DATASHEET FOR CABI AQUACULTURE COMPENDIUM

GROWOUT PRODUCTION SYSTEMS

NAME OF GROWOUT SYSTEM	**Enhancements and culture-based fisheries**

OTHER NAMES

INTERNATIONALLY USED NAME/S	INTERNATIONAL LANGUAGE
Stock enhancement, hatchery enhancement, stocking, restocking, ranching, culture-based fisheries, artificial reefs, brush parks, drain-in ponds, trap ponds, Acadja	English
OTHER NAMES	**COUNTRY**

OVERVIEW

Definition and rationale

Enhancements may be defined as supply-side interventions in fisheries. In contrast to fishing regulations, which affect the way in which existing wild fish stocks are exploited, supply-side interventions aim to directly increase fisheries production through stocking of hatchery fish or manipulation of habitats. Such manipulations affect only part of the production system, and overall yield thus remains strongly dependent on natural processes beyond management control. Also, most enhancements operate in common pool resources, i.e. resources exploited jointly by many users in such a way that each user subtracts from the resource available to others. In common pool resources, exploitation is difficult to control and there is little incentive for investment into the resource unless communal or private use rights systems or governmental intervention regulate exploitation and ensure that benefits from investments accrue to those who bear the costs. Hence to be successful, enhancements must combine technical interventions that are adapted to the existing natural resources with institutional arrangements able to regulate access and sustain investment.

The rationale for enhancements is that under certain conditions, supply-side interventions can substantially increase biological production of aquatic resources. Because enhancements rely largely on natural aquatic productivity they require little feed or energy inputs, and can provide high returns to limited investments. Moreover, introduction of enhancements in common pool resources can facilitate institutional change leading to more efficient and sustainable exploitation of resources.

Fisheries enhancements may involve techniques such as stocking and habitat creation that are similar to those used in restoration initiatives (e.g. Cowx & Welcomme 1998). However, enhancement and conservation measures differ in their objectives (production vs. biodiversity conservation), and in key aspects of the techniques used. It is thus important to clarify objectives of such interventions and develop techniques accordingly. For example, releasing hatchery fish may increase fisheries yield or support an endangered wild stock, depending on exactly how the hatchery programme and the fisheries exploitation are managed. However, it is not usually possible to achieve both aims with the same intervention.

History

Transfers of wild-caught juveniles between natural water bodies and habitat enhancements have been carried out for thousands of years. Hatchery enhancements on the other hand have been carried out only since the mid-19th century. Many hatchery technologies were originally developed for stock enhancement, with on-growing in culture developing only later.

Types

There are two broad categories of enhancements: hatchery enhancements and habitat enhancements. Note that, as explained above, all enhancements involve specific institutional arrangements as well as the technical interventions described in this section. For general overviews see Welcomme & Bartley (1998) and Lorenzen et al. (20010.

Hatchery enhancements

Hatchery enhancements involve the release of cultured animals into natural or semi-natural habitats. Several different types of hatchery enhancements can be distinguished:

- **Culture-based fisheries/ranching systems** where natural recruitment of the target species is absent or negligible. Culture-based fisheries increase yields by building up populations of species that do not reproduce in the target environment, but make effective use of resources as juveniles and adults. This may be the case in certain modified ecosystems (e.g. reservoirs), or where intensive harvesting has reduced spawning stocks to very low levels. An example is the stocking of riverine major carps in Asian reservoirs (De Silva 2003).
- **Stock enhancement and supplementation**, where hatchery fish are released into populations of naturally recruited conspecifics. 'Stock enhancement' usually refers to production-oriented interventions while 'supplementation' is used in the context of conservation, but in practice the distinction is often unclear. Where stock enhancement involves high stocking densities and intensive harvesting, the wild population tends to be replaced by hatchery fish to the extent that a culture-based fishery is created. Conversely, stock enhancement and supplementation may accelerate rebuilding of natural stocks if combined with restrictions on harvesting (Leber 2002; Aprahamian et al. 2003; Lorenzen 2005).
- **(Re-)introduction** of species not currently present in the target habitat. This involves temporary releases, usually of a relatively small number of hatchery organisms in order to 'kick-start' natural colonisation of the target habitat (Philippart 1995; Reisenbichler et al. 2003).

Some hatchery 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.

Habitat enhancements

Habitat enhancements involve modification of habitats to improve harvests of wild fish. The most important types are:

- **Artificial reefs and brush parks**. Such structures affect aquatic resources in multiple ways, through attraction of aquatic organisms from surrounding waters, enhanced production of food organisms, provision of substrate and shelter for target organisms, and physical obstruction of harvesting. Different functions may predominate depending on siting, construction and management of such structures. Artificial reefs are permanent structures, while brush parks are temporary and may be removed entirely for harvesting. See Pickering & Whitmarsh (1997) and Welcomme (2002) for general overviews.
- **Retention systems**, which provide man-made dry season habitat in highly seasonal environments such as floodplains and rice fields. Retention systems concentrate populations of aquatic organisms when flood waters recede, and allow to maintain them well into the dry season (COFAD 2003; Amilhat & Lorenzen 2005).

- **Auxiliary measures** such as fertilization, feeding or predator control are practiced in some hatchery and habitat enhancement.

Importance

Globally, enhancement yields are dominated by hatchery enhancements of freshwater and diadromous species (Lorenzen et al. 2001). Annual yields in this category are likely to be around 2 million t, including 1.3 million t of major carps from Chinese reservoirs, 0.4 million t from salmon in the north Pacific. Culture-based fisheries for food and recreation are well-established components of aquatic resource use in Europe and North America where state fisheries organisations expend an average of 20% of their budgets on hatchery enhancements. Overall, the estimate of 2 million t per year suggests that culture-based fisheries for freshwater and diadromous organisms account for about 20% of recorded capture yields, or 10% of combined capture and culture in this category.

Enhancements of marine organisms are still being carried out primarily on an experimental or pilot scale. A number of marine enhancements have entered commercial scale production: for example, culture-based fisheries for scallops in Japan now yield about 0.2 million t/year, and the technology is being adopted in New Zealand and elsewhere.

Yields from habitat enhancements are poorly documented, but it has been estimated that brush parks (acadjas) account for 12000 t or 40% of the inland fisheries production of Benin. Similar systems are in use in other African and Asian countries, and there is evidence to suggest that habitat enhancements using such indigenous technologies are more widespread in tropical inland waters than has long been realised (Neiland & Ladu 1997, COFAD 2003).

ECOSYSTEMS IN WHICH THIS GROWOUT PRODUCTION SYSTEM IS FOUND

Ecosystem/ Agroecosystem	Tick	Inland (I) and/or Coastal (C) (*Where relevant*)
Arid regions	X	I/C
Bays	X	I/C
Coral reefs	X	C
Ecosystem-independent systems		
Estuaries	X	C
Field crops and vegetables		
Floodplains	X	I
Forests, plantations and orchards		
High altitudes, uplands		
Inland saline areas		
Irrigation canals	X	I
Lagoons	X	C
Lakes	X	I
Large ruminant farms (cattle, buffalo)		
Lowlands		
Mangroves	X	C
Mudflats	X	C
Open sea *(indicate depth: m)*	X	C
Peri-urban areas	X	I/C
Pig farms		
Poultry farms (ducks, fowls and turkeys)		
Reservoirs	X	I
Ricefields	X	I
Rivers/streams	X	I
Rocky shores	X	C

Rural areas	X	I/C
Salt marshes		
Sandy shores		
Small ruminant farms (sheep and goats)		
Swamps	X	I/C

SPECIES AVAILABILITY AND SEED SUPPLY

Hatchery enhancements

Clearly, efficient hatchery seed production is a precondition for hatchery enhancements. Most production-scale enhancements use species for which hatchery production is well developed, in particular salmonids, Chinese and Indian major carps, and tilapias. Large-scale enhancement systems may be vertically integrated, with seed being produced specifically for the enhancement growout system and within the same enterprise. On the other hand, most small-scale enhancements rely on seed purchased on the open market or supplied by government agencies. Where demand for enhancement seed is sufficiently high, some hatchery operators may specialize in supplying seed for this growout system.

The availability of seed produced specifically for enhancement systems is of interest because these systems may have different requirements from other growout systems. Often, cultured fish perform very poorly upon release into natural habitats (Lorenzen 2000). This is a result of domestication effects within the culture environment which affect the morphology, physiology, behaviour and ecology of fish in a way that is advantageous or neutral in culture, but detrimental in natural habitats. Domestication effects can be reduced and the post-release performance of seed fish improved through a range of specialist production techniques. These include sourcing of broodstock from the same, or ecologically similar habitats to that in which the enhancement takes place. Breeding protocols such as factorial mating and the provision of complex semi-natural habitats in rearing facilities can minimize domestication selection and also reduce developmental responses to the culture environment. Active promotion of ‘life skills’ through feeding with live feeds, predator avoidance training etc. can also be effective in promoting post-release performance (Olla et al. 1998; Brown & Dey 2001). High mortality of stocked fish is a key limitation in many hatchery enhancements. Optimisation of seed production and release strategies may lead to significant reductions in mortality (Bilton *et al.* 1982, Munro and Bell 1997, Leber 1999). There is also evidence that culture-based fisheries may benefit from genetic selection for traits linked to the return rate or growth (Jonasson 1995). While not all of these techniques will be economically advantageous, there clearly is scope for improving seed production specifically for enhancement systems. In addition, where released fish interact genetically with threatened natural stocks, maintaining the genetic makeup of the natural population becomes an important goals in itself and requires specialist hatchery protocols (Bartley *et al.* 1995; Frankham et al. 2001).

Habitat enhancements

Habitat enhancements intervene in the life cycle of wild aquatic organisms. Seed supply is from natural reproduction and thus, dependent on the natural fauna of the enhanced system.

STRUCTURE AND DESIGN

Hatchery enhancements

Hatchery enhancements are carried out in open waters and do not usually involve construction of any special structures. The habitat within which a hatchery enhancement is carried out constitutes the ‘culture facility’, and largely determines the physical and biological conditions in this growout system. Clearly, hatchery enhancements are possible only in habitats that meet the target organism’s basic requirements. Within the habitats that do so, production tends to be positively related to trophic status (nutrient availability). Small water bodies (small lakes, reservoirs, lagoons etc.) often provide particularly good opportunities for enhancement due to the presence of natural boundaries to the physical system and often, the user group; often high nutrient availability, and relative ease of stocking and harvesting. Larger and ‘open’ water bodies pose greater technical and institutional problems, except where the enhanced population is immobile (e.g. coastal bivalves). In some cases, fencing structures are constructed to contain enhanced stocks.

Habitat enhancements

Habitat enhancements are carried out within the wider aquatic habitat to attract or trap aquatic organisms and/or raise their production. Hence both the design of the structure itself and its location within the wider habitat are important determinants of production.

Artificial reefs and brush parks

Attraction/production structures may permanent (such as artificial reefs) or temporary (such as brush parks). Most structures built specifically for fisheries enhancement are small (1 to 100 m^3), but some are much larger (up to 50,000 m^3). Of course structures built for coastal defence or resulting from the dumping of scrap material may perform similar functions to those built specifically for fisheries.

Reefs may be constructed from a single material, or a combination of several and their structure may vary from simple blocks to a complex matrix of mixed shapes (Pickering & Whitmarsh 1997). Concrete is the most widely used material, followed by rock and a plethora or mostly ‘waste’ materials such as scrap metal, tyres etc. The structural complexity of reefs, including the size and variety of crevices affects both the diversity of organisms colonizing the reef and its overall biological productivity (Baine 2001). The physical location of a reef has implications for its vulnerability to rapid sedimentation and storm damage. Smaller reefs are usually constructed in shallow coastal waters (5-20m), but larger offshore structures may be found at greater depths. The bottom substrate upon which the reef is placed, and its distance from existing hard substrate also affect its colonization.

Brush parks are temporary structures are found mostly in freshwaters and in coastal lagoons. They tend to be made of wood, located in shallow water (3 m or less) and occupying the full water column. The wood used may consist of anything from tree trunks to small twigs, or floating vegetation. There are many different designs, based on often considerable indigenous knowledge about plant species, their configuration, etc. (Welcomme 2002).

Retention structures

Retention structures are floodplain depressions that are extended in size or constructed entirely for the purpose of retaining wild fish stocks after flood waters recede. Such structures may range in size from 1 to over 50,000 m^2. Among the smallest retention structures are the trap ponds found in rice fields, for example in northeast Thailand (Amilhat & Lorenzen 2005). Very large ponds of several kilometers in length have been described from African river floodplains (Welcome 1985). Retention structures are built in such a way as to facilitate entry of wild fish, with raised banks absent or restricted to the lower side of the pond. Canals may be built to guide fish into the structure. Brush parks are often built within retention structures to attract fish into the structure, and prevent unauthorized harvesting.

FEED

All enhancements are based on the utilization of natural aquatic biological productivity. In certain systems feeding may be carried out at a low level to attract fish, but it is never a major part of enhancement production systems.

GROWOUT MANAGEMENT

Because enhancements rely on the utilization of natural biological productivity in ecosystems not primarily managed for fish production, many factors that influence production are beyond management control. Hence growout management must be tailored to the ecosystem in which the enhancement occurs.

Hatchery enhancements

Growout management in hatchery enhancements centres on the selection of species, stocking and harvesting. Because hatchery enhancements utilize natural biological productivity in habitats not primarily managed for fish production, many factors that influence production are beyond management control. Hence species, stocking and harvesting regimes must be tailored to the existing ecosystem to optimize results.

Culture-based fisheries

Culture-based fisheries usually operate for species that do not recruit naturally in the target habitat. Species selection for culture-based fisheries is thus based on an expectation that the selected species can grow out well in then target habitat even tough it may not be able to close its life cycle naturally. In general, this assessment is based on local or regional experience rather than formal evaluation of requirements, but some formal approaches exist (e.g. habitat suitability criteria for freshwater fish). Once releases of the target species have taken place, the outcomes should be evaluated empirically to assess whether the species does indeed perform well in the target habitat.

Production of culture-based fisheries is dependent on the release and harvesting regime, and the natural biological productivity of the habitat. As the latter is beyond management control, optimizing release and harvesting to make the best use of the given productivity is key optimising culture-based fisheries. The main variables that can be modified are release size and number (density), and the size at harvest and harvesting (fishing mortality) rate. There is not necessarily a single optimal strategy – the same production can usually be achieved with different combinations of these variables, but some combinations may be more practicable or economically efficient than others. A brief overview of the population dynamics underlying management of culture-based fisheries is given in POPULATION DYNAMICS/APPLICATIONS/EXTENSIVE AQUACULTURE OR CULTURE-BASED FISHERIES. In large-scale culture-based fisheries, detailed analyses of population dynamics are required to optimize management (see Lorenzen 1995, 2000; Lorenzen et al. 1997). In smaller systems, of which there are usually many replicates, it may be more efficient to analyze production responses to management with empirical models. For examples of empirical analyses of culture-based fisheries release and harvesting regimes see De Silva *et al*. 1992, Lu 1992, Li & Xu 1995, Amarasinghe 1998, Hasan & Middendorp 1998, Lorenzen *et al.* 1998a. Quantitative assessment of management regimes in culture-based fisheries can lead to very substantial gains in yield or efficiency at low cost (see e.g. Lorenzen et al. 1998a). Unfortunately such assessments are not always carried out, and many culture-based fisheries are likely to operate under very inefficient regimes. Yields from culture-based fisheries vary widely depending on the species and habitats involved. The major carp - tilapia systems commonly found throughout Asia achieve yields of 500 to 3000 kg/ha in small and shallow water bodies, and 100-750 kg/ha in larger reservoirs.

Stock enhancement and supplementation

In stock enhancement and supplementation, where hatchery fish are released into wild populations of the same species, the basic management variables are the same as in culture-based fisheries: stocking size and density, harvesting size and rate. However, the population dynamics and thus, production response to management is further complicated by natural recruitment. Almost inevitably, density-dependent processes result in compensatory reductions of wild population abundance and production when hatchery fish are released. Such responses need not be complete, i.e. the net effect of hatchery releases may be positive despite significant compensatory responses. The magnitude of compensatory responses depends on the status of the wild population as well as the management regime for the combined hatchery and wild stock (see Lorenzen 2005 for a detailed treatment). Theoretical studies and some field evidence suggest that enhancements can raise yields well above the level achievable by optimal exploitation of the wild stock, but this will normally be at the expense of wild stock abundance and production. Intensive stocking and harvesting may result in complete replacement of a wild by a culture-based fishery.

As a result of the wild stock interactions discussed above, enhancement and supplementation programme are likely to be effective only if very carefully managed on the basis of detailed knowledge of population dynamics (Lorenzen 2005). Two comparative studies on stocking effectiveness in lakes were unable to detect positive impacts on yield of releasing hatchery fish into lakes where wild populations of the same species were present, whilst release in to lakes where the species was absent were often effective (Salojaervi & Ekholm 1990, Quiros & Mari 1999). Lorenzen 2005 discusses quantitative assessment methodology for stock enhancement, and the ENHANCEFISH decision support tool may be used to carry out practical assessments (Medley & Lorenzen 2005).

Stock enhancement may be carried out as a long-term strategy to increase yields over and above the level supported by natural recruitment, or temporarily to rebuild natural spawning stocks more quickly than would be possible through harvest restrictions alone (also known as restocking, rebuilding or restoration stocking).

Re-introduction

Re-introduction of locally extinct species from cultured stocks is being widely practiced in freshwater fisheries, often as part of larger restoration programmes (Philippart 1995). Re-introduction can also be effective in reestablishing fisheries in small waterbodies affected by drought (Van der Mheen 1994). Re-introduction aims to kick-start a natural rebuilding process and the number of fish required is far less that in enhancements based on recapture of stocked fish. Adaptations to local ecological conditions are common in wild fish populations, and evolve rapidly in the span of a few generations. Hence it is best to source founder populations from environments that are ecologically similar to the target environment. Releases should be temporary only in order to allow evolution of adaptations without continuous inputs of hatchery fish which are subject to very different selection pressures (Reisenbichler et al. 2003). Obviously, harvesting should be minimized during population establishment.

Habitat enhancements

Artificial reefs and brushparks

Growout management in artificial reefs and brush parks is largely limited to harvesting. Artificial reefs create a partial harvest reserve, in that they make the use of large-scale fishing gear such as trawls difficult. Often reefs are harvested by divers, or using traps or hook and line. Brush parks on the other hand can be removed for complete harvesting. Usually brush parks are enclosed by nets, and the structure removed and rebuilt outside the enclosed area. Harvesting intensity (or frequency on the case of complete harvesting of brush parks) is a major determinant of yield from reef and brush park systems. Optimal harvesting regimes should be developed using stock assessment methods, including comparative empirical studios, experimental management and/or population modelling. Welcomme (2002) provides conceptual and empirical models for brush park harvesting.

In the lagoons of Benin, production from brush parks has been estimated as 1900 to 5600 t/ha/year (Welcomme 1972), substantially higher than the average of 0.29 t/ha/year achieved in open waters of the lagoons.

PROCESSING

In general, processing of products from enhancements is similar to that of capture fisheries products. Like those from capture fisheries, products from enhancements tend to be variable in size and other attributes, although their supply may be somewhat more predictable.

MARKETING

Inputs for hatchery enhancements consist primarily of seed fish. These may be produced in specialist, usually government hatcheries or obtained from commercial hatcheries supplying mainly the aquaculture industry.

Products from enhancements tend to be marketed in the same way as fisheries, rather than aquaculture products. This is due to the fact that they tend to be harvested by fishers and share attributes such as variable size and quality, and relatively unpredictable supply, with fisheries products. Problems of over-supply can occur where large catches are obtained over short periods of time, for example in enhancements if seasonal water bodies that dry up over a short period of time, or the harvesting of major brush parks.

In many cases, however, enhancements contribute marginally to markets dominated by the outputs from capture fisheries or aquaculture, so that enhancement production has a limited impact on prices. Market interactions between fisheries enhancements and the rapidly growing aquaculture sector may have a significant effect on the financial viability of enhancements. The expansion of salmon farming is a case in point - it led to a decline in prices that affected the viability of salmon enhancements (Boyce *et al.* 1993).

It is not unusual in community-based enhancements to market fishing rights rather than the fish produced. This often takes the form of fishing days, where individuals pay a fee for the right to participate in fishing.

ENVIRONMENTAL IMPACT OF GROWOUT PRODUCTION SYSTEM

Enhancements are intimately linked to the natural ecosystems within which they operate, and inevitably have environmental impacts. Such impacts may be positive (e.g. maintenance of ecosystem structure and function in the face of intensive harvesting) or negative (e.g displacement of wild stocks). Usually, environmental impacts are multiple and complex, and their net effect may be quite different from expectations based on consideration of a single impact pathway. For example, culture-based fisheries for exotic carps and tilapia in Lao lakes have a strongly positive effect on the abundance of native wild fish. This unexpected outcome is due to the fact that restrictions on harvesting put in place to protect the stocked fish have a far stronger effect on wild fish abundance than possible ecological interactions with the stocked exotics (Lorenzen et al. 1998b).

Hatchery enhancements

Environmental impacts of hatchery enhancements arise due to ecological and genetic interactions between released hatchery and wild fish, and due to auxiliary modifications such as changes in the harvesting regime. Ecological interactions arise from intra and interspecific competition, predation, reproduction and disease transmission (Cowx 1994, Blankenship & Leber 1995, Munro & Bell 1997). Genetic interactions arise directly from interbreeding and hybridization, and indirectly from the effects of ecological interactions on population abundance and the selection regime, even where interbreeding does not take place (Utter & Epifanio 2001).

In culture-based fisheries and ranching, where the target species does not occur naturally in the target ecosystem, environmental impacts arise through interspecific interactions and ecosystem manipulation by the target species. The magnitude of such impacts is highly dependent on the species and environment. Predator stocking can have strong impacts on prey populations and, through trophic cascades, the wider ecosystem. This effect is used positively in certain biomanipulation strategies (Mehner et al. 2003). Likewise the stocking of grass carp can radically reduce the abundance of aquatic macrophytes with strong system-level impacts. On the other hand, there are examples where stocking of exotic major carps and tilapias has had a negligible impact on resident fish populations and communities (Lorenzen et al. 1998b; Barthelmes & Bramick 2003).

In stock enhancement and supplementation, the strongest impacts are likely to arise from intraspecific interactions affecting the wild component of the target stock. Interspecific and system level impacts may become significant where enhancement raises stock biomass well above the carrying capacity for the natural stock, but this is rarely the case as intensive stocking tends to be balanced by intensive harvesting. Intraspecific ecological impacts on the wild stock occur primarily due to competition. Competition alone can drive the wild stock component to extinction, but only if releases are continual and large relative to wild population abundance. Direct genetic interactions due to interbreeding of wild and hatchery fish dramatically increases the risk of reduced productivity and even genetic extinction of the wild population (Utter & Epifanio 2002; Ford 2002). As a general rule however, released hatchery fish have much lower survival and reproductive success than their wild conspecifics, and this limits both ecological and genetic interactions (and, of course, the effectiveness of enhancement). Empirical studies have found the level of genetic introgression of hatchery into wild populations to be highly variable but often very low, even where substantial enhancement activities have occurred. Advances in hatchery production increasingly allow the production fish that perform well on the wild, and this may lead to greater environmental impacts as well as greater enhancement effectiveness. Impacts on the wild population component are expected to be greatest if the fitness of hatchery fish is only moderately compromised (Lorenzen 2005). Use of sterile fish for enhancement can greatly reduce risks to the wild stock.

Where stocking involves introduction or translocation of species, there are additional concerns such as hybridisation with native/established species, habitat alterations, changes in the trophic functioning of ecosystems, and the introduction of exotic parasites and pathogens (Courtenay & Stauffer, 1984; Moyle *et al.*, 1986; Carvalho & Hauser, 1995). These risks are widely recognised and there is now general agreement that proposals for introductions must be carefully evaluated using frameworks such as the ICES/EIFAC code of practice (Turner 1988).

Finally, major impacts (positive or negative) on wild populations can arise from change in harvesting as harvesting effort or methods change in response to hatchery enhancements. When considering the overall impact of enhancements it is therefore important to consider a broad range of direct as well as indirect effects, and to evaluate enhancement impacts against those of realistic alternatives.

Habitat enhancements

Impacts of habitat enhancements have received relatively little attention (FAO 1999). Probably the most common and significant impact of artificial reefs and brush parks is a reduction in water movement and incrased rate of sedimentation.

SOCIAL ASPECTS

Institutional considerations

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

It is not surprising that that the largest-scale enhancements were found in command economies where even large water bodies were managed by single authorities. Perhaps the prime example are the Chinese culture-based reservoir fisheries, where comprehensive management by reservoir authorities has resulted in technically very effective enhancements on a large scale. However, few such large-scale single-authority systems have survived the demise of the political-economic systems which have enabled their creation in the first place. Most enhancements have developed or are being developed in common pool resources, and many have been sustained only through continued government subsidy. However, there are also many examples of enhancements that have been sustained by resource users either independently or in co-operation with governments (Pinkerton 1994, Garaway *et al.* 2001). Self-governance of common pool resources is successful in particular where boundaries of the resource and those who can use it are clearly defined, rules are adapted to local conditions, all relevant stakeholder participate in designing use rules, enforcement is carried out by users or at least accountable to them, sanction are graduated, and low-cost conflict resolution mechanisms exist (Ostrom 1991). Results of institutional studies on enhancements are broadly consistent with these principles (Hartmann 1995, 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. This has been demonstrated for example in small waterbody fisheries in Laos where stocking has precipitated the rapid proliferation of community management systems (Garaway et al. 2001). The potential for enhancement initiatives to precipitate or re-enforce resource user-led management action should receive wider consideration in inland and coastal aquatic resources management.

Socio-economic benefits

The financial and economic viability of enhancements varies widely. Enhancements for recreational fisheries are often viable because angles are willing to pay for the experience of fishing at a rate that far exceeds the market value of the fish caught. Enhancements for food production face much tighter margins. Many, in particular government-led enhancements are of questionable economic viability, but are maintained for political reasons. However, there are also many examples of enhancements that are financially viable, i.e. benefits exceeded direct costs (Sreenivasan 1988, Ahmad *et al.* 1998, Lorenzen *et al.* 1998a, Kitada 1999). Somme of these offer very high returns to cash investment and labour, often much higher than more intensive aquaculture techniques (e.g. Lorenzen *et al.* 1998a). Full economic evaluation of enhancements requires opportunity costs, such as possible loss of yield from other (non-target) wild stocks, to be taken into account. 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 SE Asia often provide community income (Garaway 1995, Garaway 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.

Due to their low input and capital requirements, enhancements provide opportunities in particular for resource poor sections of inland and coastal aquatic resource users. Enhanced community fisheries in Laos for example make very significant contributions to village income in overall very resource poor communities (Garaway et al. 2001). Often, however, it is difficult for resource poor people to establish exclusive use rights to enhanced stocks or habitats.

Enhancements are frequently associated with access restrictions. Examples are community management of culture-based small waterbody fisheries, leasing of seasonal water bodies to individuals; and granting of exclusive rights to scheduled castes in Indian reservoirs (Lorenzen et al 2001). Such restrictions can be detrimental to those whose use of the resource has been curtailed and lead to conflicts. However, it is often possible to adapt management systems to minimize negative effects conflicts, provided that all stakeholders participate fully in decision making. 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. floodplains of Bangladesh (Ahmad 1998; Samina & Worby 1993), or West African lagoons(Welcomme 2002)).

Approaches to the development of enhancements

The degree of management control over enhancement outcomes is inherently limited. Hence it is rarely possible to fully 'design' new enhancement systems based on prior knowledge (Lorenzen & Garaway 1998). Rather, experimentation with both the technology and the institutional arrangements is normally required to develop enhancements that make effective use of the available resources and are institutionally sustainable. Such experimentation may be carried out informally by resource users, but its effectiveness can be greatly enhanced by application of principles of experimental design and quantitative analysis. Co-operative adaptive management approaches thus hold great potential for the development and improvement of enhancements. See Garaway & Arthur (2004) for practical guidance.

LINKS TO WEBSITES

Give details of any sites on the world wide web, which are of relevance to this datasheet.

NAME	ADDRESS (URL)
EnhanceFish: Fisheries enhancement decision support tool (downloadable from October 2005)	www.aquaticresources.org/enhancefish
Aquatic Resource Ecology Lab, Imperial College London (many publications on enhancements downloadable)	www.aquaticresources.org
FAO Freshwater Fisheries and Aquaculture Service	http://www.fao.org/fi/default.asp
Adaptive learning website (includes applications to enhancements)	http://www.adaptivelearning.info

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