were fished at biologically unsustainable levels. The situation is similar in species like the Atlantic cod, hake and haddock in the Northwest Pacific where stocks at peak of 2.1 MT collapsed and the recovery is yet to be realized even though the reasons for poor recovery are related not to overfishing but environmental-driven changes in productivity for some stocks (FAO, 2022). These stock assessment studies, which build on the seminal work of Schaefer (1954) titled "Some aspects of the dynamics of populations important to the management of commercial fisheries" in the mid-1950s, refute the fallacy that fish resources of the oceans and seas are inexhaustible.

The total number of cultured species (TNS) has been increasing since the earliest period of aquaculture. Fish culture, which began with the transfer of wild common carp from the Danube River to reservoir or *piscinae* in south-central Europe as well as the religious practice of releasing rare "red" aberrant form of wild gold fish into "mercy ponds", developed into culturing of fish in ponds and keeping of goldfish in aquaria respectively (Balon, 1995). Since the successes recorded with earliest domesticates, the number of cultured species have been growing steadily. The tread in TNS remains consistent despite data imperfections or data underestimation (Cai et al., 2022). If the number of cultured species were just three fish species- Atlantic salmon, tilapia and the Southeast Asian catfish (pangasius), what would have become of the state of global aquaculture in the events of the disastrous outbreaks of Infectious Salmon Anaemia, Tilapia Lake Virus and the global drop in the demand of SE Asian catfish? In this situation, increases in cultured species express the belief that diversification in aquaculture could result in improved capacity to adapt to change, that is, towards building resilience (Metian et al., 2019). So, it is expected that, since aquaculture is vulnerable to exogenous shocks that affect all the other subsectors of agriculture, the culture of the different species would reduce the risks related to production failure from diseases or weakening markets. Therefore, the culture of more species, is a form of insurance under different climate change scenarios especially unexpected events such as disease outbreaks or market issues.

Effective number of species (ENS) correlates with total number of species (TNS) in each decade because the TNS measures the richness of species composition while the ENS captures both richness and evenness. The trend towards a higher diversity of farmed species through increases in the number of farmed species have been confirmed by the global increases in Shannon Diversity Index even though over a quarter of the TNS produced six decades ago were no longer in the production line (Metian et al., 2019). Why a fairly large proportion of species were reared for a short period of time remains unclear but what is recognized is that focus on one or a limited number of species allowed for rapid innovation and improvements in techniques as it is the case in the development of Atlantic Salmon Aquaculture. Changes in number of aquaculture species and production output are indicative of the huge potential of fish culture to sustainably contribute to the growing demand for fish globally.

Characterization

A natural aquatic ecosystem is the operation theatre for the exploitation of most of the productive species often referred to as the top commercially important fishery resources. More often, fish production output reflects the size of a natural water body as indicated by the contribution of production output from the marine (87.3%) to total capture fisheries production. Furthermore, productivity of natural waters are influenced by environmental processes outside the direct control of humans as evident in the decline in the productivity of the fishery resources in the Northeast Atlantic from the 1970s and its inability to recover after five decades despite good fisheries governance (FAO, 2022). Fishing in a natural aquatic ecosystem involves the exertion of effort through the use of wide range of simple gears operated with simple crafts to large complex gears that are operated with sophisticated machines. Types of fishing gear and fishing intensity often affect growth, recruitment process and stock biomass with the risk of overfishing. Different types of management have been developed to optimize benefits from fishery resources. Traditional fisheries management- locally designed in fishing communities and often based on norms of appropriate conduct was overshadowed by conventional fisheries management with the advent of modern state involvement in large scale fisheries in the North Sea from the second half of the 20th century (Serge & Cochrane, 2009). Fishery resources are managed with the aim of achieving resource sustainability and economic productivity without leading to ecological changes that foreclose options for future generations. These objectives, which envisage sustainable fishing and sustainable livelihood, are achieved in well managed fish stock in the Northeast Pacific (the best globally) as well as in the employment of millions of fulltime, part-time, occasional and unspecified workers in the fisheries sector (FAO, 2022). Major property-right arrangements influence the access to fishery resources and types of fisheries management as a fishery resource exist in the form of either "non-property/open access", "private property", state property", or "common property" (Charles, 2009).

Aquaculture deals very often with hatchery-reared organisms that are cultured in artificial environments. Erection of hatchery complexes, culture facilities construction, feeds formulation and water quality monitoring are all parts of a system intended to co-ordinate the different operations involving hatchery-reared broodstock, seed multiplication, fingerling stocking, continuous feeding and water quality management for sustainable harvest of table-sized fish. Community or state direct involvement in aquaculture production is rare or absent as the proprietor decides production intensity (extensive or intensive), number of cultured species (polyculture or monoculture) and harvesting methods (partial or total harvesting). Unlike in fisheries, aquaculture is managed with the view to addressing shortfall in fish supply and tapping wild aquatic genetic resources for use in aquaculture production. Open access property arrangement is non-existent in aquaculture as a fish farm is owned either by an individual or partners who manage it as a sole business, partnership or limited liability company.

Insights for Higher Education

The discussions provide useful information on fisheries and aquaculture: fishery resources are the progenitors of all the diverse culture species in aquaculture, the characteristics of aquaculture as a form of production are substantially different from those of fisheries and both subsectors make significant contributions to food security/societal wellbeing.

What does a fishery resource as progenitors of cultured species mean for the definition of agriculture? The transition of a fishery resource to an aquaculture species is best described by phrases such as "domestication of native fish species", "domesticate", "selective breeding", "high-performing strains" (Balon, 1995). From these key phrases, agriculture may be defined as "the transformation of natural (fishery) resources into livestock (aquaculture species), their artificial selection into breeds (strains) and system-based culture for sustainable production. This definition, which contains key words like "transformation, natural resource and artificial selection of breed", is different from the classical form expressed as: "Agriculture is the cultivation of crop, rearing of animals and their utilization for man's use". In the classical definition the key phrases are inadvertently omitted.

A question related to the substantial difference between the fish production subsectors is "how can the distinct features of aquaculture and fisheries be harnessed for administration in Agriculture Higher Education? Aquaculture is an expression of a principle based on "germplasm selection and nurture". Germplasm selection and nurture are integral parts of the general principle of culture which underlies operations in agriculture as a science. Therefore, aquaculture rightly belongs to the Faculty of Agriculture as an independent entity or department. In the same way, the characteristics of fisheries present it as a mode of production that involves the exploration of natural resource and rational exertion of fishing effort to guaranty sustainability of the resource. In this way, fisheries express a principle based on "rational use and conservation". Rational use and conservation are cornerstones of "resource sustainability" which defines Natural Resource Management. As a result, Department of Fisheries is domiciled in the Faculty of Renewable Natural Resources. Put differently, the underlying principle of "exploitation" in fisheries contrast with the culture-centred principle in aquaculture making both incompatible as a single academic disciple.

If "Fisheries and Aquaculture" as a single entity does not fit as a department in Agriculture Higher Education where then does it belong? Fisheries and Aquaculture are intertwined for a number of reasons. First, both are fish-related socio-economic activities that support tens of millions of people across the world in terms of food, employment and income. Second, products from both sectors are protein-rich foods, highly digestible, and readily accessible making their consumption one of the best options in the fight against malnutrition and food insecurity. Next, consumption of their products are widespread with no significant restrictions based on health status, prohibition based on religious beliefs or any other known social barriers such as age or gender. Finally, both sectors make important contributions to large scale production of aquatic products (blue revolution) and the strengthening of the aquatic food systems for sustainable production (blue transformation). On the basis of livelihoods, product quality, food security and production sustainability, "Fisheries and Aquaculture" truly constitute a single category as all the themes are components of societal wellbeing and belong exclusively to Governance. From the perspective of societal wellbeing and governance, "Fisheries and Aquaculture" as a single department is domiciled in Ministries of National governments or Agencies of Inter-governmental Organizations such as the Food and Agriculture Organization of the United Nations.

Conclusion

Fish is an important resource which contributes significantly to food security in society as expressed in global fish production statistics. Nevertheless, a fishery resource has a limited contributory capacity to global fish production as evident in its inherent limitation known as Maximum Sustainable Yield (MSY). This makes the development of aquaculture a necessary option and complementary approach towards sustained supply of fish products. The development of aquaculture provides a more sustainable approach to fish production as the relevance of wild-caught fish to global production output continues to decline decade after decade. Increase in the number of aquatic animals that are cultured is likely to protect aquaculture production from the risk of production failure and sustain its advancement into the future. One step towards sustaining the advances and productivity of the sector is to promote "Aquaculture" as an independent department or a continuum of existing livestock-based department for training and research in Agriculture Universities.

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