FRESHWATER AQUACULTURE AND POLYCULTURE

Jerome Lazard
Unite de Recherche Aquaculture, CIRAD-EMVT/GAMET, France

Lionel Dabbadie
Estado da Agricultura e do Abastecimento, CIRAD-EMVT, Brazil

Keywords: freshwater aquaculture, fish farming systems, reproduction, pond dynamics, stocking, density, polyculture, carp, tilapia, statistics, nutrition, fertilization

Contents

Summary

Fish is an important food component for populations of many countries, especially in developing areas. For food fish, over a quarter of total world supply is derived from aquaculture and contribution of the latter increases quickly. Several types of fish culture can be distinguished, according to their degree of intensification, or depending on the fish feeding: mostly natural food or exogenous high protein feed. Pros and constraints of each type are reviewed, but pond production remains the most used as it permits a multipurpose production (fry, fingerlings, adults) with a wide spectrum of utilization (from extensive to hyper-intensive). The main cultivated freshwater species belong to carps (Indian and Chinese carps) and tilapia. Their biological characteristics are reviewed. Management and improvement of environmental factors can achieve fish reproduction in captivity, but most frequently, it is done using hormonal treatment: pituitary extracts, gonadotropin or GNRH with or without antagonists-inhibitors.

Fish nutrition requires high levels of protein, but expensive fishmeal can be partially replaced by vegetal protein for some herbivorous species (tilapia), or by lipids and carbohydrates as many proteins are used as an energy source. But the most important factor in many aquacultural farms is the management of the pond ecosystem and the definition of adequate stocking. Natural feed for fish can be stimulated by fertilization. Mineral fertilizers stimulate the autotrophic-based food chain, whereas organic manures improve both the autotrophic and heterotrophic food chain, thus allowing higher fish crops. Pond stocking must be defined in order to be as close as possible to the bio-technical-economic optimum. When too low, natural productivity is under-exploited and yield is low. When to high, fish growth decreases quickly and use of an expensive artificial feed become necessary. Another way of improving pond productivity consists in breeding several species with complementary feeding regimes. This is polyculture and several examples practiced around the world are given. Finally, some fish farming systems are considered from the economical point of view. Integrated systems have a higher profitability and systems that associate aquaculture to livestock breeding may show a contribution of fish to net income higher than 50%. These trends are encountered in several areas worldwide.

1. Introduction

Freshwater aquaculture is by far the most ancient aquatic living resource production system known in the world. It strikes root in more than 2500 years of history. Fish is the main, if not the only, component of freshwater aquaculture and earthen pond is historically the first and still the most utilized aquaculture production facility (contribution for more than 80–85% of the total freshwater production).

Freshwater aquaculture differs from other aquaculture systems by some characteristics. It allows a strong integration to the agricultural production systems (crops and livestock) at different levels: water use, wastes recycling into the fishponds as fertilizers, agricultural by-products as fish feed. Freshwater aquaculture production is mainly based on the culture of short food chain fish (carps, tilapias) and differs basically from marine fish culture based on carnivorous fish (salmon, Japanese amberjack). Freshwater aquaculture is mainly based on extensive and semi-intensive aquaculture production systems where polyculture, fertilization, and supplementary are the key points.

In 1995, freshwater aquaculture accounted for 65% of the total aquaculture production, if aquatic plants are excluded. Asian countries are the main aquaculture producers and in these countries, freshwater fish culture plays a major role: China, India and Indonesia (67%, 6.7%, and 3.1% of the total world aquaculture production respectively).

In the last decades, major bio-technical innovations have had a strategic impact on the freshwater aquaculture development: artificial breeding, use of supplementary feeding and artificial feed, genetic improvement, introduction of exotic species to many countries for aquaculture purposes. Despite all the scientific studies carried out in this field, the pond as a culture environment remains a black box where fish feeds at many levels of the food web and fish species interact actively.

The progresses in pond fish culture management practices have mainly been obtained by a trial and error process. This contribution aims at presenting the main available data concerning scientific and technical bases, and practices in the field of freshwater aquaculture.

2. Brief Review of the State of World Freshwater Aquaculture

In 1995, total world production of finfish, crustaceans, mollusks and plant reached 120.7 million mt, of which aquaculture contributed for 27.8 million mt. The annual contribution of aquaculture to total aquatic production increased from 14.4% in 1989 to 23% in 1995. For food fish, over a quarter of total world supply was derived from aquaculture.

Regional, cultural, and historic attributes have played a major role in influencing both the production base and rate of expansion of aquaculture.

The historic tradition of growing fish in Asian countries such as China, India and Indonesia, which are the three leading countries, has played a significant role in maintaining Asia's dominant position in aquaculture. Aquaculture production in Asia increased from 1984 to 1995 at an average annual compounded growth rate of 10.4% and accounted for over 90% of world output. Much of this growth, however, specifically relates to China. In Africa and Latin America, the aquaculture production base is considerably lower but even with low total productions compared with Asia, the growth rate reached 12.7% in Africa and 12.8% in Latin America during the same period as above, while the growth rate was 3.9% in Europe and 3.6% in North America.

If aquatic plants are excluded from total aquaculture production, the contribution of finfish and shellfish from freshwater environments continues to dominate output and in 1995, accounted for around 63% of the total tonnage of cultured finfish and shellfish. Culture from brackish water and marine environments contributed 7% (mainly crustaceans) and 30% (mainly mollusks) respectively.

Of the 292 species included in the 1995 FAO aquaculture statistics for which production data are available, the first 22 species accounted for 80% of the total production. Of these 22 species, nearly all of the farmed animals are filter feeders, herbivores, or omnivores. Only one species, Atlantic salmon, is carnivorous and is clearly a minor species in terms of production volume.

The most important group is freshwater finfish: 12.7 million mt compare with 1.4 million mt of diadromous fishes and 0.6 million mt of marine fishes.

The freshwater finfish production is dominated by Cyprinids and tilapias with a contribution of 10.3 million mt in 1995, cyprinids have a number of advantages which will maintain their leadership in the short and medium term: they can use feeds with moderate protein and fish meal content. They can be reared in polyculture systems that make optimum use of the natural productivity of the ponds and water bodies where they are stocked. They have also good markets in Asian countries due to traditions and relatively low prices.

Only a few carp species dominate global Cyprinids culture: the Chinese carps (silver, grass, bighead, crucian, black, and mud), common carp, and Indian major carps (rohu, catla, and mrigal). In 1995, these species accounted for 80% of all cultured carps. The culture of Chinese carps was dominated by three species: the silver, grass, and bighead carps (70% of total Chinese carp production in 1995). Common carp made up another 21% and is geographically the most widespread, being cultured in 86 countries. In 1995, the larger producers of common carp were besides China, India, Indonesia, Russian Federation, and Ukraine.

All landings of Indian major carps were from aquaculture and culture of the three main species increased at an annual rate of 12% from 1984 to 1995. Almost all-Indian major carp production has come from India but in recent years a growing proportion is cultured in Myanmar, Thailand and Laos.

Between 1984 and 1995, the contribution of cultured tilapias to total tilapia increased from 38% (198 000 mt) to 57% or 659 000 mt. Four cichlid species or species groups (Nile tilapia, unidentified tilapias, Mozambique tilapia and blue tilapia) dominated production between 1984 and 1995 where they accounted for 99.5% of cichlid production. Nile tilapia accounted for 72% of total tilapia production in 1995 and its annual percent growth rate from 1984 to 1995 was 19%. In 1995, major tilapia producers are China (315 000 mt), Philippines (81 000 million mt), Indonesia (78 000 mt), and Thailand (76 000 mt).

3. The Different Types of Freshwater Fish culture and Polyculture

The different fish farming production systems are generally distinguished according to their degree of intensification which is itself usually defined according to the feeding practices as food represents more than 50% of the total operating costs in intensive systems. However, intensification (or, inversely, extensification) involves many other production factors, such as water, land, capital, and labor.

A first classification could be established as follows:

- Extensive fish farming production systems are based on the use of natural feed produced in the fish culture structure/environment without any input with a very low input level. Rice-fish farming systems can be considered as belonging to this extensive level as fish takes benefit of inputs added for rice cultivation

- Semi-intensive fish farming systems rely on the use of fertilization (organic and/or mineral) to produce natural feed and/or supplementary feed, but with a significant amount of the fish diet supplied by natural feed. Integrated crop-livestock-fish farming systems are typically belonging to this type of fish culture as well as all fish farming systems recycling various types of wastes including direct excreta reuse systems (latrine ponds of Vietnam for example) and indirect sewerage systems. Both systems provide high fish yields
- Intensive and super intensive systems have all the fish nutritional requirements provided by a nutritionally complete pelleted feed with little or no nutritional benefits from natural productivity of the pond or water body where fish culture is achieved (lake, river). The feed used in these fish farming systems are generally rich in proteins (25 to 40%) and are then costly. The main facilities used for this type of fish farming are pens, cages or raceways with a very high water renewal rate (natural through water currents of artificial through pumping)

The different types of fish farming systems according to the level of intensification are summarized in Table 1.

Fish stocking density (pieces.m^{-2})	**< 1**	**1–5**		**5–10**	**10–100**
Farming system infrastructure	Pond	Pond	Pond	Pond/cage	Raceway/pond/pen
Yield (t.ha^{-1}.$year^{-1}$)	0 - 1	1 - 5	5 - 15	15 - 50	> 50 and up to 100 kg.m^{-3}
Management	No input	Low quality manure macrophytes	High quality manure, pellets	Pellets, aeration, and recirculation	Pellets, high level of water recirculation (natural or artificial)
Degree of intensification	Extensiv e	Semi-intensive		Intensive	Super intensive

Table 1. Different levels of intensification of fish farming systems.

An interesting transition between semi-intensive pond fish culture and super-intensive fish culture systems is given by tilapia floating cage culture in productive natural water bodies such as lakes in the Philippines. The stocking rate of tilapia fingerlings is adapted to the cage size, the natural productivity of the water and the culture management. At low stocking densities (up to 25 fish.m^{-2}), supplemental feeding may not be necessary especially in productive lakes during the abundant plankton season. To accelerate fish growth during the low productive months, supplemental feeding is applied at rates of 3 to 5% of body weight per day (see Table 2).

Cage size* m^2(m^2)	**Number of fish.m^{-2}**	**Number of fish per cage**	**Management**
1 (1×1)	200	20	With feeding

25 (5×5)	100	2500	With feeding
100 (10×10)	50	5000	With or without feeding
400 (20×20)	25	10 000	With or without feeding

* Cage depth of 2 meters in average

Table 2. Stocking rates for Nile tilapia in cages of different sizes and management schemes.

Another typology of fish farming production systems can be proposed, based only on the discrimination between systems where the feeds originate only (or mostly) from the ecosystem (endogenous feeds produced by the ecosystem) and systems where feeds are entirely exogenous and where fish feeding is entirely based on pelleted feeds or even trash fish.

Management of the first type involves fertilization and/or supplementary feeding, polyculture practices and there is a very strong interaction between stocking rate, final individual weight of fish (growth rate) and yield, which have to be managed very thoroughly. Management of the second type relies mainly on monoculture, high stocking rates and artificial feeding with a high protein feed.

The choice of any of these two types of fish culture systems depends on many factors, which are listed in Table 3.

Production factor	**Endogenous feeding (Mainly ponds)**	**Exogenous feeding (Mainly cages, pens, and raceways)**
Land	-	+
Water	Water area	Water flow
Impact of aquaculture on environment	+	-
Capital/cash flow	+	-
Labour (expressed per kg of fish produced)	±	±
High quality feed	+	-
Technicity level of fish farmers	-	-
Level of risk	+	-
Production costs	+	-
Yield per surface (or volume) unit	-	+
Multi-purpose of culture structure	+	-

+: Advantage for development
-: Constraint for development

Table 3. Types of fish culture systems according to the different feeding management practices.

In terms of land requirements, for a given prospected fish production, ponds need much more area of land (or water surface) than more intensive fish culture systems which, on the other hand, need higher water flow rates provided by natural currents in lakes or rivers (in the case of cages or pens) or by water supply by gravity or artificial pumping (tanks, raceways).

Ponds used for fish culture have generally a low level of negative impact on the environment. Moreover, they can be used for recycling various types of wastes. For example, ponds can recycle wastes such as night soil directly as sewage-loaded ponds where fish are cultured or indirectly within an aquaculture excreta rinse system with stabilization and maturation ponds, the fish being farmed in the latter.

Capital for investment needed for building ponds can be provided in the form of labor, which is not the case for cage, pens, tanks that require material to be purchased, or even imported. Supply of high quality feed used for exogenous feeding fish farming systems requires a high level of cash flow, which is not the case of semi-intensive fish farming systems using low cost inputs such as agricultural by-products and wastes from livestock and crops.

Expressed in man-days per unit of harvested fish, higher level of labor is required for fishpond system management (mainly for pond maintenance and cleaning, manuring, and harvesting) than for cages or other intensive fish production system. For a long time, it was admitted that endogenous feeding based fish farming systems were requiring only a low level of technical know-how from the fish farmers compared with exogenous feeding systems.

The reality is far from so simple: the former system is developed in countries with an old tradition of fish culture practice and where a strong know-how has been accumulated even if mainly empirical.

The many attempts to transfer these fish culture models into countries where there was no fish culture tradition failed because on the other hand, high feed input aquaculture models are based on technologies that are easier to transfer because their main components, (fish stocking density, feeding rate, and composition of feed,) are well defined and are carried out within a culture environment where the environment components either interfere only few (cage culture in lakes or rivers) or are under control (raceways, tanks).

Level of risks, in terms of fish diseases, is considerably reduced in extensive culture systems than in intensive ones. Similarly, production costs and yields are higher in intensive systems than in extensive, and semi-intensive culture systems.

Ponds are multipurpose fish culture systems: they can be used for brood stock stocking and maturation, breeding according various methods (natural, semi-natural, artificial), fry nursing and fish growing out. Moreover, in pond structures such as hapas used for tilapia, fry production for example can be implemented. Intensive structures usually specialized for growing out purposes from fingerlings to market size fish.

4. The Main Cultivated Species in Freshwater Aquaculture

4.1 Carps

The main carp species cultivated in the world are primarily seven in number and are often grouped on the basis of their natural geographical occurrence: the so-called Chinese carps, which include the grass carp, *Ctenopharyngodon idella*, the silver carp, *Hypophthalmichthys molitrix*, and the bighead carp, *Aristichthys nobilis*, and the so-called Indian major carps, which include catla, *Catla catla*, rohu, *Labeo rohita*, and mrigal, *Cirrhinus mrigala*. The seventh species is the common carp, *Cyprinus carpio*. Taxonomically, carps belong to the family of *Cyprinidae* (order, *Cypriniformes*).

-
-
-

Bibliography

Billard R. (1995). *Les Carpes: Biologie et Elevage*, 387 pp. Paris, France: INRA. [In French, this book gives a very wide description of carps biology and breeding. English readers may also consult *Aquaculture Of Cyprinids* by the same author, same editor.]

Egna H. S. and Boyd C. E. (1997). *Dynamics Of Pond Aquaculture*, 437 pp. Boca Raton, USA: CRC Press. [A complete review of pond ecology and management of trophic food webs.]

FAO (1997). *Review Of The State Of World Aquaculture. FAO Fisheries Circular*. No.886, Rev. 1. Rome, Italy: FAO Inland water resources and aquaculture service, Fishery resources division. [An update of the regular FAO reviews of world aquaculture.]

Guerrero III R. D. (1987). *Tilapia Farming In The Philippines*, 85 pp. Manila, Philippines: National Book Store.

Guillaume J., Kaushik S., Bergot P., and Metailler R. (1999). *Nutrition et Alimentation des Poissons et Crustacés*, 489 pp. Paris, France: INRA/IFREMER. [In French, an up-to-date complete description of fish nutrition.]

Harvey B. and Carolsfeld J. (1993). *Induced Breeding In Tropical Fish Culture*, 144 pp. Ottawa, Canada: IRDC. [A useful handbook for induced fish reproduction.]

Hepher B. (1988). *Nutrition Of Pond Fishes*, 388 pp. New York, USA: Cambridge University Press. [The reference in nutrition of pond fishes.]

Hepher B. and Pruginin Y. (1990). *Commercial Fish Farming*, 261 pp. New York, USA: John Wiley and sons. [This presents a wide description of technologies used in commercial fish farming.]

Jinghran V. G. and Pullin R. S. V. (1985). *A Hatchery Manual For The Common, Chinese, and Indian Major Carps*, 191 pp. Manila, Philippines: ADB/ICLARM.

Lazard J., Morissens P., Parrel P., Aglinglo C., Ali I., and Roche P. (1990). *Méthodes Artisanales D'Aquaculture du Tilapia en Afrique*, 82 pp. Nogent sur Marne, France: CTFT-CIRAD. [A complete review of the technologies used for tilapia production in Africa.]

PCAMRD (1990). *Integrated Crop-Livestock-Fish Farming Systems*. Los Baños, Laguna, Philippines:

PCAMRD.

Pullin R. S. V., Lazard J., Legendre M., Amon Kothias J.B., and Pauly D. (1996). Le Troisième Symposium International Sur Le Tilapia en Aquaculture, 630 pp. Manila, Philippines: ICLARM/CIRAD-EMVT/ORSTOM/CRO. [Proceedings of the international symposium on tilapia in aquaculture. Also available are proceedings of ISTA II and ISTA IV.]

Biographical Sketches

Lionel Dabbadie, post-graduated from the Agronomic School of Montpellier (France) with a doctorate from the University of Paris 6, has been working on fish farming in Africa and Brazil for the French government-owned *Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (CIRAD). He has been awarded the silver medal of the French Academy of Agriculture for his work on the pond dynamics in the framework of African extensive fish farms. He is presently working in the Brazilian Tocantins State on a project of culture of Amazonian native fish species, particularly on the endangered Osteoglossid *Arapaima gigas*, in cooperation with the Tocantins government and private operators.

Jerome Lazard graduated from Montpellier University (Ph.D. Aquatic Ecology) and Paris 12 (HDR). He is currently appointed to the French government-owned *Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (CIRAD) in Montpellier (France) where he is in charge of the Aquaculture Research Unit. He spent 15 years as a scientist in West Africa where he implemented and carried out R. and D. fish culture projects, mainly based on tilapia aquaculture. Once back in France, he did several missions both as a consultant for building research and development strategies in the field of inland fish culture in many tropical countries (Africa, Asia, South America) and for the implementation of scientific collaborative programs in this field. His research topics focus on tropical fish culture production systems. He has been awarded the silver-gilt medal of the French Academy of Agriculture and he is a Life-Member of the Society of Aquaculture Engineers of the Philippines. He is the author of publications on tilapia aquaculture and fish culture projects analysis.