ACCLIMATIZATION OF AQUATIC ORGANISMS IN CULTURE

Gilles Bœuf
Laboratoire Arago, Université Pierre et Marie Curie, BP 44, 66650 Banyuls-sur-mer and Muséum National d'Histoire Naturelle, 57 rue Cuvier, 75005 Paris, France.

Keywords: aquaculture, acclimatization, mollusc, shrimp, fish, environmental factors, temperature, salinity, light, oxygen, intensive culture, extensive culture.

Contents

Summary

Human introduced many aquatic species in culture for a long time, essentially mollusks, shrimps and fishes. These animals live and breathe in water and face very specific situations, compared to terrestrial species. Different environmental factors such as salinity, light, very variable oxygen content or presence of ammonia involve particular capabilities of adaptation.

They do not control their internal temperature and this raises very particular questions, compared to "commonly-reared" birds and mammals. Moreover, very often, some of them are "carnivorous". All these facts influence the type of rearing techniques usable to produce them and though, the level of acclimatization in culture. Human has developed a lot of techniques allowing producing species in aquaculture: how could we change from the initial status of juvenile capture in the wild to the total control of production cycle?

1. Introduction

Aquaculture is not a new concept, and evidence has been brought to light that culture in water existed at least four thousand years ago. It was born in Oriental Asia and it is interesting to note the predominance of this region in the current world production. To understand better how aquatic species adapt themselves to rearing, we could use the observations we made on terrestrial animals, but aquaculture species have their own biological specificities. This will be the object of our presentation and only animal species will be taken into account.

Another approach will consist in considering historically how human slowly started the rearing of certain species. At the very beginning, he probably based his practice on the observation of juveniles entrance in costal lagoons or ponds, where they grew bigger. It is likely that he "arranged" these systems and, still using wild juveniles from the natural environment, he parked them in "rearing frames": spots, ponds, branches, lagoons and cages. As it is still commonly practiced all around the world, these animals had to find food in this new environment in order to survive, grow and, sometimes, reproduce.

That is why the first experiences were made with species maintained at a low density (extensive aquaculture), only possibilty allowing them to supply their own needs. The organisms used then were mollusks and omnivorous fishes. Mollusk culture was extended during the Roman period in Europe. In this region, important development of mollusk culture has been known since the XIIIth century for mussels (*Mytilus sp*.) and the XVIIth for oysters (*Ostrea edulis* then later *Crassostrea sp.*). It is only several centuries later that "carnivorous" species (fish and shrimps) will appear in culture. Fish rearings in coastal managed lagoons are still traditionally practiced in Asia (*tambak*) and Europe (*valli*).

One noticeable step on the way to rearing and "domestication" is the mastery of reproduction in captivity. That is how entire culture cycle will be accomplished. This practice was roughly known for carps for a few centuries and more precisely controlled for salmonids about 150 years ago. At the middle of the XIXth century, the first serious attempts in research were made in order to control the reproduction of several fish species, and one century later, the determination of basic nutritional needs. At that time, reared "carnivorous" fish were fed with fish flesh or scraps proceeding from fishing harbours. "*Piscifactures*" were then localized near big fish landing areas. In 1905, a few promising results on reproduction and larval rearing were obtained in a first marine fish, the Dover sole *Solea solea*. Anyhow, it is only in the middle of the twentieth century, and particularly in the Seventies, that aquaculture took its modern aspect, with the tremendous development of both salmon and shrimp productions: fish, shrimp and mollusk hatcheries, mastery of biological cycles and moist and dry pellet formulation for shrimps and fish. Total rearing surfaces have extended, and densities have highly increased in intensive culture (until total recirculated-water systems). Juveniles' releases in the wild have also increased a lot (restocking and sea-ranching).

How could we change from the initial status of juveniles capture in the wild (still practiced in certain areas and for certain species) to the now total control of production cycle?

2. Biological characteristics of aquatic species

These animals can be differentiated from "traditionally" reared species (birds and mammals) on three main points: they live and breathe in water, yhet do not control their internal temperature and they are often carnivorous. .

2.1. They live and breathe in water

This will provoke many physiological changes comparing to terrestrial species. Obviously, both of them have to breathe, either in water or in air, but water characteristics are quite specific. That is why we will insist on external medium salinity effects, which have nothing to do with the situation in the air. Terrestrial animals "simply" have to keep their internal water the more they can (nephron role) and generally often drink (depending on the species).

All the ecological factors studied later (temperature, salinity, light) influence the physiological status, the growth and the reproduction through their action on the nervous central system and neuroendocrinological and endocrinological systems.

2.1.1. Stabilization and movements

Of course, aquatic species live in water, but this involves very particular constraints that we propose to develop. Moreover, except a few specific rearing groups (crocodiles, turtles, and amphibians), most species must take their oxygen from water. In water, Archimede's force embodies a specific situation. The fluid is about 850 times denser and 50 times more viscous than air. This will lead to an easier body stabilization and especially, much less energy will be needed. Movements in water are more difficult (energy cost) and maximal theoretical speeds much lower than in air. Some pelagic fishes are very efficient concerning these aspects because they are able to thermoregulate their internal organs and fluids (tunas and marlins for example). Marine mammals will have more facilities to reach a high speed swimming as they take their oxygen from the air. Among the aquaculture species, a few attempts are made with bluefin tuna (*Thunnus thynnus* or *maccoyii*), known for "moving a lot", and other very active fish, like salmonids or sea basses. As for invertebrates, nowadays practices use crustaceans, like penaeid shrimps, or filter-feeding bivalves, known to be respectively little or not mobile at all at their "adult" stage.

2.1.2. Respiration and excretion

As we saw before, the water environment is much more dense and viscous than the air's. In that way, fluid ventilation for aquatic animals will be much more difficult, meaning that the energy used by an air-breathing animal is very low (1-2 % of available energy), compared to an aquatic breathing-one (from 5 to 30 %). Some fishes must move permanently but most of them practice an active water uptake in order to obtain a correct ventilation of their gill filaments. Some fishes combine the two strategies and this will allow them to receive the precious oxygen. Moreover, respiratory gases solubility and diffusibility are highly different in air and water. Carbon dioxide is much less abundant in water (115 times less) than in air and oxygen water content also. A water volume, equilibrated with air, possesses about 30 times less oxygen than the same volume of air. Moreover, this content permanently fluctuates and sometimes a lot. Let us take the examples of a small pool of water on a beach or a pond highly-"loaded" with different types of plants including seaweeds: they can shelter an important fauna and oxygen saturation can vary from 0 to more than 200 % according to the daylight rhythm. The more water is salted and warm, the less oxygen is available.

The aquatic animals' respiratory system will then have to adapt on one hand, to the proper need of the animal (according to the metabolic rate and activity) and on the other hand, to the available ambient oxygen. That is why aquatic animals developed different strategies. They can sometimes use a large part of their body surface (mollusks and fish larvae) in order to take the water oxygen. Gill still remains the most efficient system (more than human lungs!) but can be "helped" by skin or other peripherical tissues, depending on species. As for larvae, the distance between external water and the deepest cell of organisms is very short, allowing a better O_2 overall diffusion. Gill is the universal organ of aquatic breathers and can control the total exchange surface available. For example, concerning bony fish, the value can vary from 0.1 to 1.35 m^2 per kg of body mass. The distance between the gill blood vessel and the external water can be reduced so that oxygen can easily diffuse. The blood oxygen carriers (when respiratory pigments exist) can change their afffinity. Aquatic species' oxygen needs are not lower than terrestrials' (ectotherms). Small animals (exchange surface -gills or lungs- compared to body surface) have a relative higher O_2 consumption (MO_2) and aquaculture species (and others!) had to develop very efficient systems. In rearing conditions, oxygen availability will be a crucial factor for productivity. When its available content is too low, oxygen clearly becomes a factor, that either prohibits life or limits early development and growth. In aquaculture, mortality, low productivity or bad final flesh quality often depend on oxygen level. A temporary hypoxia may have negative influence during all the life.

Aquaculture species excrete nitrogen and phophorus just like domestic animals, but they do it in water and this will lead to very specific constraints. In fact, they "auto-poison" themselves and water renewal is an aquaculture "*leitmotiv*" for all species. Some of them will be very tolerant on water quality (oxygen content, presence of "natural toxins" such as ammonia and nitrites, several parameters changes...) and others, on the opposite, will react very sensitively. This will determine satisfying aquaculture areas and the most tolerant species are very often the more produced in rearing: some mollusks, shrimps, tilapias, milk-fish, catfishs, carps…*etc*… Rearing water produces two different types of pollutants, both of them resulting from feed use: matters in suspension and dissolved substances. If they are too abundant, they rapidly become toxic for the fauna, by direct or indirect effects. Ammonia (diffusing easily through the gill) is the major final nitrogenous compound for fish (uric acid or urea in higher vertebrates). In present research, one great part of the efforts made is dedicated to the elaboration of feed that will have a less and less toxic incidence on environment (not only for the reared animal itself, but also for the aquaculture effluents in the external medium).

The water "cleaning" question is today one of the most important problems concerning aquaculture, either for the impact on surrounding (different laws according to the country) as for the treatment of water in recirculating systems (lack of natural sites or economical reasons). Fertilizers used in marine plants culture also have an impact. Several attempts have been made to try to reduce marine contamination in using seaweed and mollusk to clean fish rearing effluents.

-
-
-

Bibliography

Barnabé G. (1986). Introduction à l'aquaculture. *Aquaculture*, Vol. 1 (ed. G. Barnabé), pp. 1-12. Paris: Lavoisier. [This gives data concerning aquaculture story].

Beardmore J.A., Mair G.C. and Lewis R.I. (1997). Biodiversity in aquatic systems in relation to aquaculture. *Aquaculture Research* 28: 829-839. [Review on the relationships between aquaculture practices and freshwater and marine biodiversity].

Boeuf G. (1993). Salmonid smolting: a pre-adaptation to the oceanic environment. *Fish Ecophysiology* (ed. J.C. Rankin and F.B. Jensen), pp. 105-135. London: Chapman & Hall. [This review exposes data about salmon parr-smolt transformation, migration, sea water adaptation and applications to aquaculture].

Boeuf G. and Le Bail P.Y. (1999). Does light have an influence on fish growth ? *Aquaculture*, 177: 129-152. [A review about the effects of light (spectrum, intensity and photoperiod) on fish growth].

Boeuf G. and Payan, P. (2001). How should salinity influence fish growth? Comparative Biochemistry and Physiology, Toxicology & Pharmacology, 130C (4): 411-423. [Review on the effects of salinity on fish growth].

Brett J.R. (1979). Environmental factors and growth. *Fish Physiology*, Vol. 8 (ed. W.S. Hoar, D.J. Randall and J.R. Brett), pp. 599-675. New York: Academic Press. [Review on the influence of environmental factors on fish growth].

Fabre-Domergue J. et Bietrix E. (1905). Introduction à l'étude de la pisciculture marine. *Travail du Laboratoire de Zoologie Maritime de Concarneau* (ed. Vuibert et Nony), pp. 205-243. Paris. [The first paper mentioning data about the control of reproduction and larval rearing in marine fish].

Goulletquer P. and Héral M. (1997). Marine molluscan production trends in France: from fisheries to aquaculture. *US Dep.Commerce, NOAA Technical Reports*, NMFS 129, pp. 137-164. [A review about story, techniques, present status and perspectives for mollusk aquaculture].

Dizon A.E. and Brill R.W. (1979). Thermoregulation in tunas. *American Zoologist* 19, pp. 249-265. [A review about thermoregulation mechanisms in tunas].

Primavera J.H. (1997). Socio-economic impacts of shrimp culture. *Aquaculture Research* 28, pp. 815-827. [A review about the problems and economical development status of shrimp aquaculture].

Schmidt-Nielsen K. (1990). Respiration. *Animal physiology: adaptation and environment*, pp. 5-66. Cambridge University Press. [This book provides data about the mechanisms of animal respiration].

Spaargaren D.H. (1997). Physiological constraints in shrimp cultures. *Comparative Biochemistry and Physiology* 118A, pp. 1371-1376. [A paper on the relationships between the rearing surrounding and the potential of performances concerning shrimps].

Troadec J.P. (1998). Les systèmes extensifs de culture et d'élevages marins. *Rapport de la Sous-*

Commission des Pêches, Commission de l'Agriculture et du Développement rural, Conseil de l'Europe, 39 pp. [A review on the extensive aquaculture systems and the impact on the Economy].

Biographical Sketch

Gilles Bœuf graduated from Bordeaux and Brest Universities, France, with his D. Sc. Developmental Biology and Ph.D. Natural Sciences. He is presently Professor at the University Pierre et Marie Curie, Paris 6, Director of the Observatoire Océanologique de Banyuls-Laboratoire Arago, Banyuls-sur-mer, France. He studies fish growth mechanisms and mainly the relationships between environmental factors and endocrinological control. The Laboratoire Arago is constituted of two teams "Biological Oceanography," and "Models in Cellular Biology and Evolution". Gilles Boeuf spent 20 years in the CNEXO, then IFREMER in Brest (France), in charge of the Physiology Programs, at the head of the Laboratory "Fish Physiology". He experimented and published numerous papers and reviews on fish physiology, fish growth, endocrinology, salmonid par-smolt transformation, and aquaculture. He visited and teached in a lot of countries involved in aquaculture production (all Europe, North and South America, Japan, Australia…) and spent several years in Chile.