Strategic Review of Enhancements and Culture-based Fisheries

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Lorenzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., de Silva, S.S., Garaway, C.J., Hartmann, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., Sugunan, V.V. & Swar, D.B. 2001. Strategic Review of enhancements and culture-based fisheries. In R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp. 221-237. NACA, Bangkok and FAO, Rome.

ABSTRACT: Enhancements are interventions in the life cycle of common-pool aquatic resources. Enhancement technologies include culture-based fisheries, habitat modifications, fertilization, feeding and elimination of predators/competitors. Enhancements are estimated to yield about two million mt per year, mostly from culture-based fisheries in fresh waters where they account for some 20 percent of capture, or 10 percent of combined capture and culture production. Marine enhancements are still at an experimental stage, but some have reached commercial production. Enhancements use limited external feed and energy inputs, and can provide very high returns for labour and capital input. Moreover, enhancement initiatives can facilitate institutional change and a more active management of aquatic resources, leading to increased productivity, conservation and wider social benefits. Enhancements may help to maintain population abundance, community structure and ecosystem functioning in the face of heavy exploitation and/or environmental degradation. Negative environmental impacts may arise from ecological and genetic interactions between enhanced and wild stocks.

Many enhancements have not realised their full potential because of a failure to address specific institutional, technological, management and research requirements emanating from two key characteristics. Firstly, enhancement involves investment in common-pool resources and can only be sustained under institutional arrangements that allow regulation of use and a flow of benefits to those who bear the costs of enhancement. Secondly, interventions are limited to certain aspects of the life cycle of stocks, and outcomes are strongly dependent on natural conditions beyond management control. Hence, management must be adapted to local conditions to be effective, and certain conditions may preclude successful enhancement altogether. Governments have a major role to play in facilitating enhancement initiatives through the establishment of conducive institutional arrangements, appropriate research support, and the management of environmental and other impacts on and from enhancements.

KEY WORDS: Aquaculture, Culture-based Fisheries, Enhancement, Development, Floodplains, Reservoirs, Coastal Zone

Introduction

Definition and rationale

Enhancements may be defined as limited technological interventions in the life cycle of common-pool aquatic resources. Hence, enhancements combine attributes of aquaculture (intervention in the life cycle of aquatic organisms) and capture fisheries (exploitation of common-pool resources) in a unique way.

The rationale for enhancement is that, under certain conditions, limited technological interventions can substantially increase the utilization by man of natural aquatic productivity. Stocking of hatchery-reared seed fish, for example, can increase the yields of desired species where natural productivity is high but recruitment is limited. Habitat enhancements can have similar effects. Because enhancements rely largely on natural aquatic productivity, they require little feed or energy inputs, and can provide high returns from limited investments. Hence, enhancements provide opportunities in particular for resource-poor sections of inland and coastal aquatic resource users. Moreover, introduction of enhancement technologies may facilitate institutional change and more efficient and sustainable exploitation of common-pool resources.

Technologies

Enhancement technologies may involve, e.g.:

- stocking to create culture-based fisheries, i.e. fisheries based predominantly on the recapture of stocked fish;
- stocking to enhance or supplement self-recruiting populations;
- habitat modification to improve levels of recruitment and/or growth;
- elimination of unwanted species;
- fertilization; and
- combinations of any the above

Enhancements may involve introductions or transfers of organisms. However, introductions aimed at the establishment of capture fisheries do not constitute continued interventions in the life cycle of the organisms, and are not considered as enhancements in this review.

Contribution to global fisheries production

The global contribution of enhancement to fish production is difficult to ascertain, because yields tend to be assimilated into the statistics of either capture fisheries or aquaculture production. There is little doubt, however, that enhancement yields are dominated by culture-based fisheries for freshwater and diadromous species. Annual yields in this category are likely to be around 2 million mt, including 1.3 million mt from Chinese reservoirs (Huang et al., 2001), 0.4 million mt from salmon in the North Pacific (Shaw and Muir, 1987; Kaeriyama, 1999; Knapp, 1999), and 0.18 million mt from Indian inland waters (Sugunan, 1995 and pers. comm.). Culture-based fisheries for food and recreation are well-established components of aquatic resource use in Europe (e.g. Mattern, 1999) and in North America, where state fisheries organizations expend an average of 19 percent of their budgets on stocking (Heidinger, 1999; Ross and Loomis, 1999). Overall, the estimate of 2 million mt per year suggests that culture-based fisheries for freshwater and diadromous organisms account for about 20 percent of recorded capture yields, or 10 percent of combined capture and culture in this category (total yields 7.5 and 21.2 million mt, respectively) [FAO, 1999a]).

Enhancements of marine organisms are still being carried out primarily on an experimental or pilot scale, but hatchery production of marine organisms for stocking indicates considerable efforts (A.F. Born, pers. comm.).

A number of marine enhancements have entered commercial-scale production: for example, culture-based fisheries for scallops (Patinopecten yessoensis) in Japan now yield about 0.2 million mt/year, and the technology is being adopted elsewhere (Dao et al., 1999; Kitada, 1999).

Contributions to fish production by enhancement initiatives, other than culture-based fisheries, are poorly documented. However, it has been estimated that brush parks (acadjas) account for 12 000 mt or 40 percent of the inland fisheries production of Benin in Africa (J. Moreau and P. Laleye, pers. obs.). Similar systems are in use in other African and Asian countries (Kapetsky, 1981; Solarin and Udolisa, 1993), and there is evidence to suggest that habitat enhancement using indigenous technologies is more widespread in tropical inland waters than previously realised (Neiland and Ladu, 1997; U.W. Schmidt, pers. comm.).

Unique production systems

As defined above, enhancements are unique production systems. Technological interventions may be limited and relatively simple (e.g. stocking of seed fish), and the degree of management control over enhancement outcomes is inherently limited. This is a consequence of both the limited nature of interventions in ecosystems not managed primarily for fish production, and the common-pool (non private ownership) nature of the resource. Common-pool resources are exploited jointly by separate users, where resource use by one individual subtracts from the resources available to others and exclusion of users is difficult (Ostrom, 1990). Under such circumstances, the actions of resource users are difficult to predict, let alone control.

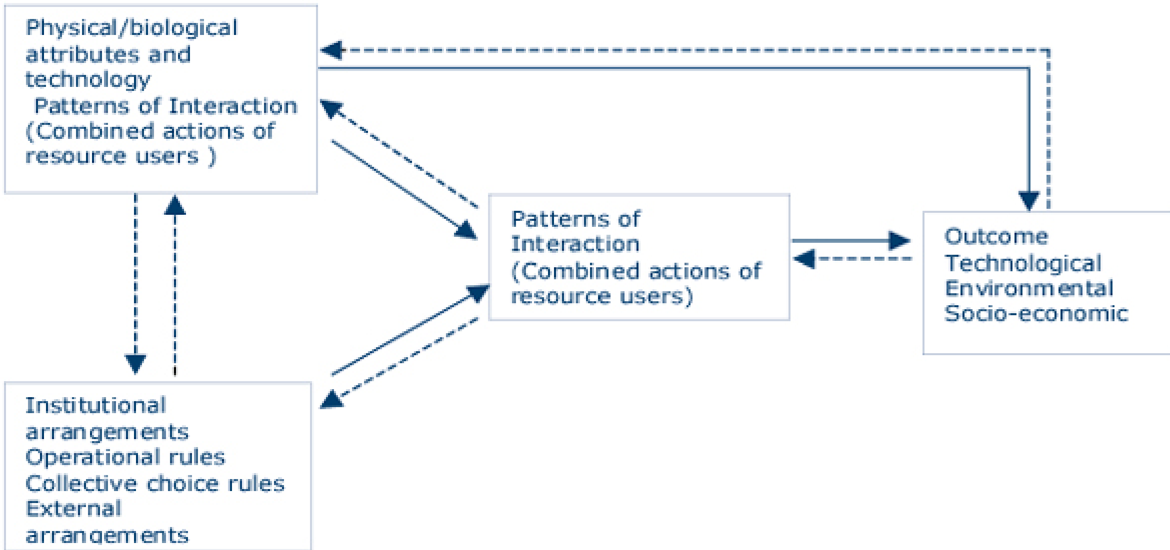
A useful framework for the analysis of enhancements is shown in Figure 1 (adapted from Oakerson, 1992). Outcomes are determined by the physical/biological nature of the resource and technology on one hand, and by the combined actions of resource users on the other. The latter are also known as patterns of interaction, being determined by the individual users' choices, as influenced by the physical/biological nature of the resource, and by the institutional arrangements governing resource use. Institutional arrangements consist of the operational rules for resource use, conditions of collective choice which determine how operational rules can be made, and external arrangements pertaining to rules and conditions of collective choice. In normal resource use, the nature of the resource and technology and the institutional arrangements are fixed and together influence the actions of resource users and ultimately the outcomes (solid arrows in Figure 1).

The development of enhancements usually involves modifying technology and institutional arrangements in the light of outcomes, a process illustrated by the dashed arrows in Figure 1. Within this process, resource users and managers will be guided by their perceptions of outcomes in terms of a wide range of attributes, and the values they attach to these (Lorenzen and Garaway, 1998).

Resource management agencies and scientists may influence the choice of intervention and interact with institutional arrangements at various levels. However, our ability to predict and influence outcomes will remain somewhat limited, and strongly dependent on our understanding of the overall production system (Lorenzen and Garaway, 1998). This implies firstly a need for managers and scientists to develop a broad-based understanding of enhancement systems. Secondly, because predictability of outcomes is inherently low, strategies for developing new enhancements must be process - rather than outcome - oriented.

In the following, we review firstly the opportunities and constraints relating to enhancements, and secondly the process of developing enhancements. We then consider the future role of enhancement and current trends, before outlining requirements and opportunities for supporting the sustainable development of these production systems. We close with a set of key recommendations.

Figure. 1 Framework for analysing common pool resource systems. Modified from Oakerson (1992).



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Opportunities and constraints

Opportunities for, and constraints to, enhancement must be understood in terms of a range of attributes that are important to various stakeholders, for example, yield, economic benefits and their distribution, environmental impacts, and institutional sustainability (Cowx, 1994; Lorenzen and Garaway, 1998). Opportunities and constraints would best be identified by reviewing outcomes of enhancements under a wide range of natural and human conditions, but in practice this is precluded by the fact that very few enhancements have been comprehensively evaluated (Cowx, 1994). Hence, we rely on a combination of theoretical considerations and experiences from enhancements that have been assessed with respect to at least some attributes.

Aquaculture techniques as a basis for enhancements

Many enhancements operating today have a basis in "indigenous" technologies, such as the transfer of wild-caught juvenile fish from rivers to small reservoirs, as practised in China and India (Lu, 1992; Sugunan, 1995), or the construction of brush parks in Africa (Welcomme, 1972). Nonetheless, it is clear that development of efficient hatchery and nursery techniques for the Chinese and Indian major carps was a

Thus different objectives for enhancements may call for different seed production strategies. For example, culture-based fisheries may benefit from genetic selection for traits linked to the return rate or growth (Jonasson, 1995). Conversely, programmes aimed at supplementing natural stocks must make every effort to maintain the genetic makeup of the natural populations (Bartley et al., 1995; Munro and Bell, 1997).

Technological effectiveness and efficiency

Depending on the enhancement technology used, there are various measures of technological effectiveness and efficiency. Effectiveness may be measured in terms of recapture rates of stocked fish or increases in yield. Efficiency relates to optimal use, within given constraints, of inputs to produce the desired outputs, and is more difficult to assess than effectiveness.

Culture-based fisheries

Culture-based fisheries, where yields are based predominantly on the recapture of stocked fish, can be effective in increasing yields where natural recruitment is lower than the environmental carrying capacity. This may be the case in certain modified ecosystems (e.g.

precondition for expansion of culture-based fishery production to current levels. Much emphasis is now placed on the development of seed production techniques for marine fish and invertebrates, and this is likely to create new opportunities for enhancements in coastal areas (Munro and Bell, 1997; A.F. Born, pers. comm.).

An important question in this respect is to what extent enhancements benefit from specific seed production techniques which differ from those used for aquaculture. The large-scale inland enhancements in Asia rely on seed produced for both purposes. Conversely, much research into marine stock enhancement is aimed at producing seed with desirable characteristics specifically for enhancement (Munro and Bell, 1997).

reservoirs), or where intensive harvesting has reduced spawning stocks to very low levels. However, chronic recruitment limitation can also arise naturally, e.g. in seasonal and/or isolated freshwater bodies, or in marine habitats with poor connectivity to spawning sources (Doherty, 1999). By decoupling recruitment and natural spawning, culture-based fisheries also allow manipulations of population structure to increase production in a way that is unattainable in self-recruiting stocks. Where resource requirements of different size groups overlap (e.g. many planktivores and detritivores) and fish are marketable below their normal size at maturity, large and somatically unproductive size groups can be replaced by high densities of somatically productive smaller fish, thus increasing production from the given resources (Lorenzen, 1995). Hence, culture-based fisheries can, under certain conditions, increase yields over and above the level achievable from self-recruiting populations of the same species.

There are many examples of culture-based fisheries that have been effective in increasing yields of desired species: carps in small water bodies (Amarasinghe, 1998; Hasan and Middendorp, 1998; Lorenzen et al., 1998a; Nguyen et al., 2001), medium-size reservoirs (De Silva et al., 1991; Lu, 1992; Li and Xu, 1995; Lorenzen et al., 1997; Phan and De Silva, 2000), or floodplains (Ahmad et al., 1998); coregonids in lakes (Salojaervi, 1992); and scallops in coastal environments (Kitada, 1999). In all of these cases, the stocked species were either absent before enhancement or their abundance very much reduced by overfishing. The remarkable success of culture-based fisheries in Chinese reservoirs, which are reported to have raised average yields from 150 to 750 kg/ha/year (Huang et al., 2001), is based on the stocking of riverine major carps that are unable to reproduce successfully under the lacustrine conditions of reservoirs, but can make good use of the available food resources.

Unfortunately, the effectiveness of culture-based fisheries varies widely between locations, and the reasons for this are not well established. High mortality of stocked fish is frequently a key limitation. A comparative analysis of stocking experiments (Lorenzen, 2000) showed that mortality of stocked fish may be slightly lower, or up to an order of magnitude higher than the

Stock enhancement

Where stocks have been depleted by overfishing, there may be a choice between stocking to develop a largely culture-based fishery while maintaining high exploitation rates, or supplementation stocking combined with more restricted harvesting to rebuild natural spawning stocks more quickly than would be possible through harvest restrictions alone.

Culture-based enhancement of self-recruiting populations aims to increase recruitment to the spawning stock, as well as to the fishery. The goal of enhancing, or at least maintaining natural recruitment to a population implies a need to restrict exploitation to levels that maintain an adequate spawning stock.

As in the case of culture-based fisheries, stock enhancement can be effective when natural recruitment is limited to levels well below the carrying capacity for the recruited stock. Where this limitation is temporary, enhancement measures should also be temporary in nature. Such interventions can be effective where the causes of temporary recruitment limitation are easily established, e.g. in small water bodies affected by drought (Van der Mheen, 1994). Because stocking is unlikely to be effective when natural recruitment matches carrying capacity, recruitment must be assessed in time to produce average for wild fish of the same size. Optimization of seed production and release strategies can, however, significantly reduce such mortality (Bilton et al., 1982; Wahl et al., 1995; Munro and Bell, 1997; Leber, 1999).

The potential production of culture-based fisheries is strongly linked to ecosystem productivity, as clearly shown in comparative studies (De Silva et al., 1992; Lorenzen et al., 1998a; Hasan and Middendorp, 1998). Optimizing management regimes, so that the given production potential is utilized efficiently, remains a key challenge in the management of culture-based fisheries. The assessment of stocking and harvesting regimes requires quantitative information on density-dependent population processes (Peterman, 1991; Lorenzen, 1995). At present such information can only be obtained by (active or passive) experimental management, but further development of population dynamics theory and meta-analyses (joint analyses of data from several enhanced stocks) may reduce the need for experimental management in the future. So far, few culture-based fisheries have been analysed comprehensively, and it is likely that stocking and harvesting regimes are often suboptimal.

the required additional seed fish (Munro and Bell, 1997; Giske and Salvanes, 1999).

The effectiveness of releasing cultured juveniles for stock enhancement is particularly difficult to assess. It depends on regulatory processes at different life stages that are poorly understood in broad terms, let alone for specific fisheries (Botsford and Hobbs, 1984). In the absence of detailed information, however, comparative studies provide some guidance for management. Studies on coregonids and tilapias suggest that there is little benefit from stocking lakes with established populations of these species (Salojaervi and Ekholm, 1990; Quiros and Mari, 1999), but definitive conclusions require further studies of higher statistical power.

Habitat enhancements

A wide range of habitat enhancements is being carried out in inland and marine fisheries, using traditional and recently developed technologies (Williams et al., 1997; Cowx and Welcomme, 1998; Morikawa, 1999). The effectiveness of these measures has often proved difficult to evaluate due to the time scales involved in responses, the levels of natural variation in natural habitat and recruitment, and institutional impediments to monitoring and evaluation (e.g. Kershner, 1997; Munro and Bell, 1997). As a result, little scientific guidance can be given for choice of habitat enhancement approaches.

A common and effective habitat enhancement approach found in tropical Africa and Asia is the construction of brush parks, such as the acadjas in West African lagoons. Brush parks provide substrate for periphyton (micro-algae growing on submerged surfaces) production and protection from certain predators, in addition to serving as fish aggregation devices. In the lagoons of Benin, production from brush parks has been estimated

Stocking for culture-based fisheries and stock enhancement/supplementation may affect wild populations through the transmission of diseases, increased competition and predation, and genetic interactions (Cowx, 1994; Blankenship and Leber, 1995; Munro and Bell, 1997; Bartley, 1999; Subasinghe et al.,. This volume). These issues are particularly important where stocking is aimed at rebuilding populations and the proportion of released animals is high relative to the remnant wild stock. Where stocking involves introduction or translocation of species, there are additional concerns, such as hybridization with native/established species, habitat alterations, changes in the trophic functioning of ecosystems, and the introduction of exotic parasites and pathogens (Courtenay and Stauffer, 1984; Moyle et al., 1986; Arthington, 1991; Carvalho and Hauser, 1995; Moreau, 1999; Subasinghe et al., This volume). These risks are now widely recognized, and there is general agreement that proposals for introductions must be carefully evaluated using frameworks such as the International Council for as 1.9 to 5.6 mt/ha/year (Welcomme, 1972; P. Laleye pers. obs.), substantially higher than the average of 0.29 mt/ha/year achieved in open waters of the lagoons (J. Moreau and P. Laleye, unpubl. data). Similar results have been reported from Nigeria (Solarin and Udolisa, 1993).

Indigenous technologies, i.e. habitat enhancements developed by resource users in developing as well as developed countries, have long been neglected by research and urgently require attention.

Environmental impacts on and from enhancements

Enhancements are limited interventions in the life cycle of aquatic species, and therefore remain closely linked to the wider aquatic ecosystem. This implies the potential for significant environmental impacts, both on and from enhancements. In both cases, impacts can be positive as well as negative.

Agricultural and industrial demand for fresh water has led to water scarcity and pollution, as well as habitat fragmentation and loss of biodiversity. These factors, along with increasing land degradation and forest loss in some areas, may impact on the potential for future aquatic resource enhancement in inland and coastal aquatic systems (FAO, 1999a).

the Exploration of the Sea (ICES)/European Inland Fishery Advisory Commission (EIFAC) code of practice (Turner, 1988; ICES, 1995; OIE, 2000) and equivalent regional guidelines.

Environmental impacts from a broad range of inland enhancements have recently been reviewed by the Food and Agriculture Organization of the United Nations (FAO, 1999b). Impacts of habitat modifications have received relatively little attention, but the example of brush parks suggests that such impacts can be significant constraints to the sustainability of enhancement initiatives. The high density of brush parks in some areas prevents circulation of the water and results in high rates of sedimentation (Anon., 1994; J. Moreau and P. Laleye, pers. obs).

Most impact assessments focus on the negative effects of enhancements. However, enhancement can have direct and indirect positive impacts:

- Hansson et al. (1997) found pikeperch stocking in the Baltic has helped to sustain ecosystem functioning despite very high fishing pressure on top predators.
- Lorenzen et al. (1998b) showed that fishing restrictions introduced in conjunction with tilapia stocking in Laos created refuges for wild stocks.

Although the beneficial effects in both cases could have been achieved through reduced fishing pressure alone, it is doubtful that this would actually have happened.

When considering the overall impact of enhancements, it is, therefore, important to consider the direct as well as indirect effects, and to evaluate these against realistic alternatives.

Because most information on environmental impacts of enhancements is based on theoretical considerations, or on generalizations from case studies, it remains difficult to predict under which conditions any particular impacts might occur, or what their magnitude would likely be. More comprehensive impact assessments of operational enhancements are urgently required to provide a better basis for decision making.

Economic and social benefits

Enhancements are frequently associated with institutional change, including arrangements for access to resources. Examples are community management of culture-based small waterbody fisheries in Thailand and Laos (Chantarawarathit, 1989; Garaway, 1995, 1999), leasing of seasonal water bodies to individuals in India, and granting of exclusive rights to particular social groups in Indian reservoirs (Peters and Feustel, 1998). Concerns about the socio-economic consequences of such restrictions have been voiced, e.g. by Somnasung et al. (1991) and Samina and Worby (1993), among others. However, investigations in small waterbody fisheries (Garaway 1995, 1999) have shown that communities are often capable of adapting management systems to minimize any negative

Many effective enhancement technologies have proven financially viable (Sreenivasan, 1988; Hansson et al., 1997; Ahmad et al., 1998; Lorenzen et al., 1998a; Garaway, 1999; Kitada, 1999). Some enhancements offer very high returns to cash investment and labour (Hansson et al., 1997; Lorenzen et al., 1998a; Garaway, 1999). Full economic evaluation of enhancements requires knowledge of opportunity costs, e.g. possible loss of yield from other (non target) wild stocks. Unfortunately such evaluations are rare.

Many enhancements appear to play a niche role, in that they provide types of benefits that differ from the benefits obtained from either capture fisheries or aquaculture. For example, small waterbody fisheries in Southeast Asia often provide community income (Garaway, 1995, 1999), and seasonal reservoirs in Karnataka (India) are leased by farmers who are not otherwise involved in fishing or aquaculture, but appreciate the high returns to small investments provided by culture-based fisheries (K. Lorenzen, pers. obs.).

Marketing problems affect some enhancements, such as the seasonal tanks in Sri Lanka which are concentrated in certain areas and harvested over a short period of time (De Silva, 1988). In many cases, enhancements contribute marginally to markets dominated by the capture fisheries or aquaculture, and thus enhancement production has a limited impact on prices. Market interactions between fisheries enhancement and the rapidly growing aquaculture sector can have a significant effect on the financial viability of enhancement initiatives. The expansion of salmon farming is a case in point - it led to a decline in prices that affected the viability of salmon stock enhancement (Boyce et al., 1993).

effects of access restrictions and avoid potential conflicts. This may be different where resource users are very heterogeneous in terms of wealth and power, and resources are perceived as highly valuable (e.g. the floodplains of Bangladesh (Ahmad et al. 1998); or West African lagoons (J. Moreau and P. Laleye, pers. obs.)). In such cases, external regulation of resource use (e.g. by government) may be required to avoid non equitable allocation of resources. However, government regulation may in itself contribute to non equitable outcomes, for example the Kerala reservoirs, where fishing rights were reserved for members of certain castes, turning all other fishers into poachers (S. Kumar and W.D. Hartmann, pers. comm.).

Institutional sustainability

Enhancements require significant and often regular inputs, such as stocking or the maintenance of habitats. To sustain such inputs into common-pool resources, conducive institutional arrangements are required. Under open-access conditions, technically effective enhancements attract additional effort into a fishery. If the result were rent dissipation, individual fishers would be no better off than before and would be unable and unwilling to contribute to the costs of enhancement. Hence, institutionally sustainable enhancements are usually associated with access restrictions.

In Chinese (and some other) culture-based reservoir fisheries, management responsibility has been vested in reservoir authorities who have exclusive rights to the fish stocks. This has allowed management authorities to sustain the inputs that have made Chinese reservoir fisheries the most technically successful enhancements worldwide.

Box 1. Design principles illustrated by long-enduring common-pool resources institutions (Ostrom, 1990).

- Boundaries of the resource and those who can use it are clearly defined.
- Appropriation and provision rules are adapted to local conditions.
- Collective-choice arrangements allow participation of resource users in designing operational rules.
- Rule monitors are the appropriators or at least accountable to them.
- Sanctions are graduated.
- Low-cost conflict resolution mechanisms exist to solve disputes.
- Rights of user-communities to devise institutional arrangements are not challenged by external government authorities.

Most other enhancements developed in common-pool resources have been sustained through continued government subsidy. Such systems remain particularly vulnerable to political changes, as illustrated by the collapse of culture-based fisheries in Sri Lanka following withdrawal of government patronage in 1990 (Amarasinghe and De Silva, 1999).

However, there are many examples of enhancement activities sustained by resource users, either independently or in cooperation with governments (Pinkerton, 1994; Garaway, 1995, 1999; Garaway et al., 2001; J. Moreau and P. Laleye pers. obs.). Given the worldwide trend towards reduction of government subsidies and direct support (e.g. Barbosa and Hartmann, 1998), future enhancement approaches will rely increasingly on the sustainability of resource-user and cooperative institutions. Ostrom (1990) identified a set of design principles associated with long-enduring resource-user organizations for the management of common-pool resources (Box 1). Results of institutional studies on enhancements are broadly consistent with these design principles, indicating their value as indicators of enhancement potential and for guiding institutional development (W.D. Hartmann, pers. comm.; Middendorp at al., 1996; Garaway 1999).

The introduction of new enhancement technologies can provide strong incentives for collective action by resource users where users themselves invest in the technology and conducive conditions exist (Box 1). This has been demonstrated in small waterbody fisheries in Laos, where stocking precipitated rapid proliferation of community management systems (Garaway, 1999; Garaway et al., 2001).

It has long been recognized that crises such as stock collapses can provide the impetus for collective action and co-management (Sen and Nielsen, 1996; Pomeroy and Berkes, 1997). Experience from Laos and elsewhere suggests that opportunities for enhancement can play a similar facilitating role. The potential for enhancement initiatives to precipitate or re-enforce user-led resource management should receive wider consideration in inland and coastal aquatic resources management.

A move away from government implementation of enhancements must not be misunderstood as meaning that governments have no role in aquatic resource enhancement. At the very least, governments have to recognize the rights of resource users to organize and make management decisions (Point 7 in Box 1). Moreover, governments are in a privileged position to support enhancement initiatives through the provision of research and extension services, the resolution of conflicts and the management of environmental impacts. Unfortunately, these opportunities are often not realised due to differences in perceptions and objectives, lack of communication, poor focusing of research support and other institutional factors (Smith et al., 1997; Lorenzen and Garaway, 1998).

The process of developing enhancements

Enhancement is a process, not an event. Large technological and institutional uncertainties and lack of management control preclude a blueprint approach to the development of enhancements. An effective process approach is crucial to the success of enhancement initiatives, and will eventually lead to a higher degree of predictability and control.

Initiating enhancements

Enhancements may be initiated by resource users, government organizations, or a combination of both. Resource users often initiate enhancements where investment requirements are moderate and benefits are likely to accrue to those who bear the costs. Habitat enhancement, such as brush parks or trap ponds, has traditionally been initiated and

Providing technological inputs

While certain enhancement approaches rely on indigenous technologies (e.g. brush parks), others require inputs, such as seed fish, that traditional users of aquatic resources may find difficult or impossible to provide. Therefore, many government-initiated enhancement programmes make provisions for seed production in government hatcheries or the implemented by resource users (Welcomme, 1972; U.W. Schmidt, pers. comm.; K. Lorenzen pers. obs.). Likewise, where seed fish are readily available, resource users often initiate culture-based fisheries in small water bodies (Lorenzen et al., 1998a; Garaway, 1999). Such enhancements may proliferate as a result of direct extension between users, either locally, as in the case of small waterbody fisheries in Laos (Garaway et al., 2001), or over longer distances through itinerant fishers, as in the case of acadjas (J. Moreau and P. Laleye, pers. obs.).

Large-scale enhancements often involve substantial investments and a lower chance of recovering costs, and have generally been the preserve of government-led initiatives. Also, where breakthroughs in aquaculture technology, such as hatchery production, are required, there is likely to be a degree of involvement from governments and development agencies at the outset.

The decision to initiate enhancement is usually based on perceived opportunities, but may also stem from dissatisfaction with current management outcomes and the belief that enhancements will, at least, not do much harm. The assessment of enhancement potential requires both technological and institutional considerations. In the past, fisheries scientists and managers placed most emphasis on technological considerations, whereas resource users tend to be concerned mostly with institutional considerations (Garaway, 1999). Some general frameworks for the assessment of technological potential have been developed (e.g. Cowx, 1994). However, specific decision rules for the assessment of local potential are as yet available only for certain species and geographical areas (e.g. EIFAC, 1994; Heidinger, 1999). Hence, in many cases it is not yet possible to assess the potential of enhancement technologies without pilot-scale intervention.

development of private hatchery capacity (Ahmad et al., 1998). In the longer term, this function may be taken over by the private sector, e.g. most village-based Thai enhancement initiatives now obtain their seed from private operators, as opposed to government hatcheries which dominated supply in the early stages of development (Lorenzen et al., 1998a). Demand for seed for enhancement alone may be too restricted or uncertain to stimulate the development of private seed production. However, where aquaculture development stimulates seed production, this may in turn facilitate enhancement initiatives, and sales for enhancement may then account for a significant share of the total income of seed producers. Hence, aquaculture development and enhancement using cultured fishes are often implicitly linked. It is likely that a more explicit consideration of this link will lead to further synergies, as with giant clam culture (Bell, 1999).

Developing effective and efficient management systems

Where enhancement initiatives have been taken, the key challenge is to make them as effective, efficient and sustainable as possible under local conditions. This challenge has two components: (a) to identify locally optimal management approaches, and (b) to achieve the implementation of these by resource users through adequate institutional arrangements (see Fig. 1).

Uncertainties regarding local conditions and ecological and institutional dynamics are generally too large to allow optimal management regimes to be identified at the outset of new enhancement initiatives. Hence, management must be modified in the light of outcomes, through an adaptive approach that treats management as essentially experimental. Adaptive approaches are a constructive way of dealing with uncertainty and lack of control, and have developed independently in fields such as natural resource management and public administration (Walters, 1986; Rondinelli, 1989).

In practice, such approaches are implemented in a variety of ways. In resource user-led enhancement, users may experiment with both technical and institutional variables, albeit not necessarily in a very systematic way (Garaway et

a great deal of management information. The wider use of powerful analytical frameworks, such as population models or IAD, will further enhance the scope for comparative studies.

al., 2001). Formal adaptive approaches are increasingly being used in government-led enhancements to address technological uncertainties (e.g. Bilton et al., 1982; Blankenship and Leber, 1995; Leber, 1999). In many programmes, however, lack of monitoring and evaluation precludes adaptive improvement (Cowx, 1994).

The evaluation of enhancement management and adaptive strategies requires the use of quantitative models. Population dynamics models that incorporate sub models of key density- and size-dependent processes enhance comprehensive evaluation of management regimes. Such population models have recently been developed for certain culture-based fisheries and stock enhancements (Lorenzen, 1995, 2000, 2001, Lorenzen et al., 1997; Giske and Salvanes, 1999; Barbeau and Caswell, 1999). Purely empirical models (i.e. models not incorporating any mechanistic understanding of population dynamics) can be used to assess certain aspects of management, provided that empirical data provide sufficient contrast in the variable(s) of interest. Empirical models have been used most commonly to assess stocking densities in smaller inland water bodies (e.g. De Silva et al., 1992; Hasan and Middendorp, 1998; Welcomme and Bartley, 1998; Lorenzen et al., 1998a). Geographic information systems (GIS) provide new opportunities for integrating geographical information into the analysis of enhancement (e.g. Kapetsky, 1998).

Institutional analysis and design (IAD), a conceptual framework for analysing common-pool resource systems (Ostrom, 1990), has emerged as a powerful tool for the assessment and improvement of management institutions. The approach has great potential in the management of enhancements, and has already been used by W.D. Hartmann, pers. comm., Middendorp et al. (1996), and Garaway (1999). Wider application will require training of fisheries management staff and/or increased involvement of social scientists in fisheries development.

Comparative analyses of enhancement outcomes under different local conditions and management regimes hold the key to resolving technological, ecological and institutional uncertainties. Even simple comparative studies using empirical regression models can provide

Eventually, analyses are likely to improve the predictability of enhancement outcomes to such a degree that the need for adaptive management is reduced and a more programmed approach becomes possible. This has already been achieved for some enhancements (Cowx, 1994; EIFAC, 1994; Heidinger, 1999).

Managing environmental impacts and risks

A number of frameworks have been developed to minimize environmental risks and manage impacts from enhancements. Key documents include the Codes of Practice and Manual of Procedures for the Consideration of Introductions and Transfers of Marine and Freshwater Organisms (Turner, 1988), the ICES Code of Practice on the Introductions and Transfers of Marine Organisms (ICES, 1995), the Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995), and the corresponding guidelines for aquaculture development (FAO, 1997).

When assessing and managing environmental impacts on and from enhancements, it is usually necessary to consider the environment beyond the enhanced fishery, i.e. at the catchment (De Silva, 2000) or coastal zone level.

Co-management

Whether initiated by resource users or government, enhancements often develop towards some form of cooperative management. Resource user-led enhancements may require government intervention to resolve conflicts or regulate environmental impacts. The expansion of indigenous acadjas in West Africa, for example, has resulted in a level of conflict that has prompted government regulation and ultimately the development of a co-management system (J. Moreau and P. Laleye, pers. obs.). On the other hand, government-led initiatives have proved difficult to sustain unless resource users assume a degree of management responsibility and contribute to costs. A need for cooperative management may be evident even where government involvement in enhancements is limited to regulation to prevent negative impacts.

Where inputs to enhancements are easily available to resource users, such as seed fish in areas with a well-developed aquaculture industry, effective regulation may be almost impossible without cooperation of resource users. Indeed, uncontrolled stocking is widely perceived to be a problem by resource managers in developed countries (Cowx, 1994; Li and Moyle, 1999).

Co-management implies a sharing of management responsibility between resource users and government, but the term has been applied to a wide range of arrangements (for reviews see Sen and Nielsen, 1996; Pomeroy and Berkes, 1997). To achieve effective co-management, a number of issues need to be addressed in the areas of:

- communication,
- objectives of stakeholders,
- facilitation of self-governance,
- decision making, and
- monitoring and enforcement.

Effective communication between stakeholders at different levels (resource users, local decision makers, scientists etc.) is crucial to the success of co-management. Participatory appraisal and action approaches have been developed and used successfully in many contexts (e.g. Chambers, 1992; Pido et al., 1996), and their wider application to co-management of enhancements is likely to generate substantial benefits. For a further analysis of communication issues in management involving multiple stakeholders (Bilio, 1997; M. Bilio, pers. comm.).

Co-management requires a degree of congruency on objectives and in perceptions of management issues and expected outcomes among the stakeholders. In practice, both are often lacking. In Laos and Thailand, for example, government objectives for small waterbody enhancements were geared towards increasing yields and community cohesion through communal aquaculture. However, in both cases, communities focussed primarily on increasing efficiency of resource use (i.e. high returns to cash investment and labour). In Thailand, communal aquaculture was abandoned in favour of selling fishing day licenses to individuals, while in Laos a communal harvesting system persists, but is marred by incentive problems. In both cases, government organizations have been slow to recognize resource user's objectives and perceptions, and to adapt their extension and research support services accordingly (Garaway et al., 2001).

Co-management, in the strict sense, implies an element of self-governance by resource users. The design criteria given in Box 1 provide an indication of the conditions under which self-governance can realistically be developed. In general, governments need to create a conducive legal arrangement to allow self-governance to develop. Decision making in co-management involves different levels, i.e. operational rules, collective choice rules and external arrangements. Exactly how and by whom decisions at the different levels are made is a key problem to be resolved in the design of co-management systems. Many of the more detailed frameworks for enhancement decision making (e.g. Cowx, 1994) provide comprehensive and rational guidelines which can be implemented only where management bodies have effective hegemony over resource users. Since this is unlikely to be the case in many practical situations, decision-making frameworks must be adapted to local arrangements. Lorenzen and Garaway (1998) discuss broad requirements for a co-management approach to the implementation of enhancement initiatives.

Monitoring and enforcement of rules is a key element of any active management system for common-pool resources. Ostrom (1990) points out that where self-governance arrangements exist, rule monitors (enforcers) must be accountable to the self-governing institutions. This is relatively easy to achieve in clearly delineated systems under the control of a single body, such as for small water bodies (Garaway et al., 2001). Where this is not the case, however, governments have to play a greater role in monitoring and enforcement. This may lead to problems, unless government enforcers are also accountable to the self-governing institutions. In medium-sized reservoirs in Brazil, for example, rules are laid down by a fisher congress, and the agreement is submitted to the federal environment agency for ratification. In this case, the government agency favours generally applicable and easily controllable rules to the myriad of locality-specific regulations emanating from the participatory process. Thus, enforcement of rules by the agency is largely lacking, and this is seen by the fishers as a key problem jeopardizing co-management. Difficulties in enforcing rules are the most important cause for changes in community rules (Barbosa and Hartmann, 1998; W.D. Hartmann, pers. comm.).

The future role of enhancements

Enhancements can be technically efficient and generate socio-economic as well as environmental benefits provided that a conducive physical and institutional environment exists, and that appropriate technical and institutional measures are developed. Although dominated by both capture fisheries and aquaculture, in terms of output, enhancements are an important "niche" form of aquatic resource use. Enhancements can provide:

- benefits to sections of the population who cannot benefit from, or develop, proprietary aquaculture;
- food and income from under-utilized, new or degraded aquatic ecosystems, with a minimum of feed or capital inputs;
- a wide range of socio-economic and environmental benefits, including community income from small water bodies that is difficult to obtain through other management systems; and
- incentives to improve the management of common-pool aquatic resources.

In the medium term, the contribution of enhancements to fisheries production and their wider benefits are likely to increase in both absolute and relative terms, due to:

- increasing demand for aquatic products, combined with increasing modification of inland and coastal aquatic ecosystems, in many developing countries;
- full development of new enhancement technologies, primarily for the coastal marine environment;
- increasing availability of hatchery-reared juveniles for a wide range of aquatic species, which have a strong potential to facilitate enhancement initiatives in areas where these are currently limited by lack of seed; and
- improved management of enhancements resulting from better understanding of resource population dynamics, institutional requirements and research support needs.

A quantitative estimate of global enhancement potential is difficult to give. Examples such as the culture-based fisheries in Chinese reservoirs or Japanese scallop enhancement suggest considerable potential, but there are both natural

In inland waters, where enhancement technologies are reasonably well developed and natural conditions (e.g. boundaries of resources) are conducive to the design of enduring institutions, a rough estimate puts the global contribution of enhancement at 20 percent of capture production.

In the marine environment, natural conditions are more limiting with respect to technical effectiveness and institutional design, and the potential relative contribution of enhancements to catches is likely to be lower than the 20 percent achieved inland. Nonetheless, a contribution to marine catches of several percent (i.e. several million mt) of the total appears feasible, and is likely to be achieved with species of importance to coastal economies. Both inland and coastal enhancements stand to gain in efficiency as a result of better research support, with corresponding increases in socio economic benefits.

Recommendations

For enhancements to achieve their full potential and provide benefits on a sustainable basis, improvements are required in both policy and research support.

Principles

- Development of institutional arrangements to manage common-pool aquatic resources and sustain investment in them is crucial. Usually there will be a strong element of co-management where user organizations play an important role, frequently facilitated by various interest groups.
- Government organizations have an important role in enhancement initiatives through creation of supportive institutional arrangements and research. A key factor in this role is creation of conditions under which resource users can actively support and have management responsibility for enhancement.
- Government needs to strike a balance between facilitating initiatives and regulating environmental impact on and from enhancement.

Approaches to management and development

and institutional limitations to the expansion of enhancements (Kapetsky, 1998 and this review).

- Government involvement, including research, planning and implementation, should be guided by the principles of participation and empowerment of resource users.

- Management and policy support for enhancements must be based on a production systems approach, integrating analyses of institutional arrangements, ecology, technology, marketing and socio-economics.
- Information and communication systems should be established to facilitate management and development, as well as regional and inter-regional cooperation.
- Government and other "supra-level" organizations should support development through comparative analyses, and facilitate adaptive learning.
- Development of enhancement initiatives should be integrated into watershed-level planning.
- Development of enhancement projects should follow international codes of practice on conservation and sustainable use of biological diversity, appropriate for local conditions. Key elements of these codes include: environmental impact assessment, responsible use of introduced species and genetic resource management.

Research needs

- Determination of the interactions between technological and institutional factors affecting the outcome of enhancement initiatives, and further development of adaptive learning approaches to deal constructively with uncertainties.
- Determination of the biological, ecological and genetic dynamics of enhancement and development of appropriate methods to assess technological management regimes.
- Comprehensive and quantitative assessment of environmental risks and impacts of enhancements in relation to complete watersheds.
- Consideration and evaluation of a wide range of enhancements and local resources (including indigenous technologies), and development of new enhancement approaches.

This would involve:

- training and capacity building in appropriate methods of institutional and technical analysis, e.g. Institutional Analysis (IAD), population dynamics, empirical modelling and Geographic Information Systems (GIS);
- regional data collection and dissemination using agreed, standard methodologies; and
- regional data analysis and workshops to identify conditions conducive to enhancement initiatives, appropriate policies and management interventions.

Acknowledgements

The authors would like to acknowledge financial support from the following organizations: Department for International Development of the United Kingdom (DFID) (KL and CJG); Australian Centre for International Agricultural Research (ACIAR) and FAO (USA); International Center for Living Aquatic Resources Management (JDB) (ICLARM Contribution no. 1576); and the Ministry of Co-operation and Development of the French Government (JM and PL).

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