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SPECIES CHOICE IN AQUACULTURE: DOMESTICATION PROCESSES, GENETIC IMPROVEMENT, AND THEIR ROLE IN SUSTAINABLE AQUACULTURE

INTRODUCTION

1. The Fifth Session of ACFR, "recommended that the Fisheries Department examine issues related to species choice in aquaculture, i.e., domestication processes, genetic improvement, and genetic conservation" in order to improve the sustainable contribution that aquaculture makes to the future world fish supply needs. The choice of which species to farm will depend on a variety of factors and will be influenced by market demands, economic feasibility, farmer capacity, biodiversity and environmental concerns, and species availability. Sustainability of aquaculture can also be influenced by the choice of which aquatic species are farmed.

2. The number of farmed aquatic species has increased over the last decades (Table 1) and there is increasing interest to domesticate more species, especially high value species. There are a number of factors that drive the increase in number of farmed aquatic species. The number of farmed species is currently much less than the number that are harvested or trapped from capture fisheries. The consumer is exposed to many more species than are farmed and as a result, farmers have constant motivation to domesticate more species. As many of the world's capture fisheries have reached their biological limit, there is further motivation for aquaculture to fill the gap in demand for aquatic production.

3. Additionally, aquaculture development is not at the same level throughout the world; there are areas that have species and genetically improved strains that are sought after in other parts of the world. Thus, there is further motivation to use alien species or genetically altered species from other areas. Because aquaculture is primarily an economic enterprise, decisions on which species to domesticate, farm or introduce may be based on economic rather than on sustainability criteria or even on general feasibility criteria.

4. The FAO Fisheries Department, primarily through the work of FIRI, has been involved in several activities related to the above recommendation of the ACFR. These activities include an examination of capture-based aquaculture, implementation of genetic improvement training courses and capacity building, analysis of aquaculture seed supply, improving information on alien species and developing policies for genetic resource management. These activities, the lessons learned from them and advice sought from the Committee are discussed below.

CAPTURE-BASED AQUACULTURE

5. Aquaculture with seed harvested from the wild is practiced worldwide on a variety of marine and freshwater species. It is estimated that 20 percent of marine aquaculture production comes from such capture-based aquaculture representing a value of US$ 1.7 billion.

6. Capture-based aquaculture has advantages and disadvantages compared to aquaculture that controls the full breeding cycle of farmed species. In many situations, and especially in developing countries, the collection and grow-out of juveniles present more socio-economic benefits than hatchery based aquaculture since the collection and sale of juveniles to grow-out operators can provide income for sectors of the population that are otherwise excluded from the aquaculture sector. The fact that fish can be farmed without the need to develop expensive hatcheries or breeding programmes is also an important quality. It is an additional benefit that many of the environmental concerns associated with the grow-out of juveniles produced in hatcheries (e.g., the transfer of diseases and the “genetic pollution” of wild stocks), are avoided when seed come from local wild stocks. On the down side, there will be no genetic improvement through breeding when the seed comes from the wild.

7. However, the main concern related to such farming practices is whether they have negative impacts on wild stocks of the targeted species as well as on non-targeted species. The increased production from the culture of juveniles should at least offset any loss in yield from the wild stocks, and collection should not affect wild populations negatively or disadvantage other users of the resource. The impact on natural populations needs to be addressed to determine the sustainability of the practice.

8. Responsible application of aquaculture based on animals captured from the wild requires that juveniles are caught before they experience severe mortality, recruitment must be sufficient to ensure that fisheries targeting adults are compensated, and capture methods must minimize by-catch of non-target species and may not damage supporting habitats.

9. As capture-based aquaculture is a practice which is constantly developing, countries need to create or amend the comprehensive regulatory framework to ensure that the sector develops in a sustainable manner. In most fishery management laws there are minimum sizes on harvested species, and often restrictions on the harvest of spawning adults. In some situations, Governments have tried to outlaw such fisheries, but these attempts have mostly not been supported by scientific data, and have generally been unsuccessful due to inadequate enforcement.

USE OF ALIEN SPECIES

10. Given the increasing number of species being farmed, aquaculturists are faced with choices between using alien species and local species. Alien species are a proven means to increase production and profitability from aquatic systems. However, they have also been identified as one of the most significant threats to biodiversity. Adverse impacts to social and economic systems have also been associated with development of fisheries or aquaculture based on alien species. In order to balance the benefits derived from the use of alien species with these

threats, FAO Fisheries has developed a framework for the responsible use and control of alien species. The framework consists of :

- An overarching international agreement, the Code of Conduct for Responsible Fisheries (CCRF) which is complementary to the Convention on Biological Diversity;

- Means to implement the agreement which include international guidelines such as ICES Code of Practice on the Introduction and Transfer of Marine Organisms[1]; the Asia Regional Technical Guidelines on Responsible Movement of Live Aquatic Animals in Asia[2];

- An information source, the FAO Database on Introductions of Aquatic Species (DIAS) that contains over 4 000 records of international movement of aquatic species, their impacts and the group responsible for the introduction; and

- A means to deal with uncertainty and incomplete information, the FAO elaboration of a Precautionary Approach.

11. FAO is in the process now of creating technical guidelines on the issue as an additional element in the framework to support implementation of the CCRF.

12. Experience has shown that few resource managers are familiar with most of the above framework and very rarely employ guidelines or risk analysis before introducing aquatic species. However, it also appears that many of the species introduced have, as yet, not created significant environmental damage[3] and that the economic benefits have outweighed environmental or social damage. Efforts to domesticate and genetically improve local species as an alternative to using alien species have met with only marginal success.[4]

13. Missing from the framework is consideration on eradication and control measures needed if an alien species becomes invasive.

GENETIC IMPROVEMENT TRAINING AND CAPACITY BUILDING

14. As more aquatic species are being bred in captivity, domestication and genetic improvement will follow. Domestication may be almost inadvertent as those species that adapt to culture systems survive and are reproduced by farmers. However, genetic improvement involves the establishment of specific breeding programmes with specific objectives and broodstock management. Farmers are faced with a choice of species ranging from near wild-type to those that have been subjected to generations of breeding programmes. Usually, the genetically improved

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[1] This code has been accepted in principle by the FAO Regional Bodies, EIFAC, COPESCAL and CIFA.

[2] FAO/NACA. 2000. Asia regional technical guidelines on health management for the responsible movement of live aquatic animals and the Beijing consensus and implementation strategy. FAO Fisheries Technical Paper 402, 53 pp. ftp://ftp.fao.org/docrep/fao/005/x8485e/x8485e00.pdf

[3] Bartley, D.M. and C.V. Casal. 1999. Impact of introductions on the conservation and sustainable use of aquatic biodiversity. FAO Aquaculture Newsletter, 20: 15-19. D.M. Bartley et al. (eds and comps). 2005. International Mechanisms for the Control and Responsible Use of Alien Species In Aquatic Ecosystems, 27-30 August 2003, Xishuangbanna, People's Republic of China. FAO Non-Serial Publication, Rome.

[4] Mattson *et al.* 2005. Aquaculture of indigenous Mekong Species. In: D.M. Bartley et al. (eds and comps). 2005. International Mechanisms for the Control and Responsible Use of Alien Species In Aquatic Ecosystems. FAO Non-Serial Publication, Rome.

species are more expensive and require capacity to manage the breeding programme and broodstock so that the genetic gains persist.

15. In aquaculture, the traits most often targeted for improvement is growth-rate. However, in marine shrimp disease resistance is often of greater interest. Traditional animal breeding using additive genetic variance has been extremely successful at improving growth rate and other related characters. The Genetic Improvement of Farmed Tilapia (GIFT) fish has been an especially successful example of the gains possible from selective breeding[5]. Other techniques for genetic improvement are also available to the farmer and include chromosome-set manipulation, sex-reversal, hybridization, and genetic engineering.

16. Not many of the world's farmed aquatic species have been subjected to formal breeding programmes. Therefore the potential for gains in production from genetic improvement programmes are substantial. It has been estimated that the so-called supply demand "gap" in food from aquatic systems, i.e. the difference between supply from stagnating capture fisheries and current aquaculture production and the demand from a growing human population, could be met simply by instituting genetic improvement programmes on the current farming systems with no additional land or production facilities needed.[6]

17. These techniques can create farmed-species that use resources more efficiently thus reducing inputs and outputs, but they also represent the creation of species that are different from wild relatives and may pose a risk to those wild relatives. In theory if domestication proceeds far enough, farmed species may not be viable in the wild and would not pose a risk. However, this level of domestication has not been achieved and perhaps it is unreasonable to think that it would ever reach this stage.

18. In collaboration with the FAO Inter-Departmental Working Group on Biotechnology, FAO helped coordinate the production of a book on Marker-Assisted Selection (MAS). Two chapters in this book concern aquaculture and they have been edited by a prominent geneticist in the USA. Both chapters indicate that MAS is not used in commercial aquaculture at present and indeed may not be very practical for application in aquaculture, at least in the near term.

19. FAO made the decision to redefine the post of the fishery resources officer that dealt with fishery genetic issues and therefore does not now have the capacity to work full-time or directly on research in this area. FAO does work with competent partners such as the WorldFish Center and advanced scientific institutions such as Kasetsart University in Thailand, and members of the International Network for Genetics in Aquaculture (INGA). Two recently convened workshops have demonstrated that resource managers and private industry are extremely interested in learning genetic principles to help manage broodstock, protect biodiversity and improve farmed species. However, at other fora it has been apparent that there is tremendous controversy over one particular genetic technology, gene-transfer and the creation of trans-genics or genetically modified organisms (GMOs).

20. Experience from partners has shown that generally farmers lack the capacity to manage genetically improved broodstock and continually request that genetically improved breeds are re-sent to them, i.e. the stock has deteriorated. This appears to apply to individual farmers as well as breeding centers.

21. A recent FAO Expert Workshop on Freshwater Seed as Global Resource for Aquaculture held in Wuxi, China P.R., 23-26 March 2006, highlighted a number considerations which are

[5] http://www.adb.org/Documents/Books/Tilapia-Dissemination/IES-Tilapia-Dissemination.pdf

[6] R. Subasinghe et al. (eds.). 2000. Aquaculture in the Third Millennium. FAO/NACA/Government of Thailand

essential in enhancing the development of the freshwater seed production sector to support aquaculture sustainability in addition to an enabling environment whose main elements consist of basic production and human infrastructure, financial/business/marketing support, and policy and legal frameworks. These considerations include seed quality, genetics and breeding, seed certification, seed networking and entrepreneurship, seed production technology, farmer innovations and indigenous knowledge, private-public sector partnerships and strategic elements that will enhance the benefits to rural farmers.

22. The Expert Workshop made the following recommendations:

- Integrating approaches to genetic improvement using successful research findings (e.g. selective breeding, application of genetic markers, sex control techniques, chromosome set manipulation, crossbreeding and transgenesis) with good genetic management, during domestication and translocation of aquaculture stocks;
- Supporting such approaches with efficient and equitable dissemination and technology transfer strategies coupled with awareness and/or certification programs;
- Strengthening awareness of and institutional capacity to deal with ecological risks associated with introductions of alien and/or genetically improved fish; and
- Promoting the use of indigenous species and their domestication for freshwater aquaculture production.

23. The Expert Workshop considered farmer's indigenous knowledge and farmer's practical experience as important and can significantly contribute to research and development. Suggested key actions include:

- Implementing research in a participatory manner, involving farmers, where possible, at every stage of the process;
- Identifying research areas based on farmer needs. Specific areas of research which are thought to benefit rural fishfarmers include: (1) improved seed (genetics and growth rates); (2) disease risk and management; (3) feed formulation using locally available materials; (4) breeding of indigenous species; (5) management of aquatic resources (for wild caught seeds).
- Translating research results in practical terms and ensuring wide dissemination for efficient field application by actors involved in the seed production sector.
- Recognising that there are many currently practiced farmer innovations in many countries, such practices can be further verified through appropriate research and improve such innovations for further dissemination.

24. There is tremendous potential, yet lack of FAO specialized expertise in this area.

ESTABLISHING POLICIES FOR GENETIC RESOURCE MANAGEMENT

25. Earlier fora highlighted the lack of international policies on genetic resources[7]. The FAO Commission for Genetic Resources in Food and Agriculture (CGRFA) has recently decided to

[7] R.S.V.Pullin, D.M. Bartley and J. Kooiman (eds), Towards Policies for Conservation and Sustainable Use of Aquatic Genetic Resources. ICLARM Conference Proceedings, 59. Manila.

begin work that will help establish a programme of work for the commission on policies for fishery genetic resources. With support from CGRFA, FAO convened a workshop of international experts in the fields of aquaculture, capture fisheries, deep sea fisheries and genomics and advanced genetic technologies in order to present the status and trends of genetic resources and biodiversity in these areas and to use this information to develop issues that could be part of the work programme of the CGRFA and other groups interested in policies on fishery genetic resources.

26. Recommendations of the group of experts on species choice and domestication were as follows:

- The current FAO datasets, e.g., on aquaculture and fisheries production, include almost no information on genetic resources either of farmed or wild populations. Similarly, FAO Species Fact Sheets contain good information on taxonomic features and natural history, but nothing on genetic diversity or on strains, stocks, or sub-populations. As the number of farmed strains (hybrids and other genetically altered forms) increases in aquaculture, FAO aquaculture statistics will need to change to accommodate this change (the livestock sector has done this with the world-watch list for livestock breeds[8]). If farmers are expected to choose appropriate species for farming, there needs to be an authoritative, freely accessible and unbiased information system available to help them make informed decisions.

- Cost/benefit analysis of breeding programmes and genetic resource management is needed, so that farmers can choose those technologies that will provide the most benefits for their situation.

- Potential benefits from selective breeding have been barely tapped; application of the techniques is now hampered by lack of capacity and lack of prioritized funding.

- Extremely poor awareness of the value and importance of FiGR at all levels.

- There are different perceptions of the value of wild (native) FiGR.

- Consumer ignorance of how food is produced constrains progress.

27. Thus, policies must be put in place to help farmers make good choices in terms of domesticated strains, genetically improved species and alien species. These policies should be science-based and directed research or compilation of case studies could assist.

28. Additionally, with the increased capacity of African aquaculturists, African farmers are requesting importation of the GIFT fish (see above). WorldFish Center policy at the beginning of the GIFT project was NOT to re-introduce the fish back into Africa because it could endanger native tilapia genetic resources. However, the technology that produced the GIFT fish, i.e., selective breeding, was to be developed and promoted in Africa and elsewhere. In light of a scarcity of examples of environmental damage from tilapia, increased pressure from farmers, and a realization that introducing GIFT selective breeding as a technology into Africa is only a few years different than actually introducing the GIFT fish, WFC has changed its policy on re-introduction of the GIFT fish.

29. None-the-less, biodiversity concerns exist with the use of GIFT fish and other genetically improved or alien species. Thus, species choice will depend on the environment where the species

[8] http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGA4.htm

is to be used. There are areas where farming of tilapia should not be allowed, and areas where aquaculture of any kind should not be allowed.

GUIDANCE SOUGHT FROM THE COMMITTEE

30. The Committee is requested to advise on possible future directions for research on:

- how to increase awareness of the value of genetic resources in aquaculture;
- measuring the actual impact of capture-based aquaculture on recruitment of wild species;
- the role of alien species in responsible aquaculture, e.g. how to improve the FAO Framework on alien species, how to predict whether a species will establish itself and become “invasive” in new environments, and how to compare benefits and risks of domesticating local species vs introducing alien species;
- how to address eradication and control measures for invasive alien species once established;
- how to identify researchable areas on freshwater seed production based on farmer needs and how to enhance farmer involvement in research;
- how to use research in verifying farmers’innovative practices prior to wider dissemination;
- improving capacity of farmers to maintain genetically improved lines;
- appropriate genetic technologies that are pro-poor;
- how to zone and enforce areas where aquaculture or certain species should not be allowed;
- future role of genomics and advanced genetic technologies in aquaculture; and
- how to prioritize work in this area given the shortage of human and financial resources, and the tremendous diversity of species, environments and capacities in developing countries.

31. The FAO Fisheries Department gratefully acknowledges the suggestion from the 5th Session that the “ACFR may be able to play a role in this area” and further requests the Committee to elaborate what such a role could be.

Table 1. Number of Species Farmed in Asia 1950 - 2000

Species Group	1950	1960	1970	1980	1990	2000
Aquatic Plants	6	8	10	13	15	15
Cephalopods			1			
Crustaceans	3	9	11	17	26	29
Demersal Marine	3	5	8	13	23	34
Freshwater & Diadromous	29	33	36	41	54	60
Marine Fish Nei	1	1	1	1	1	1
Misc. Aquatic Animals	2	5	6	6	6	6
Molluscs	10	10	18	22	23	25
Pelagic Marine	2	2	3	4	4	9
TOTAL	**56**	**73**	**94**	**117**	**152**	**179**