GOVERNMENT OF JAPAN

INTERNATIONAL CONFERENCE ON SUSTAINABLE CONTRIBUTION OF FISHERIES TO FOOD SECURITY

Kyoto, Japan, 4-9 December 1995

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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

MARINE AND COASTAL AREA HATCHERY ENHANCEMENT PROGRAMMES:

Food Security and Conservation of Biological Diversity.

By

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FOOD SECURITY AND CONSERVATION OF BIOLOGICAL DIVERSITY

EXECUTIVE SUMMARY

Marine ranching offers an interesting solution to obtaining more animal protein from the aquatic environment. This involves the use of hatchery management to support, augment, or create new fisheries. Although subtly different in meaning, the terms "marine ranching", "hatchery enhancement" and "culture-based fisheries" are synonymous for the purpose of this paper.

Three main criticisms have been levelled at the use of ranched fish to replenish natural populations: lack of evidence that such enhancement benefitted the fishery; the high cost of maintaining the hatcheries; and the fear of losing natural genetic diversity through interaction of hatchery fish with native populations. Moreover, ranching has not had a particularly bright history. The continuing decline of cod stocks despite the release of billions of Atlantic cod into the Atlantic from both North America and Norway provides an example. Reasons for this lack of success include the following: the decline of the fishery was inadequately addressed and a rather simplistic approach to enhancement was adopted - dumping millions of larvae into appropriate water bodies and hoping; most programmes were not monitored and hatchery fish were not tagged, thereby making it difficult to differentiate between hatchery and native fish.

Nevertheless, despite fears of loss of genetic diversity and other harmful effects through interaction of hatchery and native fish, the goal of many enhancement programmes is for the wild fish to mix with hatchery fish and form a new and larger mixed population. Therefore, an important option for certain enhancement programmes and for certain aquatic species will be to try and create fish in the hatchery that are compatible with wild stocks and the environment. To achieve this, the hatchery enhancement programme must have clearly defined objectives and goals. A major objective should be to conserve genetic resources in wild and cultured stocks. Given that most of these resources reside in wild populations and that fisheries make up the largest single source of animal protein, every effort should be made to protect the wild resources.

This paper aims at outlining general principles and procedures that should be incorporated into a hatchery enhancement or ranching programme to conserve and utilize genetic resources (biodiversity). Items addressed include the understanding of natural levels and organization of genetic diversity, the objective of ranching programmes, the understanding of the reasons for decline in original fishery, special considerations for the establishment of a new species, assessment of hatchery technology and husbandry, assessment of ecological requirements of ranched species, and the monitoring of both the hatchery and wild populations.

The paper concludes that aquatic ranching is a complicated area involving technology, biology, ecology, socio-economics and politics. A recent meeting of experts from around the world established a "responsible approach" to hatchery enhancement that involves multi-disciplinary assessment, monitoring and action. Although genetic considerations alone will not ensure a successful ranching programme, the long-term success of production and conservation efforts will be impossible without applying the principles of genetic resource management.

PROGRAMMES DE MISE EN VALEUR DES ECLOSERIES EN MILIEU MARIN ET COTIER: SECURITE ALIMENTAIRE ET PRESERVATION DE LA DIVERSITE BIOLOGIQUE

RESUME

Le "ranching" marin est un moyen intéressant de retirer davantage de protéines animales du milieu aquatique. Cela implique que l'on gère l'incubation afin de préserver ou d'accroître les pêcheries, ou encore d'en créer de nouvelles. Malgré leur signification légèrement différente, les expressions "ranching marin", "amélioration à partir d'écloseries" et "pêche fondée sur l'élevage" sont ici considérées comme synonymes.

L'utilisation de poissons d'élevage pour reconstituer des populations naturelles a fait l'objet de trois critiques principales : rien ne prouve apparemment que la pêche ait tiré profit de cette amélioration, l'entretien des écloseries coûte très cher et il est à craindre que l'interaction des poissons d'élevage et des populations indigènes ait un effet préjudiciable sur la diversité génétique naturelle.

De plus, les résultats obtenus jusqu'ici n'ont pas été particulièrement brillants. La diminution constante des stocks de morue de l'Atlantique malgré la libération, à partir de l'Amérique du Nord et de la Norvège, de milliards de ces poissons dans l'Atlantique en fournit un bon exemple. Au nombre des raisons de cet insuccès, on peut évoquer le fait que l'on n'a pas su faire face de façon adéquate au recul de la pêche et qu'on a adopté une approche quelque peu simpliste de l'amélioration, en déversant des millions de larves dans des masses d'eau appropriées et en espérant que tout irait ensuite pour le mieux; en outre, la plupart des programmes n'ont fait l'objet d'aucun suivi et les poissons d'élevage n'ont pas été marqués, ce qui n'a pas permis de les distinguer aisément des poissons indigènes.

Toutefois, en dépit des risques de perte de diversité génétique et des autres effets néfastes qui peuvent résulter de l'interaction des poissons d'élevage et des poissons indigènes, bon nombre de programmes d'amélioration ont pour objectif de mélanger poissons sauvages et poissons d'élevage en vue de former une nouvelle et plus nombreuse population mixte. En conséquence, pour certains programmes d'amélioration et pour certaines espèces aquatiques, une des principales options consistera à essayer d'obtenir, dans les écloseries, des poissons qui soient compatibles avec les stocks ichtyologiques sauvages et l'environnement. A cet effet, il convient de définir clairement les buts et objectifs des programmes d'amélioration en écloseries. Ces programmes devraient en particulier s'attacher à préserver les ressources génétiques des stocks sauvages et d'élevage. Etant donné que l'essentiel de ces ressources se trouvent dans les populations sauvages et que la pêche constitue la plus importante source de protéines animales, aucun effort ne doit être épargné pour protéger les ressources sauvages.

L'article expose les méthodes et principes généraux auxquels devraient se référer les programmes d'amélioration en ecloseries ou de "ranching" pour préserver et tirer parti des ressources génétiques (diversité biologique).

Au nombre des points abordés figurent les niveaux naturels et l'organisation de la diversité génétique, les objectifs des programmes d'amélioration, les raisons de la régression de la pêche dans son état originel; l'article contient également des considérations spéciales sur l'implantation des nouvelles espèces, une évaluation des techniques d'incubation et des méthodes d'élevage, une analyse des besoins écologiques des espèces élevées et un aperçu des techniques de surveillance des populations sauvages et d'élevage.

L'article s'achève par la constatation que le "ranching" aquatique est un domaine complexe où interviennent des considérations techniques, biologiques, écologiques, socio-économiques et politiques. A l'occasion d'une réunion récente, des experts du monde entier ont défini une "approche responsable" de l'amélioration à partir d'écloseries, fondée sur un processus d'évaluation, de surveillance et d'intervention de caractère pluridisciplinaire. Bien que la prise en compte des facteurs génétiques ne puisse à elle seule assurer la réussite d'un programme de "ranching", les efforts déployés en matière de production et de conservation ne pourront être durablement couronnés de succès que dans la mesure où les principes de la gestion des ressources génétiques auront été appliqués.

PROGRAMAS DE REPOBLACION EN ZONAS MARINAS Y COSTERAS: SEGURIDAD ALIMENTARIA Y CONSERVACION DE LA BIODIVERSIDAD

RESUMEN OPERATIVO

La repoblación marina representa una solución interesante para obtener más proteína animal del medio marino. Esta práctica implica el uso de piscifactorías para mantener o ampliar pesquerías existentes o bien para crear otras nuevas. Para los fines de este documento, los términos "repoblación marina", "fomento a través de piscifactorías" y "pesquerías basadas en la acuicultura" se utilizarán como sinónimos, pese a existir entre ellos sutiles diferencias de significado.

La repoblación marina para reponer poblaciones naturales ha sido criticado por tres motivos principales: la falta de pruebas de que esta forma de fomento resulte beneficiosa para la pesquería; los altos costos de mantenimiento de las piscifactorías; y el temor de que la interacción entre peces de criadero y poblaciones indígenas ocasione pérdidas de diversidad genética natural. Además, la historia de la repoblación marina no ha sido particularmente brillante: un ejemplo de ello es la constante reducción de las poblaciones de bacalao del Atlántico, por más que tanto América del Norte como Noruega hayan liberado en este océano miles de millones de ejemplares de la especie. Entre los motivos de tal falta de éxito cabe señalar que la decadencia de la pesquería en cuestión no se abordó en forma adecuada, adoptándose para su fomento un enfoque bastante simplista que consistía en repoblar con millones de larvas esperando que todo fuera bien; además, en la mayor parte de los programas no hubo seguimiento, y como tampoco se había procedido a marcar los peces de criadero, posteriormente resultó difícil distinguirlos de los ejemplares indígenas.

Sin embargo, a pesar de los temores de pérdidas de diversidad genética y otros efectos perjudiciales de la interacción entre peces de criadero y salvajes, la finalidad de muchos programas de repoblación es que los peces salvajes se mezclen con los producidos en piscifactorías integrando así una nueva y más numerosa población mixta. Por consiguiente, una opción importante para determinados programas de repoblación y para ciertas especies acuáticas será la de intentar producir, en los criaderos, peces que sean compatibles con las poblaciones salvajes y con el ambiente.

Para lograr este fin, el programa de repoblación debe tener objetivos y metas claramente definidos. Una de sus finalidades principales debe ser la conservación de los recursos genéticos, tanto de las poblaciones salvajes como de las cultivadas. Dado que la mayor parte de estos recursos genéticos se halla en las poblaciones salvajes la pesca constituye la mayor fuente individual de proteínas animales, es necesario que se haga todo lo posible por proteger los recursos salvajes.

Este documento se propone resumir los principios y procedimientos generales que deben incorporarse a un programa de repoblación, con miras a conservar y utilizar los recursos genéticos (biodiversidad).

Entre los temas tratados figuran el conocimiento de los niveles naturales de diversidad genética y de la organización de ésta última, la finalidad de los programas de repoblación, la comprensión de las causas que han provocado la decadencia de la pesquería original, consideraciones particulares relacionadas con el establecimiento de una nueva especie, una evaluación de la tecnología y las prácticas zootécnicas empleadas en las piscifactorías, la valoración de las necesidades ecológicas de las especies empleadas en la repoblación, y el seguimiento de las poblaciones, tanto de criadero como salvajes.

La conclusión del documento es que el de la repoblación acuática es un tema complejo, que guarda relación con la tecnología, la biología, la ecología, las disciplinas socioeconómicas y la política. En una reciente reunión de expertos de todo el mundo se estableció un "enfoque responsable" para la repoblación por medio de piscifactorías, que comprende una evaluación multidisciplinaria, prácticas de seguimiento, y actividades pertinentes. Si bien es cierto que las consideraciones de índole genética no garantizarán por sí solas el éxito de un programa de repoblación, si no se aplican los principios de la ordenación de recursos genéticos será imposible que los esfuerzos de producción y conservación puedan obtener buenos resultados a largo plazo.

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1. INTRODUCTION

1.1 Background

This thematic study was prepared as part of the background material for the International Conference on Sustainable Contribution of Fisheries to Food Security being held in Kyoto, Japan, in December 1995.

An abridged version of this paper was presented at the International Forum on Biodiversity. Science and Development: towards a new partnership. Unesco, IUBS, and the Government of France, September 5-9/1994. Paris, France.

1.2 Acknowledgements

The many helpful suggestions and reviews of D.B. Kent and K.M. Leber are gratefully appreciated.

1.3 Overview of Marine and Coastal Area Hatchery Enhancement

As more protein from the aquatic environment becomes necessary due to increasing population pressure, new management practices and innovative technologies must be applied to the world's aquatic resources and environments. One such management tool is the use of hatcheries to support, augment, or create new fisheries. This practice is often termed "marine ranching", "hatchery enhancement" or "culture-based fisheries". Although the terms have subtle differences in meaning, for the purpose of this presentation they are synonymous.

Pacific salmon (*Oncorhynchus spp.*) are perhaps the most widely ranched species of fish (Netboy, 1980; Isaksson 1988a). However, other species including, cod, *Gadus morhua*, (Svåsand et al. 1990), Atlantic salmon, *Salmo salar*, (Isaksson 1988a,b), sturgeon (*Acipenseridae*) (Binkowski and Doroshov 1985; FAO 1992c), red drum, *Sciaenops ocellatus*, (Rutlege 1989), white seabass, *Atractoscion nobilis*, (Kent et al. in press), red seabream, *Pagrus major*, (Smith 1983; Sugama et al. 1988), striped mullet, *Mugil cepalus*, (Leber et al. in press) and several invertebrate species are also currently being raised in hatcheries to augment natural fisheries (Lockwood 1991). Japan is a leader in ranching technology, conducting ranching and research on approximately 80 marine species and currently has several commercial fisheries based primarily on fish produced in hatcheries (Watanabe et al 1988; Ikenoue and Kafuku 1992).

However, the use of animals raised in captivity to replenish natural populations has been questioned and criticized for the following three reasons: i) lack of evidence that the hatchery enhancement benefitted the fishery; ii) lack of a cost-effective use of resources, i.e., the hatcheries were too expensive to maintain (MacCall 1989; Hilborn 1992); and more recently iii) the fear of losing natural genetic diversity through interaction of "hatchery" fish with native populations (Hindar et al. 1991, Philipp et al 1993). Hatchery enhancement programmes must address these concerns.

The history of ranching, especially marine ranching, has not been very bright. Billions of Atlantic cod were released into the Atlantic from both North America and Norway, yet the cod stocks continued to decline (MacCall 1989; Griffin 1993). Of the eggs produced in USA enhancement programmes of the 1940's, 98% were of the marine species cod, flounder species, and pollack, *Pollachius virens*; these programmes were ended when the associated fisheries did not increase (Larkin 1991; Richards and Edwards 1986).

Many past ranching or enhancement programmes failed mainly because the causes for the decline in the fishery were not adequately addressed or corrected and because a rather simplistic approach to restoring the population was adopted: simply dump millions of larvae into convenient water bodies and hope (Troadec 1991). Furthermore, most hatchery enhancement programmes were not monitored and hatchery fish were not tagged. Therefore, it was usually impossible to differentiate "hatchery" fish from "native" fish (Parker et al. 1990 and references).

However, the complexity of natural aquatic populations is now understood better. Current hatchery enhancement programmes involve ecological and genetic considerations (Bartley et al. in press). Tagging technology has improved to incorporate electronic tags (Kent et al. in press) and genetic tags that can uniquely identify fish or groups of fish (Utter and Ryman 1993; Jorstad et al. 1994; Wirgin and Waldman 1994).

Recent reviews demonstrated that many anadromous salmonoid populations are well adapted to their native habitat and that infusion of exotic genes from populations from different habitats, including hatcheries, may harm the native fish (Hindar et al. 1991; Waples 1991a). Some of the reported effects of the interaction between hatchery fish and closely related or conspecific fish, are genetic erosion (loss of alleles), introduction of badly adapted genes, introduction of disease organisms, changes in genetic sub-population structure, changes in stock size, reductions in survival, changes in adaptive behaviour, reductions in homing accuracy, changes in migration patterns, reductions in recapture rate and increased disease susceptibility (Ryman et al. in press). Moreover, the effective size of an enhanced population could theoretically be reduced by the addition of hatchery fish with variable reproductive success and reduced genetic variability (Ryman and Laikre 1991). The above effects are due to both direct competition, predation, and disease transmission between hatchery and wild stocks, as well as to the introgression of "hatchery" genes into the wild population.

Strategies to reduce or eliminate the interaction between hatchery and wild fish include i) creating hatchery fish that are substantially different from wild stocks in migration patterns, spawning times, or food preference, so that hatchery and wild stocks would not come into contact; ii) altering release or aquaculture sites to minimize contact (Isaksson 1988b); iii) and producing sterilized fish so that hatchery and native fish cannot reproduce (Turner 1988; Seeb et al. 1993).

Each option has its strengths and weaknesses for conserving the native gene pools and each should be considered in a hatchery programme.

However, the goal of many enhancement projects is for the hatchery and wild fish to mix and form a new and larger mixed population (Bartley et al. 1995). Therefore, trying to create fish in the hatchery that are compatible with wild stocks and the environment will be an important option for certain enhancement programmes and for certain aquatic species.

The creation of a "wild" fish under culture conditions should be approached by minimizing artificial and inadvertent selection and by sound hatchery management to conserve genetic diversity. However, it may be difficult to create such a fish successfully in an artificial environment such as a hatchery (Durand et al. 1993; Howell 1994).

Appendix 1 presents an annotated table of marine and coastal hatchery enhancement programmes and projects. The majority of the activity is in the developed countries of the northern hemisphere and has involved high value species, such as salmonids. The primary objective of many hatchery enhancement projects is to increase a sport fishery, rather than to increase commercial catches or to provide more food.

Although governments may not always need to generate products or profits as long as they are seen to be providing for their constituents, the effective use of government resources and the avoidance of non-sustainable or ineffective practices, e.g., many government subsidies, should be priorities in overall fisheries management.

Therefore, the hatchery enhancement programme must have clearly defined objectives and goals (Barber and Taylor 1990). A major objective of any aquatic development programme should be to conserve aquatic resources (FAO 1993). Given that most of these resources reside in wild populations and that fisheries make up the largest single source of animal protein (Table 1), every effort should be made to protect the wild resources.

Table 1. Global animal protein production in 1989. Data from the Food and Agriculture of the United Nations, Rome, Italy (FAO 1992a,b).

SECTOR	PRODUCTION (thousand metric tonnes)
Capture Fisheries	88 514
Aquaculture	11 021
Swine Farming	67 460
Beef and Veal Farming	49 436
Poultry Farming	37 817
Mutton and Lamb Farming	6 473

This paper aims at outlining general principles and procedures that should be incorporated into a hatchery enhancement or ranching programme to conserve and utilize genetic resources (biodiversity) . Hatchery enhancement must consider the hatchery fish to be released into the wild, the broodstock used to produce them, the wild populations in the area of release, and the mixture of the hatchery and wild fish.

2. PROTOCOLS FOR CONSERVATION OF BIODIVERSITY IN AQUATIC RANCHING

The following section outlines general considerations for aquatic ranching that will help conserve the genetic resources in both hatchery and wild populations. Items addressed include the understanding of natural levels and organization of genetic diversity, the objective of ranching programmes, the understanding of the reasons for decline in original fishery, special considerations for the establishment of a new species, assessment of hatchery technology and husbandry, assessment of ecological requirements of ranched species, and the monitoring of both the hatchery and wild populations.

2.1 Assessing Natural Levels and Organization of Genetic Diversity

The first step in conserving genetic resources is to know what genetic resources exist. This basic information is often lacking or incomplete for many aquatic species (Allendorf and Utter 1979). Protein or isozyme analysis enables the genetic variability of numerous species to be examined quickly and relatively cheaply. Protein variation can provide information on geneflow, population structure, species identification, taxonomy, hybridization, and evolutionary relationships in fishes (Allendorf and Utter 1979; Utter and Seeb 1990). More information is becoming available on DNA level variation in aquatic species (Wirgin and Waldman 1994).

Because a prime desire is to conserve natural diversity, a hatchery enhancement or ranching programme should strive to utilize the known information on natural diversity and complement or reproduce it in the hatchery product (Meffe 1990). When an exotic species is being ranched, knowledge of natural levels of diversity will help pick strains for evaluation in the new environment or will help identify strains for crossbreeding in the hope of establishing a well adapted population (see discussion in Waples 1991a).

2.2 Defining Objectives of Enhancement/Ranching Programmes

This obvious step is often neglected or misinterpreted by managers and evaluators. An all too common goal of past enhancement projects has been simply the release of x number of eggs/fry or fish (Troadec 1991).

However, clearly defined goals are absolutely essential to design appropriate hatchery management strategies, as well as to evaluate realistic alternatives to hatchery enhancement (Allendorf and Ryman 1987).

One means to help set realistic objectives is to include input from the various user groups, e.g., sport and commercial fishermen, in the development of a stock enhancement programme's objectives.

Thus, the fishing sector will be better informed and will understand constraints and special regulations that may be associated with the enhancement effort. In addition, the fishing sector may be required to contribute to the evaluation/assessment of the project in order to determine if stated objectives are being met (Kent et al. 1995).

It is given that a major objective is the conservation of genetic resources in wild and cultured stocks. Since the Earth Summit in Rio de Janeiro, development agencies as well as aquaculturists have been emphasising that sustainable production from natural systems must involve the conservation of genetic diversity. This requires thorough documentation of the existing biological and genetic resources (Ryman et al. in press).

Currently nearly all of the aquatic genetic resources are found in wild populations, as little domestication has taken place. It will be necessary to preserve the existing stock structure and migration patterns found in wild populations and to ensure that culture practices do not adversely affect the wild stocks.

The conservation objectives that the hatchery should establish will be based on the results of the survey/documentation of the wild stocks. Components of genetic diversity to be conserved include more than simply alleles and genes, but may encompass numerous subpopulation or metapopulations. Fishery geneticists for the US Endangered Species Programme recommend the conservation of "ecologically significant units", defined in the National Marine Fisheries Service statement on endangered species to be a genetic population/stock which is (i) genetically unique, (ii) which exhibits unique adaptation, (iii) which inhabits unique habitat, or (iv) whose extinction would represent loss of an evolutionarily significant legacy (Waples 1991b).

The preamble to the Convention on Biodiversity (UNEP 1992) identifies intrinsically significant units as a genetic population/stock which has social, economic, scientific, educational, cultural, recreational, or aesthetic value, and thereby worthy of conservation.

Production goals in terms of real increases to a fishery and other measures of success of many enhancement projects are also necessary, but often omitted. Although such goals are essential to planning and evaluation and compatible with conservation goals, they will not be discussed further here (see Blankenship and Leber 1995).

2.3 Assessing Reasons for Decline in Original Fishery

This critical phase is necessary to evaluate the logic behind the enhancement programme and to discover means to optimize effort. For example, nearly 80% of salmon spawning habitat has been degraded in California (Netboy 1980) and there has probably been a similar loss of sturgeon spawning habitat in the tributaries to the Caspian Sea (FAO 1992c).

Therefore, hatchery production of juveniles was seen as a means to replace the function of these habitats. This is at least logical.

The fishery for white sturgeon, *Acipenser transmontanus*, was collapsing in California due to overfishing. A ban on commercial fishing and a moratorium on sport fishing has been effective at partially reviving the stock in the San Francisco Bay and Sacramento River to the point where an active sport fishery is now allowed (Kohlhorst 1980).

Hatchery enhancement has been suggested for the Black and Azov Sea fisheries, which are collapsing due to pollution and an exotic and voracious comb jellyfish, *Mnemiopsis leidyi* (Travis 1993). Although the restocking of these seas would involve fish theoretically resistant to the comb jelly, enhancement would appear ill-advised until pollution and fishing regulations were implemented.

Many stocks may be so diminished from various causes that the study of wild populations may be impractical. In such cases, reviews of past studies on the stock and on related species or populations could be undertaken, with the aim to plan additional studies as needed and where possible.

2.4 Special Considerations for Use of "Exotic" Species

The use of exotic species in ranching or enhancement projects is a special case that requires planning and evaluation of the ecological and socio-economic risks associated with using a species in an area outside its natural range.

The introduction of Kapenta, *Limnothrissa miodon*, a freshwater herring-like fish, into Lake Kariba, Zimbabwe, resulted in a fishery that produces 20 000 tonnes/yr valued at over US$10 000 000 (Bartley 1993a); farming of Nile tilapia, *Oreochromis niloticus*, as well as other tilapia species, provides fish farmers throughout the world with a highly desirable and marketable product (Pullin 1988). Besides the additional animal protein introduced species may provide to an area, exotic species often command a higher market price than local species and may provide local economies means to acquire foreign currency from tourism or through export (Reynolds and Greboval 1989).

Unfortunately, the results of an introduction are not always predictable (Mann 1992) and not always positive. Introductions of aquatic species are now considered one of the main threats to natural aquatic populations (Williams et al. 1989).

European populations of crayfish, *Astacus astacus*, were decimated by a fungal disease inadvertently introduced when American crayfish, *Orconectes limosus*, was brought to Europe (Furst 1984). The use of Atlantic salmon from the Baltic Sea in stock enhancement programmes in Norway introduced a parasite to the Norwegian Sea that now threatens native stocks (Bakke 1991; Folsom et al. 1992).

The widespread movement of rainbow trout, *O. mykiss*, throughout the western United States, has reduced local aquatic invertebrate fauna and threatened other species and subspecies of salmonids through competition, predation, and hybridization (Nicola 1976; Bartley and Gall 1991).

The introduction of the Nile perch, *Lates niloticus*, into Lake Victoria changed primarily small-scale artisanal fisheries into a multi-million dollar commercial fishery that supports industrialized processing and exportation ventures; the Nile perch may have also led to the extinction of several hundred of Lake Victoria's species of fish (Barrel et al. 1985, Reynolds and Greboval 1989).

The purposeful movement of fish and shellfish from one area to another has been, and will continue to be, a viable method to increase aquatic food production (Welcomme 1988). However, institutions responsible for introductions and transfers of aquatic organisms must be aware of and evaluate both the disadvantages and advantages.

In this light, professional fisheries societies and international organizations are promoting a responsible approach to the use of introduced or transferred species through the use of codes of practice and protocols (Appendix 2). Foremost in this regard are the International Commission for the Exploration of the Sea and the European Inland Fisheries Advisory Commission (ICES/EIFAC) Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms (Turner 1988).

The code in Appendix 2 states that a proposal to import an exotic species should be made by the person, company or institute wishing to use it. The proposal should be reviewed independently by local authorities or resource managers.

Local authorities may wish to seek the advice of external authorities, such as ICES or EIFAC, on the risks/benefits of the proposal. The review could either lead to an approval to use an exotic species, a refinement or redraft of the proposal, or a denial. If approved, quarantine, monitoring and evaluation will be essential to determine the success of the project and to benefit future uses of exotic species.

These codes and associated protocols provide a framework for decision-making, facilitating thorough consideration and evaluation of such things as the need for the introduction, disease and quarantine safeguards, potential alternatives to the proposed introduction or transfer, and the protection of the local and neighbouring resources (Kohler and Stanley 1984).

"These are similar considerations that any good financial analyst would look at to assure success of a new product or business enterprise: is there a need for the product? what other local product may be better developed? how will the new product fit in amongst established products? how will the new product affect the market in general? how will distribution and production be controlled?" (Bartley 1993b).

Aquaculture is currently the number one cause of species introductions into freshwater habitats (Welcomme 1988). For this sector to continue growing positively, due consideration should be given to codes of practice promoting the responsible use of introduced and transferred aquatic species.

2.5 Assessing Established Hatchery Technology, Husbandry and Fish Health

It will be imperative to produce healthy offspring from a large base of healthy broodstock. Therefore, controlled breeding, larval rearing and nutrition and disease control need to be optimized. An alternative scenario would involve harvesting naturally produced seed for growth outside the hatchery if controlled reproduction in the hatchery is not possible. Although this option may be cost effective in some marine culture (Hoffman 1991), this type of "mining" of the natural population to support a hatchery may be detrimental to the wild populations and may not be sustainable. For a variety of aquatic species, such as salmon, tilapia, red seabream, carps, and oysters, hatchery technology is well established (Jhingran and Pullin 1985; Pullin 1988; Folsom et al 1992). For others, such as many coral reef fish (excluding the popular clownfish, *Amphiprion spp.*), and many marine invertebrates, it is possible to raise only the early larval stages (Allen 1991; Lee and Wickens 1992) that would probably survive poorly in the wild. Often hatchery technology exists, but is too expensive to produce animals of a given size, as in the case of homarid lobsters, which are cannibalistic under culture conditions (Lee and Wickens 1992).

Technological breakthroughs or advances may make previously difficult species more suitable for hatchery enhancement: the use of pituitary extract to induce spawning in Chinese carps greatly increased the use of these species in culture (Pullin in press). The development of techniques to mass rear cod in semi-natural ponds has led to renewed interest in cod-ranching (Svåsand et al. 1990). Advances in larval and broodstock nutrition will also enable more species to be considered for hatchery enhancement (Watanabe et al. 1989).

A major concern in aquaculture is the control of pathogens; technology and protocols to minimize the risk of disease transmission should be applied to all hatchery enhancement programmes. Fish health issues will be especially important when fish that are cultured, often in high densities and under potentially stressful conditions, are released into the wild. As mentioned earlier, the use of exotic species or even exotic populations in hatchery enhancement can also introduce new pathogens into the environment. A further example is the spread of furunculosis from wild populations of salmonids to farm stocks in the United Kingdom and Denmark, which then spread to both farmed and wild salmonoid stocks elsewhere (Johnsen and Jensen 1994).

Current codes of practice set out protocols to minimize this risk (Turner 1988). The European Community has issued directive 91/67/EEC that stipulates the fish health conditions that must be met before cultured animals or their products can be imported and marketed in the EU.

Basic elements of minimizing the risk of disease spread are listings of known pathogens/parasites for which to screen, periodic screening and inspection by qualified fish health personnel, designation of species that are disease-prone, designation of geographic zones that either have a high risk or low risk of disease occurrence, and quarantine (Turner 1988, Hodson and Hill 1993).

In light of the fact that fish health is a result of the interaction among the fish, the pathogen, and the environment, optimizing the culture environment and proper husbandry will be vital in maintaining healthy stocks in the hatchery and thus minimizing the risk of disease transmission to natural stocks.

2.6 Assessing Proposed Areas for Reintroduction or Enhancement

It will be of little benefit to stock a good fish into a degraded environment. Even in unpolluted areas, site of release is an important survival condition for hatchery produced fish. Research in Hawaii on striped mullet, *Mugil cephalus*, (Leber et al. 1994) and in California on white seabass (Kent et al. in press) demonstrated that fishes released in protected areas and bays survived better than on the open coast. In anadromous species or other migratory species, timing of release, as well as location, will be important (Cresswell 1981; Naiman et al. 1987).

In an enhancement project, this assessment should also include the level of fishing activity likely to impinge on the developing enhanced population. Care should be taken not to increase the fishing activity or to relax regulations and limits on the enhanced fishery simply because fish are now being introduced into the wild. There is a real danger in optimistic fishers reducing the wild and enhanced stocks to a point below pre-enhancement levels (Larkin 1977; Nelson and Soulé 1987).

Indeed, successful enhancement projects in Japan and off of the Texas coast in the Gulf of Mexico were coupled with habitat renovation and more restrictive fishing regulations (Bhat 1989; King et al. 1993). Again, the objectives of the ranching programme will determine whether or not and to what extent fishing should be allowed on the hatchery product. It is likely that fishing regulations will need to be adapted to give the enhancement project time to work.

2.7 Monitoring

An often neglected step in ranching and enhancement programmes has been the monitoring of a hatcheries contribution to a fishery or to a wild population. This is due to the difficulty in accurately identifying hatchery fish without using expensive tags or unduly handling large amounts of fish. However, techniques for the mass marking of large amounts of fish are being developed (Parker et al. 1990). Genetic analyses using allozyme and DNA markers can now identify hatchery contributions to mixed fisheries and even individual fish (Utter and Seeb 1990; Wirgin and Waldman 1994). An advantage of genetic markers over physical tags is that they can assess introgression and hybridization between hatchery and wild populations in subsequent generations (Campton and Johnston 1985; Bartley and Gall 1991).

The monitoring of the population in the hatchery is often overlooked in ranching programmes. It is necessary to maintain levels of genetic variability in the hatchery in order to produce viable and well adapted fish for release. Hatchery populations of broodfish will usually have reduced levels of variation compared with that found in the wild (Allendorf and Ryman 1987).

However, effective hatchery management can prevent this reduction from becoming problematic (Tave 1986). Management would involve using large numbers of broodfish, avoiding high levels of inbreeding, periodic infusion of new genes, and maintaining genetic lines or stocks (Bartley et al. in press).

Allozyme studies on shrimp, *Panaeus japonicus*, cultured in Italy (Sbordoni et al. 1987) revealed that after seven generations in a hatchery, heterozygosity was reduced and that coincidentally the percentage hatch of shrimp larvae also decreased.

An explanation for the decrease in hatchability was inbreeding depression, brought on by small effective population size of hatchery broodstock.

The number of shrimp actually contributing genes to the next generation was much lower than the number of shrimp actually present in the hatchery. Analysis of allozyme genotypes and effective population size in a hatchery enhancement programme on white seabass revealed that only about one half of the parents were contributing genetic resources to the progeny that were to be released (Bartley et al. 1992). Conservation goals were established that called for a specific number of adult white seabass spawners; monitoring revealed that the hatchery needed to keep twice that amount in captivity (Bartley et al. in press).

Striped bass, *Morone saxatilis*, was successfully introduced to the west coast of the USA and has been supported by a state hatchery enhancement programme. Currently, in the wake of recent drought conditions that have affected a federally listed endangered species of chinook salmon, *Oncorhynchus tshawytscha*, which is also prey upon by striped bass, the stocking of striped bass has been discontinued (D. Kent, Hubbs-SeaWorld Research Institute, pers. comm.). Thus, continued monitoring is necessary in light of environmental changes that may cause differential impacts on species of equal or greater importance.

An implicit assumption of most stocking programmes is that the carrying capacity of the habitat has not been reached and density dependent factors will not seriously reduce the success of hatchery plantings.

However, this assumption is rarely tested and there is a question as to whether hatchery fish displace or replace wild individuals. Monitoring of areas adjacent to areas stocked with striped mullet, *Mugil cephaelis*, demonstrated that wild individuals were not moving out of the stocked area and that the nursery habitat could support additional juveniles released from a marine hatchery (Leber et al. 1995).

However, monitoring of cod stocked in Norway suggested some density dependent factors were operating in the release areas (Svåsand et al. 1990).

Identification of hatchery fish and monitoring of both the stocked and adjacent areas should become standard procedures for enhancement evaluation.

3. CONCLUSION

Aquatic ranching is a complicated area involving technology, biology, ecology, socio-economics and politics. Recently, a group of experts from around the world met and established a "responsible approach" to hatchery enhancement that involves multi-disciplinary assessment, monitoring and action (Appendix 3). Genetic considerations alone will not ensure a successful ranching programme; nevertheless, the long-term success of production and conservation efforts will be impossible without applying the principles of genetic resource management.

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APPENDIX 1. Examples of hatchery enhancement activities in marine and coastal areas worldwide

COUNTRY	SPECIES	RETURN	STATUS	REFERENCE
Australia	Southern Blue fin tuna	Research only. 100 adults of 60 -65 kg. Raise to 5 - 7cm and release	Port Lincoln, 1 million$ project with Overseas Fishery Cooperation Foundation, Fed. of Japan Tuna, S.A. Gov. and Tuna Boat owners Assoc.	Anon. 1993.
Australia	Barramundi	Profitable return rate predicted for sport fishery; 50 - 80% survival in lakes.	200 000 stocked in coastal waterways from 85 - 90. More stocked in reservoirs with no sea connection	Gillespie 1991, Rutledge et al. 1991.
Baltic States	Atlantic salmon	15%	6 million smolts released/yr, 2.2 million from Finland, 2.4 mill Sweden	Isaksson 1988a, PUSH 1994.
Canada	Atlantic salmon	.35 - 2.14 %; 3% in 85; 0.1% in 1987.	(East Coast) Decreasing returns, almost 100 000 smolts stocked/yr.0.6million in 85. Herring fishery also seeing reduction in numbers. Proposing selection programme. Crossed adults from 4 Rivers to synthesize hatchery population and these had the lowest return rates.	Bailey 1987.
	Chinook salmon	Returns went from 2.3% in 1975 to 0.3% in 1985.	In 1989, 81 hatcheries released 63 million fish. A targeted species, but catch did not increase much. 1:1 cost:benefit.	Hilborn and Winton, 1993
	Chum salmon	Return rate of ca. 2.06%.	In 1982 200 million pinks and chum released. Since 1984 70 -90 million fish/yr released	Hilborn and Winton, 1993, Isakkson 1988a.
	Coho salmon	Returns dropped from 14.7% in 1975 to 9.5% in 1985.	Targeted species. 30 million coho and chinooks released in 1982, from 1984 - 1989 ~19 million coho/yr released.	Hilborn and Winton 1993.
	Pink salmon	7.1%	1983 - 1987 ~8.8 million fish/yr released.	Hilborn and Winton 1993.
Chile	coho	.01 - .12 % before mid 1980's, then returns of ~1% in mid 1980's.	Early Japanese attempts failed, but a few private farms had some success. Early to mid 1980's 1 - 1.5 million fish released.	Lindberg and Brown 1982.

COUNTRY	SPECIES	RETURN	STATUS	REFERENCE
China	Chinese prawn	Experimental returns of 1.1% - 3.3% for larger shrimp. 4.6 - 8.2% returns in Pohai and Yellow Seas indicated a $20 Million profit potential.	Experimental release of 123 572 juveniles over 3 yr period prior to 1988. 4 billion juveniles released in 1986 to Pohai and Yellow Seas.	Xue et al. 1988; Shang 1989.
China	False halibut	Greater than 1%	Numerous cultured juvenile shrimp released in 1980.	Wu et al. 1987.
Denmark	Atlantic cod	Returns of 3.18% one year after release.	Experimental release of 6 917 fish in 1991.	Anon. 1992; Støttrup et al. 1994.
France	Lobster	22/25 000 from 1987 to May of 1989.	Experimental tag and release of 25 000 juveniles from 1984-87.	Latrouite and Lorec 1991.
Iceland	Atlantic salmon	2 - 15% (9% average) in 1987.	6 million smolts, ca 1 million in 1987	Isaksson 1988b.
Iran	Sturgeon, 5 species.	Only 100 Huso huso taken/yr other data not available	6 million juveniles stocked/yr in Caspian Sea	FAO 1992c; Anon. 1993a.
Iran	white fish	Not available	6 million juveniles/yr; or 90mill larvae stocked in 91 in Gilan and 80 mil in Mazandaran. Accounts for 80 - 90% of fishery.	FAO 1992c; Anon. 1993a.
Ireland	Atlantic salmon	Differing return rates of 1 - 6% in 1970's; 2 - 5% in mid 1980's and 0.2 - 5% in late 1980's. 27% of released smolts taken in coastal drift net fishery.	170 000 smolts/year released in the 70's, ended when modelling showed non-economic for private ranches; 30 000 smolts released/yr mid 1980's; 1 million smolts/yr stocked by government in late 1980's.	Piggins 1987; Brown 1988; Burkart and O'Brien 1988; Isaksson 1988a
Japan	chum and pink salmon	2 - 3%	2 billion smolts/yr and a profitable return rate. Approximately 90% of Pacific salmon fishery is from stocking.	Isaksson 1988a; PUSH 1994.

COUNTRY	SPECIES	RETURN	STATUS	REFERENCE
Japan	Flounder spp.	36 982 out of 246 300 releases over 3 years	Samples commercial landings, income and benefit were 32.6 and 7.9 mill yen, ergo it is profitable. ca 15 million fry/yr released; 16 mil released in 87.	Watanabe et al 1989; Kitada et al. 1993; PUSH 1994.
Japan	Kumura Prawn	10 - 20% from artificial tidelands; 5 tons of shrimp recaptured for each million post larvae released.	315 - 500 million post larvae stocked/yr late 80's. Stocking accounts for ~50% of total prawn production	Bhat 1989; Ungson et al. 1993.
Japan	maso trout (cherry salmon)	95/53,700 and 1.314/135 000 in 1982 and 85, respectively.	53 700 and 135 000 smolts released in 1982 and 85; 11 million smolts released in 1989	(Ikenoue and Kafuku 1992)
Japan	Red sea bream	Profitable return rates with survival up to 75%.	Started in 1971 and over 20 million fish (~6-7cm size) released/yr from 1982 - 1990;	Watanabe et al 1989; Honma 1993.
Japan	Striped jack	5.7% return to angling and set net fisheries; 11.7% return with feed conditioning.	120 000 experimental release with another 694 000 released in 1987; 110 000 conditioned with feed around cages for 6 months and released in 1988.	Watanabe et al.1989; Anon. 1994.
Japan	Stocking or research on an additional ~80 marine species including scallops, sea urchin, swimming crab, abalone, striped knife jaw, tiger puffer, yellow tail, black sea bream, rhodurus salmon, and plaices.			Watanabe et al. 1989; Nose 1991; Honma 1993; PUSH 1994.
Kerguelen Islands Subantarctica	Coho salmon	0.55 - 0.84 %	Pilot scale from 1984 - 1990; some harsh winters decreased stocks, size decreased in later years. Fear for logistic difficulties and poor market price of salmon ended project.	Davaine 1991.
New Zealand	Red snapper	Not available	Plan to release 500 000 in 1995 following Japanese model.	Anon. 1992a.
Norway	Arctic Charr	32 % for 2yr old smolt released in fjords.	Experimental or pilot for recreational fishing. North Norwegian specialty.	PUSH 1994.

COUNTRY	SPECIES	RETURN	STATUS	REFERENCE
Norway	Atlantic salmon	3.1 - 4.6 % (7 -8 % needed for profit);5 - 15% in 87.	Push says 900 000 smolt released in pilot scale from 1990 - 93. with 2 - 500 000 planned for 94 - 95. 20 -30% of catch is from releases or escapes. 11 mil released in 87	Isaakson 1988a; Holm et al. 1991.
Norway	Atlantic Cod	No data from before 1980's. Since 1980's, 1 - 25 %, 2 - 4 % for 0 age released to 16% for 1 yr olds.	70 billion released over 90 yr period. Stocking ended in 1971 when no visible impact seen. Renewed interest with 186 000-300 000/yr released from a variety of sites since 1985 (fry or juvs).	Svåsand et al 1990 and 1991; Griffin 1993; Danielssen and Gjφsæter 1994.
Norway	Brown trout	1 - 30% depending on acclimation and life history character.	Experimental release of 20 000 resident and anadromous fish after periods of acclimatization.	Jonsson et al. 1994.
Norway	Lobster	ca 0.5%	1990 - 93 pilot releases of 200 000 juveniles	PUSH 1994.
Russia	chum and pink salmon with some other Pacific salmon;	Fluctuates 0.01 - 6% with 1 - 3% for pinks, 0.2 - 0.4 for chum. 5 - 8% and 2% of commercial fishery is hatchery pink and chum, respectively	2 billion smolt released by State/yr in early 1980's, decreased to ~650 million in 1985. Some research on sockeye.	Isaksson 1988a; Dushkina 1994.
Russia	Sturgeons	NA	10 -15 mil Huso huso, 400 - 500 mil Acipenser spp.	FAO unpub. data.
Spain	Brown trout	0 - 2%, with little monitoring	15 000 - 120 000 in rivers, reservoirs and lagoons of northern Spain. Stocking more effective in non-flowing waters.	Martinez et al. 1993.
Spain	Turbot	9.5% one year after release.	3 000 stocked at 158g.	Iglesias and Rodríguez-Ojea 1994.
Thailand	Freshwater prawn	2% recaptured	3 million stocked over 3 years in early 1980's.	

COUNTRY	SPECIES	RETURN	STATUS	REFERENCE
United Kingdom (England)	Lobster	.2 -.3% in England	Experimental release of 20 000 in England, Wales and Scotland from 83 - 88	Bannister and Howard 1991.
USA	Pacific salmon	Pink 2-3%, Chum:2-3%, Chinook:2-10; Coho:2-20% and >40% when 25g coho released in June	Over 2 billion smolt released/yr with 1.4 billion from Alaska alone. Efforts to ranch pink and chum in West Atlantic failed.	Allee 1988;Isaksson 1988a;and 88; Sawyer et al. 1990; Seeb et al. 1993.
USA	Atl. salmon	1.0%	1.2 million smolt in 85	Isaksson 1988a.
USA	Red drum (redfish)	20% of catch is hatchery fish off Texas coast. 2% cumulative return to Florida from 1988 - 93.	20 million fry, 200 million eggs with plans to stock 15 mill. introduced since 1983 in Texas. Florida released 1 000 000 fish; experimental release of 43 000 juveniles in South Carolina.	Rutledge 1989; King et al. 1993; Roberts et al. 1994
USA	Striped mullet	2.1% return in nursery areas.	Pilot project released 30 000 in nursery areas in 1990. Stocked mullet increased population by 33%.	Leber et al. in press.
USA	White seabass	Not available	Experimental only	DonKent Hubbs SeaWorld,p.comm.
USA	Atlantic cod	No increase seen 1924 - 1950.	1924 - 1950 1.5 - 2 billion larvae stocked in New England. ~50 billion released 1890 - 1950, but ended in 1952. Current efforts to stock larger fish following Norwegian model.	MacCall 1989; Griffin 1993.
USA	Lake trout	Disproportionately high contribution of one strain indicated its superiority.	318 - 919 000 fish from 5 strains stocked from 1976 - 1987 in Eastern Lake Ontario.	Grewe et al. 1994.
USA	Pacific threadfin/Moi	Not available	In 1994 81 000 fingerlings were tagged and released.	Anon. 1995.
USA	Sea run cutthroat trout	2.3% and 12.8% for small and large fish, respectively.	Smolt larger and smaller than 21 cm released in 1982 - 83.	Tipping 1986.

APPENDIX 2. A diagrammatic code of practice on the introduction of exotic aquatic species

Proposal to Import Including:

Planned use of exotic species
Location of facility
Passport information
source of exotic species

Independent Review Including Evaluation of:

Disease organisms associated with exotic species
Ecological requirements/interactions
Genetic structure and hybridization potential
Social-economic considerations
Local species that may be impacted

REFINE

Advise/Advice

Approval

Protocols if Approved:

Quarantine
Confinement
Monitor

APPENDIX 3. Toward a "responsible approach" to marine ranching. The following guidelines were established by an ad hoc committee of the World Aquaculture Society (Blankenship and Leber in press).
1) Establish priorities and methodologies for selecting species to be ranched or enhanced.
2) Create a species management plan with long and short term goals, harvest regimes and genetic conservation objectives.
3) Incorporate life history and ecological attributes into enhancement strategies and tactics.
4) Create a genetic resource management plan to minimize inbreeding/outbreeding depression and to conserve genetic resources.
5) Create a disease and health management plan.
6) Define an empirical process for defining optimal release strategies.
7) Identify and implement means to identify hatchery-produced fish.
8) Assess the enhancement project in terms of stated objectives in management plan. Include quantitative measures of success and socio-economic evaluation.