General aspects of stock enhancement in fisheries developments

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Abstract: Stocking occurs in freshwater, estuarine and marine environments worldwide to replenish, maintain or enhance populations of aquatic organisms, especially fish as well as gastropods and crustaceans. Stock enhancement is used by fisheries managers to restore depleted populations of recreationally and commercially significant fish species. Stock enhancement is also used to increase productivity of a fishery by augmenting the natural supply of juveniles, and optimising harvests by overcoming recruitment limitation. Stock enhancement in culture-based fisheries is most often undertaken in small waterbodies on a regular basis to sustain or increase yields. Stocking typically involves the release of large numbers of early-life stage animals that are mass-produced in hatcheries.

The primary purposes of stocking in developed countries is for recovery of threatened species and to support recreational fishing, whereas in developing countries it is more to increase food fish supplies for rural communities and improve their livelihood through income from fish harvested.

Stocking programs use seedstock produced for aquaculture purposes and in some cases captive breeding techniques have been established specifically to support stocking programs. Advances in techniques to breed fish in captivity have seen a proliferation in the number of species and quantities of juveniles produced in hatcheries for stocking.

In recent years, however, stocking programs have been subjected to substantial criticism due to perceived impact of hatchery-bred fish on genetic structure and fitness of wild stocks, transfer of disease, introduction of exotic species and non-target species, and their effects on other aquatic species and the environment.

To maximise the potential benefits to fisheries from stock enhancement, and to address the above criticisms, a responsible and ecologically sustainable approach should be adopted for all stocking programs. This requires, clear and well-defined objectives, an a priori evaluation of the need for stocking, well-formulated stocking strategies that consider the risks, benefits, the water to be stocked, and the fish to be used (e.g. species used, source of fish, size of fish, and number stocked). Equally important is the evaluation of stocking success in terms harvest yields as well as social, economic and cultural benefits. Other fisheries management measures will also need to be implemented to support stock enhancement, such as fisheries policies, regulations and guidelines for dealing with property and access rights. There are also technical aspects to consider, such as managing the stocked water bodies, harvesting, marketing, and education and training for participating communities.

Key words: *Culture-based fisheries, stakeholders, impacts of stocking, risk management.*

Introduction

"Stock enhancement" is broadly used to describe many forms of stocking, irrespective of purpose, as well as other measures that are supposed to facilitate an increase in the size of the stocks. Stock enhancement, which typically involves the release of large number of juveniles mass-produced in hatcheries, is an important and widely used tool in fisheries management, particularly for maintaining or enhancing populations of aquatic organisms.

Stocking occurs in freshwater, estuarine and marine environments worldwide to replenish, maintain or enhance populations of aquatic organisms. Many species of fish as well as gastropods and crustaceans have been released into freshwater, brackish and marine environments. Stocking hatchery-produced fish is seen as a means of meeting the demands for seafood products and to meet the need for food security in an increasingly populated world. Stocking as a means of providing a food resource will be a priority for future aquaculture. In addition, stocking programs are playing an important role in the conservation and recovery of threatened species, and also satisfying social needs of communities, such as sport and recreational fishing in developed countries.

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Fish introductions to improve capture fisheries are likely to have accompanied the early developments of aquaculture, which date back several thousand years. Stocking programs have taken advantage of seedstock production for aquaculture purposes and captive breeding techniques that have been established specifically to support stocking programs. Advances in techniques to breed and rear fish in captivity have seen a proliferation in the number of species and juveniles produced in hatcheries for stocking. Fish introduction has become a popular method of enhancing rural fisheries, and stocking has been a high priority on fisheries development agendas for several decades (De Silva and Funge-Smith 2005; Miao et al. 2010). For example, fisheries stock enhancement in Cambodia and Lao PDR has gained popularity with government and communities alike and has become part of cultural and ceremonial events, such as the annual National Fish Day.

There have been various major reviews of fisheries stock enhancements, including culture-based fisheries (CBF), both globally (Cowx 1998; Welcomme and Bartley 1998; Lorenzen et al. 2001; Molony et al. 2003; Bell et al. 2006; Bartley 2007) and within Asia (Petr 1998; Li 1999; Welcomme and Vidthayanon 2003; De Silva and Funge-Smith 2005; Miao et al. 2010). No attempt will be made here to further review the above, and this article will instead provide a general overview of the benefits, risks and management of stocking, focusing mainly on freshwater finfish. Other forms of fisheries enhancement, such as fish attracting devices, environmental engineering and fish reserves, will not be discussed here.

Purpose and benefits of stocking

Stocking generally involves releasing animals cultured in a hatchery or a fish farm into the wild for various purposes (Table 1). A global review of inland fisheries enhancements undertaken by FAO (FAO Inland Water Resources and Aquaculture Service 1999) indicated that stockings are primarily undertaken for increasing yields, production of food and generation of income (Figure 1).

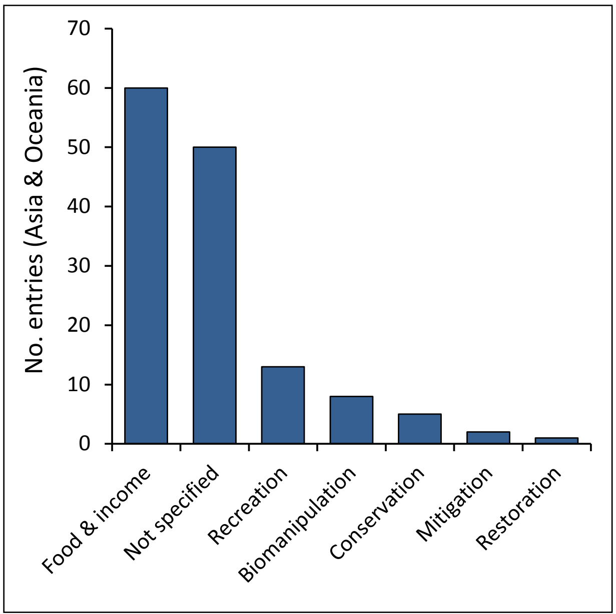
Stocking is the primary source of fish in CBF, in which fish are released into typically small permanent and temporary water bodies (<100 ha) to increase the supply of fish as food in rural areas, as well as providing additional income to rural farmers, thereby contributing to poverty alleviation (Lorenzen et al. 2001; De Silva et al. 2006; De Silva 2008). Both exotic and indigenous species may be stocked on a regular basis. CBF is practised widely across Asia, and numerous examples of this practice are available (see other chapters in this volume). Enhancement of inland fisheries is estimated to yield about 2 x 10^6 t/year, which is mostly from CBF (Lorenzen et al. 2001).

Stocking is undertaken to create or enhance recreational and sport fisheries, especially in artificial impoundments in developed countries. For example in the state of Victoria (Australia), up to 3 x 10^6 fish representing 11 species, both exotic (salmonids) and indigenous, are stocked annually (Ingram 2013). These stockings, which are strongly supported by government, primarily cater to anglers seeking fishing opportunities for sport and food, and also supports rural communities and ancillary industries such as bait and tackle suppliers.

Stocking is also used for mitigation, restoration and conservation purposes as well as to control environmental conditions and aquatic pests (Figure 1). Stocking may occur to overcome recruitment limitations in existing fisheries, restore severely deleted populations/stocks to a more productive levels or sustainable yield levels, to reduce the time needed to rebuild over-exploited fisheries, or to even create new fisheries.

Stocking is an important tool assisting in the recovery of threatened species for conservation purposes (e.g. Ingram et al. 1990; Soorae 2008). For example, stocking has played a major role in the recovery of the critically endangered, IUCN listed, trout cod (*Maccullochella macquariensis*), an Australian freshwater species. Stockings undertaken since 1986 have resulted in several self-recruiting populations being re-established in at least six areas (Koehn et al. 2013). In populations or species with low fitness, a new management strategy called genetic rescue has been advocated to help avoid possible extinction. Genetic rescue involves introduction of populations from a different locations (outbreeding) to

Figure 1. Reasons for stocking in Asia and Oceania regions (Source: FAO Inland Water Resources & Aquaculture Service 1999).



a low fitness population, resulting in increased genetic diversity and vigor in populations that previously lost genetic diversity (McClelland and Naish 2007). Such genetic rescues have proven a valuable conservation measure for many species (Frankham et al. 2002) and may prove to be beneficial for some fish populations.

The principle benefit of stocking is to produce food and income from fish harvested from stocked waters. Some stock enhancement activities, including CBF, can provide very high returns to cash investment and labour (e.g. Hansson et al. 1997; Lorenzen et al. 1998; De Silva 2008). Stocking activities also provide benefits through ancillary industries, such as employment in hatcheries, aquaculture feed mills, fishing, processing and marketing, as well as tourism associated with recreational and sport fisheries (De Silva and Funge-Smith 2005).

Species stocked

Most stocking programs have required, and usually preceded by, the development of hatchery and nursery production techniques for the target species, though some stockings may involve the capture of juveniles/seedstock in one area, where recruitment is healthy,

Table 1. Purposes of stocking in inland waters

Stocking type	Rationale	Key assumptions	Comments & examples
Augmentation and enhancement	Improve production and profit over natural conditions.	Stocking carried out to supplement an existing fishery where the habitat is below carrying capacity or fishery recruitment is limited. Consumers accept released fish.	Developing and developed countries. Example. Stock enhancement for recreational and sport fishing.
Mitigation	Counter disturbance to the environment (flood, fire, toxic spill etc).	Disturbance event has passed. The environment can support stocking and is below carrying capacity. Consumers accept release.	Developed countries.
Community change	Improve production and profit over natural conditions.	Species performance in new environment acceptable, habitat is below carrying capacity and resource base will not change substantially. Consumers accept released fish.	Developing countries. Example. Replenish stocks for culture-based fishery.
Environmental change	Control environmental conditions and aquatic pests.	Species stocked will achieve desired outcome.	Developing and developed countries. Examples. Biomanipulation. Control algal blooms in eutrophic ecosystems by enhancing herbivores through a reduction of planktivorous fish and introduction of piscivorous fish. Stocking of selected fish species to control of mosquito larvae. Stocking of grass carp to control aquatic weeds.
Conservation	Recover threatened species/populations.	Stocking within historical range of species. The environment can support release and is below carrying capacity.	Developed countries.
Create new fisheries	Fill a vacant niche.	Species performance in new environment acceptable, habitat is below carrying capacity and resource base will not change substantially. Consumers accept released fish.	Developing countries. Newly created artificial reservoirs. Transfer fish into new water bodies or where new species are introduced into existing fisheries.

and translocation to another area where recruitment is inadequate or lacking. Advances in captive breeding, larviculture and fry rearing in hatcheries have seen a proliferation in both the number of species and number of seed available for stocking. The number of species that are farmed, and therefore available for stocking programs, continues to grow. More than 160 freshwater species (molluscs, crustaceans, finfish, amphibians and reptiles) are being commercially farmed (FAO aquaculture statistics) and therefore potentially available for stock enhancement.

Many species have been the subject of stock enhancement, including fish, molluscs and crustaceans. The most commonly used species for stocking inland waters are cyprinids (common carp, Chinese or Asian carps and Indian major carps), salmonids (salmon and trout) and cichlids (tilapias) (Table 2). Thirty -three finfish, two crustacean and one reptile species have been used directly in stock enhancement practices in Asia and those that are directly and or indirectly impacted through inland fisheries enhancement programs/activities (Miao et al. 2010). Of the fish species, 51% were cyprinids and 12% were salmonids. De Silva (this volume), listed 14 species commonly used in CBF in four Asian countries. While most stock enhancements have focused on finfish, invertebrates have also been released, including giant freshwater prawn (*Macrobrachium rosenbergii*) in Thailand (Jutagate and Kwangkhang, this volume) and Sri Lanka (Amarasinghe and Wijenayake, this volume) and mitten crab (*Eriocheir sinensis*) in China (Wang et al. this volume).

In Lao PDR, for example, 13 fish species are produced in government and private hatcheries, only four species are indigenous (Table 3). These species are used for both aquaculture (grow-out in ponds and cages) and CBF. Although the number of seedstock produced for

Table 2. The more common hatchery-produced species used for stocking in Asian inland waters (Source: FAO Inland Water Resources and Aquaculture Service 1999)

Family	Species	No. of countries released
Cyprinidae	Common carp (*Cyprinus carpio*)	33
	Grass carp (*Ctenopharyngodon idellus*)	31
	Silver carp (*Hypophthalmichthys molitrix*)	26
	Bighead carp (*H. nobilis*)	26
Salmonidae	Rainbow trout (*Oncorhynchus mykiss*)	19
	Brown trout (*Salmo trutta*)	13
Cichlidae	Nile tilapia (*Oreochromis niloticus*)	30
	Mozambique tilapia (*O. mossambicus*)	28
	Blue tilapia (*O. aureus*)	18

Table 3. Number of government and commercial hatcheries producing fish seedstock in Lao PDR (Source: Department of Livestock & Fisheries, Ministry of Agriculture & Forestry, Lao PDR)

Species	No. hatcheries		
	Government	Private	Total
Tilapia (mixed sex & monosex) (*O. niloticus*)	20	48	68
Silver barb (*Barbonymus gonionotus*)*	17	42	59
Common carp (*Cyprinus carpio*)	19	39	58
Rohu (Indian carp) (*Labeo rohita*)	10	22	32
Clarias catfish (*Clarias*)	7	19	26
Silver carp (*Hypophthalmichthys molitrix*)	7	4	11
Grass carp (*Ctenopharyngodon idella*)	2	6	8
Catla (*Catla catla*)	2	3	5
Mud carp (*Cirrhinus molitorella*)*	2	1	3
Mrigal (*Cirrhinus mrigala*)	2	0	2
Pa phia (*Labeo chrysophekadion*)*	2		2
Catfish (*Hemibagrus spilopterus*)*	1		1
Bighead carp (*H. nobilis*)	1		1
Frogs*	42		6

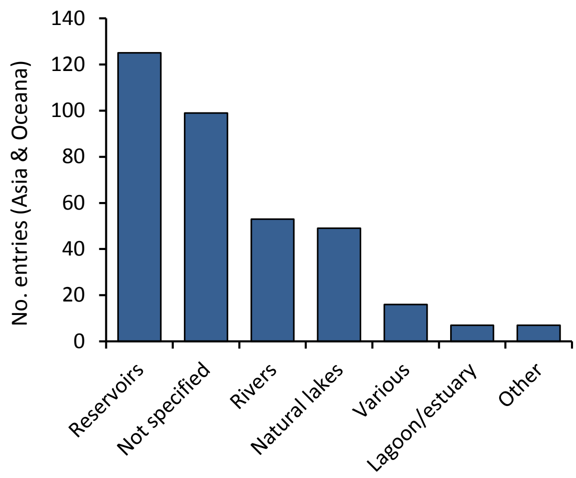
** Indigenous species.*

each species is not available, the number of hatcheries producing each species may reflect their popularity by growers and consumers in LAO PDR.

Hatcheries producing seed for stocking may be large and well-established facilities incorporating broodstock holding facilities (ponds and tanks), spawning and egg incubation facilities and nursery facilities (tanks and greenwater ponds for rearing fry and fingerlings).

In more remote and rural areas, some of these facilities may be on different farms; hatcheries producing larvae which are reared in small specialised nursery farms, which is the case in Sri Lanka (Amarasinghe and Wijenayake, this volume). Seedstock may also be produced by mobile hatcheries, which are small systems designed to be portable and moved from one area to another. Mobile hatcheries are being used in both Thailand and Lao PDR (Imsilp et al. 2003).

Figure 2. Types of water bodies being stocked. (Source: FAO Inland Water Resources and Aquaculture Service 1999).



Waterbodies stocked

Globally, reservoirs and lakes (manmade impoundments, natural lakes, floodplain depressions, oxbow lakes, lagoons etc.) are most commonly stocked (FAO Inland Water Resources and Aquaculture Service 1999) (Figure 2). The primary purpose of stocking these water bodies in developing countries is to increase the food fish supplies, whereas in developed countries it is to enhance recreational fisheries and for conservation purposes (Welcomme and Bartley 1998). Stock enhancement of riverine systems for fisheries development in Asia is relatively rare compared with developed countries (De Silva and Funge-Smith 2005).

Stock enhancement of existing, wild and open-access fisheries that may or may not be self-recruiting, typically occurs in larger waterbodies (reservoirs, lakes and river systems) where there is little or no property rights to the stock. Generally, in these water bodies recapture rate may be low and repeated enhancement is not always necessary to maintain the fishery if natural recruitment occurs (Welcomme and Bartley 1998). In contrast, in CBF, typically smaller waterbodies are stocked on a regular basis and usually the stocking activity is the only means of sustaining the fishery. In these waters, a person or a group of persons and/or an organisation will have property rights to the stock.

Stakeholders

A wide range of stakeholders are involved in stocking programs, both directly and indirectly, and include decision-makers at all levels from village leaders to country agencies, fisheries, aquaculture, water, environmental and conservation managers, water agencies and end users (e.g. commercial and recreational fishers, fish mongers and consumers).

Waterways and water bodies that are stocked may be managed by agencies for the state as common pool (non-private ownership), or be owned by individuals, communities or corporate bodies. Some waters may be exploited jointly by separate users, such as large dams used for hydroelectricity generation and irrigation.

Often, particularly in developed countries, stocking activities are governed by various policies, regulations and legislation, to ensure that stocking is conducted in a responsible an ecologically sustainable manner. Stocking of public waters tends to be more heavily regulated by authorities, and may also require a permit, which reflects the apparent higher potential of risks in stocking open waters as well as a greater responsibility from managers of public environmental ecosystem resources. In contrast, stocking of private waters (on private land) tends to be less regulated.

Assessing stocking success

Outcomes from stock enhancements can be highly variable. Stocking in one year in one location for one species does not guarantee that similar results will occur in other years and locations for that species, or for other species (Lorenzen et al. 2001). Outcomes, in terms of yields, distribution of economic and social benefits and institutional sustainability, may even be different from those initially expected. For these reasons it is often difficult to assess either the benefits or impacts of stocking programs (Lorenzen 2005; Garaway et al. 2006).

Stocking is not always successful, and varying degrees of results may be obtained. There are numerous examples in the literature where stock enhancement programs have failed (e.g. Moran et al. 1991; Amarasinghe 2010), made no discernible impact (e.g. Saltveit 2006) or have been highly successful (e.g. Lorenzen 2008; Amarasinghe 2010). An evaluation of several major stocking programs to enhance recreational fisheries in Victoria (Australia) indicated highly variable outcomes with stocked fish representing from 11% to >99% of stocks of particular species in the enhanced fisheries (Ingram et al. 2015). CBF, on the other hand, have demonstrated clear and substantial benefits, with good, regular and predicable returns being obtained from well-managements operations in several countries across Asia (e.g. see papers this volume).

Success of stocking programs may be affected by a number of variables, including but not limited to (Wahl et al. 1995; Li 1999; Brown and Day 2002):

- Stocking density and ecological carrying capacity of the receiving environment
- Age and size of fish at stocking
- Condition and health of fish
- Genetic factors
- Presence and amount of suitable habitat, food, competitors and predators at release sites
- Timing of stocking relative to above factors
- Release methods.

Since evaluation of stockings can be time-consuming and expensive, or not even considered, assessment of stocking success is not always undertaken, or undertaken in a manner that does not allow full assessment (e.g. see Miao et al. 2010). A well-designed monitoring and evaluation program needs to be developed at the commencement of stocking programs to fully assess their effectiveness, yields and economic and social returns to beneficiaries at their conclusion. Characteristics of such a program include a clearly stated objectives or questions, a statistical study designed to answer those questions, an appropriate geographic framework, standard sampling methods so that observed differences are not confounded by methodological differences, quantitative indicators with known precision to maximise explanatory power and public reporting of survey results (Hughes 2014).

Major risks associated with stocking

Despite the widespread use of hatchery-bred fish for stock enhancement purposes, this practice continues to be controversial especially for genetic reasons. There have been numerous reviews of the effects of stocking practices on the receiving environment and endemic species (e.g. Arthington 1991; Lorenzen et al. 2001; Brown and Day 2002, Welcomme and Vidthayanon 2003; Cowx and Gerdeaux 2004; De Silva and Funge-Smith 2005; Bell et al. 2006; Vitule et al. 2009).

Genetic impacts

In recent years, stocking programs have received substantial criticism due to perceived impact of hatchery-bred fish with altered or inferior genetic make-up breeding with wild populations resulting in loss of genetic diversity or loss of viability (Allendorf 1991; Meffe 1992; Philipp et al. 1993; Brown and Day 2002; Araki and Schmid 2010). Hatchery-produced fish are perceived to have reduced genetic diversity and reduced fitness. These fish, when stocked into the wild, may interbreed with wild populations of the same species (genetically different strains or populations) or related species impacting on genetic structure (change in allele frequencies, genetic diversity etc.), which may lead to merging of taxa and hybrid speciation. The rapid development of genetics technologies for studying the genetic structure of populations has shed considerable light on how stocking activities have affected species and populations that are the subject of stocking programs (e.g. see Nguyen this volume).

Ecological and environmental impacts

Fish translocation and stocking activities harbor many risks through complex interactions with endemic organisms and the environment. These risks are more apparent when dealing with fish produced under the hatchery environment because of 'domestication selection'. Apart from the genetic issues already described, fish that are captive-bred may exhibit differences in behaviour, physiology, and morphology that potentially affect competition with wild stock (Brown and Day 2002; Weber and Fausch 2003). Non-endemic stocked fish may out-compete, displace or prey on native endemic species altering food web and community structure, and modify the habitats. One of the classic examples in this regard is the introduction of Nile perch (*Lates niloticus*) into Lake Victoria in the 1950s, which may have contributed to the extinction of up to 260 endemic fish species (Leveque 1995). Another example is the introduction of grass carp into Donghu Lake, Wuhan, China, which resulted in the decimation of submerged macrophytes. The subsequent ecological changes brought about an upsurge of bighead carp and silver carp populations and the disappearance of most of the 60 fish species native to the lake (Chen 1989).

There are also risks associated with other aquatic organisms that may be inadvertently translocated with the species being stocked, such as algae and macrophytes, invertebrates (planktonic and macroinvertebrates) and vertebrates (fish and amphibians). The introduction of banded grunter (*Amniataba percoides*) into the Clarence River (NSW, Australia) was thought to be the result of stocking farm dams and waters with batches of fish contaminated with the species (Rowland 2001). This accidental introduction of a hardy, aggressive, omnivorous fish, may pose a serious threat to endemic fauna and as such, banded grunter has been declared a noxious fish in NSW.

Impacts of stocked fish, and other organisms introduced with them, may be transient in that escaped organisms survive but do not breed, or long-term if self-sustaining populations become established. Impacts may be localised or even ecosystem wide, exceeding the carrying capacity of the system, affecting trophic cascades, and causing extinctions of species (Arthington 1991).

Infectious disease or pathogen transmission

Stocking of fish can lead to the transmission or introduction of infectious diseases and pathogens. For example, the monogenean parasite Gyrodactylus salaras caused losses to both Atlantic salmon fishing and aquaculture industries in Norway following its introduction from infected hatcheries through fishery enhancement programs (Johnsen and Jensen 1991). An organism exposed to a new disease or pathogen may not necessarily die from becoming infected, but the resulting infection can negatively influence immunity, growth, feeding ability, reproduction ability and distribution (Cunningham 1996).

Chemical release

A range of chemicals are commonly used during the breeding and rearing of fish in hatcheries and aquaculture facilities. These chemicals include disinfectants, therapeutants, feed additives, anaesthetics and hormones. Some chemicals can remain in treated fish or the environment for a considerable period, and may be present for some time after the fish are released.

Exotic species versus native species

Studies have shown that stocking of exotic species (e.g. tilapia and carps) have supported substantial increases in harvestable biomass while having minimal ecological impacts (e.g. De Silva et al. 2004; Gozlan 2008; Arthur et al. 2010b). However, the negative impacts of stockings introduced or exotic species are well documented (e.g. Chen 1989; Leveque 1995; Vitule et al. 2009), which have driven the debate to restrict their use in aquaculture and fisheries enhancements, and an increasing interest in development of native species for such purposes (e.g. Naylor et al. 2001; Ross et al. 2008). Use of native species has been considered for CBF development in the Lao PDR where species, such as Pa Phia and mud carp (Table 3), are preferred by consumers in some areas and can command a relatively high price compared to exotic species (De Silva 2008; Ingram and Lasasimma 2008). Native species should always be considered when planning stocking activities, taking into account the purposes of the stocking, ecological and genetic risks and stakeholder views.

Management approaches for stocking programs

Management activities that operate on the scale of the ecosystem, rather than arbitrarily defined jurisdictional boundaries, are far more likely to meet their objectives (Scott-Slocombe 1993). Stocking programs are undertaken in complex human–environment systems, involving dynamic interactions between the resources, the technical intervention and users (Bell et al. 2006). Species populations, management units and evolutionary significant units (ESU's[1]) therein can extend across jurisdictional and country borders and therefore potentially are governed by, and managed under, several different legislative and regulatory frameworks, posing substantial challenges to ensure that populations structuring is managed consistently. Effective communication, coordination and collaboration are required for governance of such species and populations. Therefore, an ecosystems approach to stocking programs is encouraged. Decision makers should aim to consider environmental, ecological and genetics factors, social needs and jurisdictional differences in planning of stocking programs that will achieve the desired outcomes with minimal impacts on the environment.

Avoiding loss of genetic diversity or change in genetic structure of receiving populations must be an important goal in managing hatchery-based stocking programs

1. Evolutionary significant unit (ESU): a population of organisms that is considered genetically distinct for the purposes of conservation (Moritz, C., 1994. Defining Evolutionarily Significant Units' for conservation. *Trends in Ecology & Evolution* 9 (10): 373-375).

where the species being stocked already occurs in the receiving environment. A precautionary approach that ensures genetically sound management strategies are incorporated into stock enhancement programs should be adopted. In order to counteract the potential detrimental genetic effects of stocking programs and conserve genetic diversity of wild populations, a range of genetic guidelines for captive breeding programs that produce fish for stocking purposes have been developed (e.g. Miller and Kapuscinski 2003; Bert et al. 2007; Kapuscinski and Miller 2007). Some of the key points from these guidelines are outlined below.

Management programs for stocking in inland waters should strive to achieve the objectives of the stocking, while at the same time seeking to minimise impacts. Clearly articulated goals are needed for genetic management of species and should include preservation of biodiversity, including population level genetic diversity. This can only be achieved by incorporating genetic objectives into the stocking programs. Genetic management plans (GMPs) can provide a guideline for managing the genetic diversity of indigenous species that are the subject of stocking programs. These plans can assist hatchery operators in managing the genetic quality of stock, and geneticists and fisheries managers to monitor and evaluate the genetic impacts (both positive and negative) of stocking and translocation activities. These plans are an important tool supporting the conservation and recovery threatened species in particular.

GMPs are critical where stocking is for conservation purposes and the stocked fish are expected to interbreed with wild populations, but are less critical for programs where stocked fish are expected to be harvested before breeding can occur, such as in CBF. However, if CBF occurs in water bodies where there is a risk that fish will escape to adjacent waters and interbreed with endemic stocks, then genetic management of hatchery stock becomes more important.

Stocking species into riverine habitats where existing and otherwise healthy populations of the same species occur should be discouraged, except where there is a recognised need to recover depleted populations. Attempts to increase the numbers of fish in these habitats beyond the carrying capacity of the habitat by stocking may be fruitless as stocked fish can disperse more widely. Efforts to increase carrying capacity in river systems may be better directed towards, for example, habitat improvement.

Stocking should not be seen as a panacea to recovering failing fisheries. Stocking should always be considered as one management option. Other fisheries enhancement and management options must always be considered, including changes to regulations affecting access and take (size limits, bag limits, closed seasons), use of reserves and refuges, and habitat protection and improvement.

Risk assessment

Use of a risk assessment approach for identifying and understanding the hazards and their impacts should be a key step in the development of translocation and stocking guidelines and codes of practice for movement of aquatic organisms (Bartley et al. 2006; Bartley et al. 2007). This approach relies on a panel of experts to assess the likelihood and consequences of identified risks associated with a proposed stocking activity, where the likelihood is defined as a general description of probability or frequency of an event occurring, while the consequence is defined as the outcome or impact of an event. Outcomes from the risk assessment are then used to develop control measures to limit or eliminate the risks. Risk assessment attempts tend to be quantitative but can also be qualitative. A detailed description of how risk analysis can be applied to aquaculture is provided by Arthur et al. (2010_a). Other guidelines and information that will assist risk assessment for fish movements include the FAO guidelines for responsible fisheries (FAO 1995, 1996), and the Asian regional guidelines on health management for the responsible movement of aquatic animals (FAO/NACA 2000).

Better Management Guidelines

Better Management Practices (BMP) may also be developed for hatcheries producing fish for stocking programs. BMPs are developed in consultation with the practitioners and relevant stakeholders, and on an evaluation of current practices. BMP guidelines aim to improve overall practices, reduce risks, improve yields, and contribute towards sustainability and economic viability (Tucker and Hargreaves 2008). BMPs may provide guidelines aimed at minimising the impacts of stocked fish on receiving populations and environments. Guidelines may include:

- Genetic resource management (e.g. broodstock numbers, mating plans, incubation of eggs and stocking of larvae, broodstock turnover) for broodstock management and breeding programs used in conservation, harvest stocking and commercial aquaculture.

- Fish health management (monitoring, diagnosis and treatment to reduce and/or minimise disease occurrence).

- Improved record keeping, reporting and information management.

- Improved education of individuals and groups associated with the stocking programs.

Conclusions

Stock enhancement is being undertaken in a wide variety of environments across the globe to replenish, maintain or enhance populations of aquatic organisms, especially finfish. Most importantly, stock enhancement practices, such as CBF, are improving productivity of fisheries through increased yields and, in developing countries, improving both food supplies and livelihoods in rural communities.

Hatcheries are pivotal to the success of stock enhancement programs, providing a reliable and regular supply of large numbers of seedstock for release. Although stocking programs have been subjected to substantial criticism due to perceived impact of hatchery-bred fish on wild populations and the environment, these are being addressed by adoption of more responsible and ecologically sustainable approaches.

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