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Responsible stocking and enhancement of inland waters in Asia

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Responsible stocking and enhancement of inland waters in Asia

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FOREWORD

Stocking through formal stocking programmes is generally recognized as an important tool to compensate for losses in fish productivity and fish species diversity. Stocking programmes are widely implemented in Asia in a variety of aquatic habitats as an essential element in increasing or maintaining fish production in the region. In Asia, capture and culture fisheries are often closely integrated through the extensive and semi-intensive management of man-made waterbodies and rice paddies.

Provided that conditions are conducive and the enhancement measures well-designed, these enhancements can be effective in increasing fisheries yields for food or income, or as opportunities for recreational fishing and wider socio-economic benefits. In practice, many enhancements are likely to be ineffective and some have caused demonstrable ecological damage. Recently, there have been increasing concerns about the potential risks associated with the stocking and introduction of fish, particularly with respect to ecosystem functioning, changes in community structure and losses of genetic integrity.

In developing countries the emphasis is on food security and inland fisheries are being called on to maximize the supply of protein for human consumption. Since most inland water systems have now reached their maximum potential natural production, rising demand is now pushing fisheries managers to maximize yields in tropical waters through enhancement. In many countries this process is now advanced and the infrastructure to cope with the required production of fingerlings for stocking has been developed. A major weakness of many stocking programmes is the failure to evaluate fully the outcomes of the activity or limiting the evaluation of their effectiveness, in terms of benefits as well as adverse impacts.

Consequently, there is a need to develop guidelines that accommodate risk and uncertainty, as well as enhancing protocols associated with other aspects that require decision-making so stocking programmes are carried out in an environmentally friendly, socially acceptable and economically justified manner. Additionally, there is a need to review existing and completed stocking programmes to evaluate their effectiveness as this could inform the design of new programmes. There is also a need to consider alternative means of enhancing fish productivity.

This FAO/APFIC review provides guidance on the development of responsible stocking programmes and importantly, guidance on how such programmes should be evaluated objectively. It is expected that this will assist those who are involved in stocking programmes and their management throughout the Asian region and contribute to sustainable, equitable and environmentally acceptable practise in capture fishery stocking.

Kundhavi Kadiresan

Assistant Director-General and Regional Representative
FAO Regional Office for Asia and the Pacific

CONTENTS

INTRODUCTION

This document provides an overview and guidance to inform responsible stocking and enhancement of inland waters in Asia. It comprises three technical papers prepared for and presented to the APFIC/FAO regional consultation "Improving the contribution of culture-based fisheries and fishery enhancements in inland waters to blue growth", 25–27 May 2015, Jetwing Blue Hotel, Negombo, Sri Lanka.

The first paper in this review summarizes the main conclusions of various global reviews and research in stocking and develops guidance on fish species introductions and stocking. The purpose is to avoid the negative impacts and maximize the positive benefits of such activities. A decision framework for assessing the suitability of fishery enhancement in inland waters is proposed. This framework requires input and decisions at various steps to decide whether a new species introduction is acceptable and whether measures have to be taken to regulate such practices. This review provides support for these various steps for environmentally sound procedures for stocking activities and how these activities should be evaluated.

The second paper reflects on the competition for use of water and aquatic environments for human purposes other than fisheries. The cost-benefit resolutions to such conflicts are rarely explored, but are crucial to future management decisions regarding mitigation of environmental impacts and fisheries practices such as stocking. There are four main types of environmental interventions: protection; restoration/rehabilitation; mitigation and intensification, and some or all of these may involve the stocking of fish. The current trend in the stocking of open waters in Asia tends to be pursued uncritically with limited evaluation of its impact, both in terms of cost-effectiveness, environmental consequences and social impact.

Although floodplain stocking has been credited with increasing fish production and fishers' incomes, concerns have been raised about its implication for ecological and social equity, as well as its cost-effectiveness and sustainability. Even taking into account the costs of such enterprises, critical evaluation may well show that careful management of the natural environment through rehabilitation and mitigation techniques may be a more viable option in sustaining fish production from river and reservoir systems than stocking. This paper reviews some of the environmental and habitat actions that can deliver benefits to fisheries in lieu of, or alongside, stocking.

The third paper focuses on the form of stock enhancement most commonly used in Asia, namely stocking seed for the primary purpose of increasing yield. One of the most common stock enhancement practices in the region is culture-based fisheries. This is often conducted in small waterbodies to increase production. Some of these waterbodies are sometimes incapable of sustaining even a subsistence fishery through natural recruitment. In this paper, the benefits and constraints of culture-based fisheries practices in inland waters in Asia are considered. Details on species used, fish yields, income distribution patterns, and other community benefits such as improved nutrition are presented and discussed.

The review highlights that the adoption of culture-based fisheries can result in significant increases in food fish production, especially in aquatic habitats that are limited in terms of natural recruitment (e.g. small seasonal reservoirs), but also including instances where there has been a shift from conventional capture fisheries to culture-based fisheries.

GLOSSARY

Definitions of terms used for the purpose of the APFIC/FAO Regional Workshop and for these papers were compiled from the FAO Term Portal Web site or from FAO technical guidelines and documents.

a.	FAO Term Portal.[1]
b.	FAO. 2011. Technical guidelines for the ecolabelling of fish and fishery products from inland capture fisheries.[2]
c.	FAO. 2008. FAO Technical guidelines for responsible fisheries. Aquaculture development. 5 Suppl. 3. Genetic resource management.[3]
d.	FAO. 1997. FAO Technical guidelines for responsible fisheries. Aquaculture development – 5.[4]

Aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms that are harvested by an individual or corporate body that has owned them throughout their rearing period contribute to aquaculture.	**d**
Culture-based fishery	A fishery in which the use of aquaculture facilities is involved in the production of at least part of the life cycle of a conventionally fished resource. Aquaculture is usually the initial hatchery phase that produces larvae or juveniles for release into natural or modified habitats.	**a**
Enhanced fisheries	Fisheries that are supported by activities aimed at supplementing or sustaining the recruitment of one or more aquatic organisms and raising the total production or the production of selected elements of a fishery beyond a level that is sustainable by natural processes. Enhancement may entail stocking with material originating from aquaculture installations, translocations from the wild and habitat modification.	**b**
Enhancement	Any activity aimed at supplementing or sustaining the recruitment, or improving the survival and growth of one or more aquatic organisms, or at raising the total production or the production of selected elements of the fishery beyond a level that is sustainable by natural processes. It may involve stocking, habitat modification, elimination of unwanted species, fertilization or combinations of any of these practices.	**a**
Habitat enhancement	A fishery management tool with the sole purpose of providing better environmental conditions for desired species of fish, e.g. the construction of brush parks as found in tropical Africa and Asia.	**a**

[1] http://www.fao.org/faoterm/en/
[2] http://www.fao.org/docrep/015/ba0001t/ba0001t00.htm
[3] http://www.fao.org/docrep/011/i0283e/i0283e00.htm
[4] http://www.fao.org/docrep/003/W4493E/W4493E00.HTM

Inland capture fisheries	The removal of fish and other aquatic organisms from natural or enhanced inland fisheries, but excluding aquaculture.	**b**
Naturally reproductive stock component	In fisheries enhanced through stocking, that component of the total stock that is maintained by natural reproduction. This component may include organisms derived from natural reproduction of stocked fish.	**b**
Recreational fishing	Any fishing for which the primary motive is leisure rather than profit, the provision of food or the conduct of scientific research and which does not involve the sale, barter, or trade of part or all of the catch.	**a**
Stock enhancement	Activities aimed at supplementing or sustaining the recruitment of one or more aquatic species and raising the total production or the production of selected elements of a fishery beyond a level that is sustainable through existing natural processes. In this sense, stock enhancement includes enhancement measures that may take the form of: introduction of new species; stocking natural and artificial waterbodies, including with material originating from aquaculture installations; fertilization; environmental engineering including habitat improvements and modification of waterbodies; altering species composition including elimination of undesirable species or constituting an artificial fauna of selected species; genetic modification; and introduction of non-native species or genotypes.	**a**
Stocking	The practice of placing aquatic organisms into natural or modified waterbodies. Stocked material may originate from aquaculture facilities or translocations from the wild.	**a**

PAPER 1: GUIDELINES FOR FISH STOCKING PRACTICES IN TROPICAL FRESHWATER FISHERIES

Ian G Cowx, Simon Funge-Smith and David Lymer

CONTENTS

1 INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) defines stocking as "a technical intervention in existing aquatic resource systems, which can substantially alter its environmental, institutional and economic attributes."[1]

The FAO Glossary defines stocking as "any activity aimed at supplementing or sustaining the recruitment, or improving the survival and growth of one or more aquatic organisms, or at raising the total production or the production of selected elements of the fishery beyond a level that is sustainable by natural processes."[2]

1.1 Inland fishery management

Inland fisheries are underpinned by a complex interaction of physical, chemical and biological conditions that need to be regulated in such a manner to enhance the fishery output and maintain quality fishing (Figure 1). There are three broad types of strategy available to fisheries management, namely traditional management, habitat rehabilitation and stocking.[3]

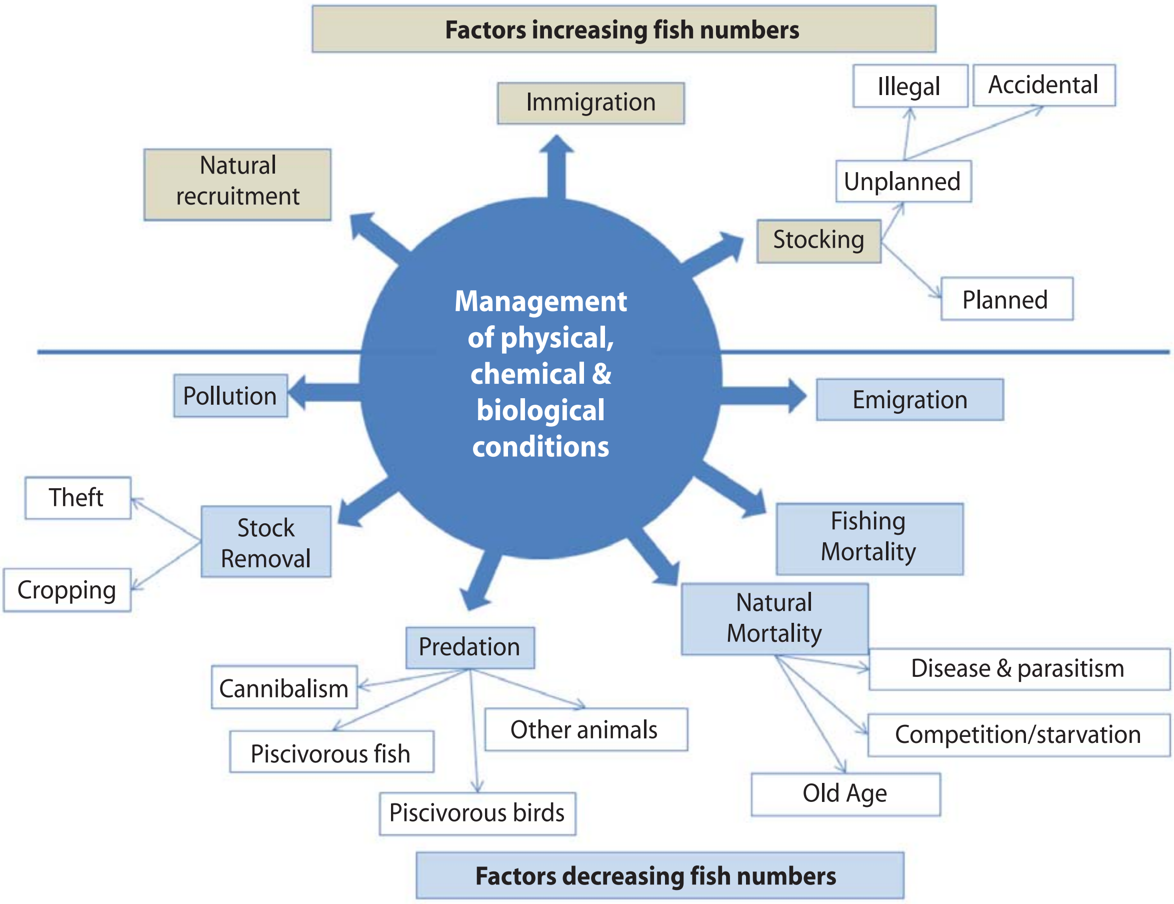

Figure 1 Factors influencing the numbers and size of fish in a fishery

[1] FAO (1997)
[2] http://www.fao.org/fi/glossary/default.asp
[3] Blankenship and Leber (1995); Cowx and Gerdeaux (2004)

Traditional management tools commonly applied are generally categorized as either input or output based, and include gear and size restrictions, seasonal closures, quotas and bag limits, and limitations on entry, taxes, levies and property rights.

Although such approaches can work, stock recovery is often perceived as too slow and changes in traditional management (e.g. no-take zone[4]) are unpopular or unacceptable.[5] Traditional management tools are also unlikely to be effective in cases of habitat loss or modification.[6]

Habitat rehabilitation tools are also widely applied. Typically, these refer to the increase in available habitats and/or access to key habitats for at least some life stages of a target species.[7] Such an approach may range from increased connectivity along a river (fish passage facilities), through reconstruction of the habitat to the installation of artificial habitats (such as low weirs or creating backwater ponds). Although rehabilitation is becoming popular, evaluation of its effectiveness is generally lacking.[8] This is dealt with in more detail in *Alternative strategies for enhancement of fish stocks* (Paper 2 of this publication).

Stocking tools refer to manipulation of the fish stocks by addition of material, usually of a desired species, to improve the fishery productivity (catch rates) or diversity of the fishery. There are several enhancement practices which range between culture enhanced capture fisheries to intensive aquaculture (Figure 2).

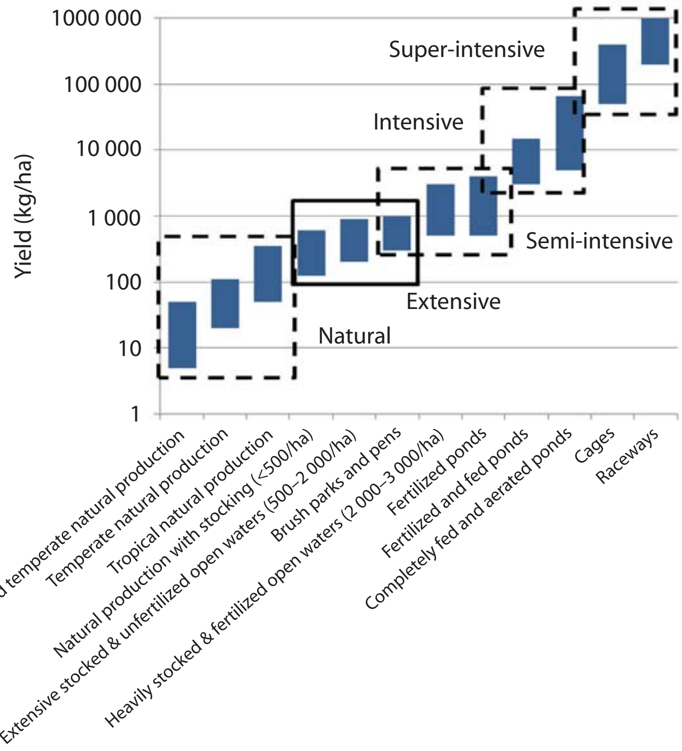

Figure 2 Production from different capture and culture systems Note: Adapted from Welcomme and Bartley (1998b)

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4 Crowder *et al*. (2000)
5 Burton and Tegner (2000)
6 Southworth and Mann (1998); Goldberg *et al*. (2000)
7 see Cowx and Welcomme (1998)
8 Cowx *et al.* (2004)

They are often adopted in a stepwise manner leading to a progressive increase in fishery production per unit area of water through increasing human controls on essential parameters of the fish assemblages. Stocking is popular because of its perceived simplicity.[9] This aspect of stocking is the main focus of these guidelines, but it is important to recognize that **stocking is not the sole mechanism for improvement of a fishery.**

Present trends in the use of inland waters for fisheries indicate that the production from such systems is typically limited for two reasons. First, declining quality of the aquatic environment resulting from eutrophication, pollution and habitat modification has led to increasing incapacity on the part of native fish assemblages to adapt and maintain their form, diversity and biomass. Second, poor fisheries management means that many fish species are unable to compensate for excessive or inappropriate fishing pressure through natural reproduction.

As a result of these two stressors, catch from inland water fisheries based on naturally reproducing fish populations is declining worldwide. The response to this crisis in management has been to increase the level of human interventions through a series of activities that may be individually termed enhancements or, collectively, intensification of production. Two main strategies for the management of inland waters for fisheries are being adopted based on differing societal views of natural resources and their use (Table 1) and these condition the approach to enhancement.

Table 1 Differing strategies for management of inland waters for fisheries in developed and developing countries

	Developed (temperate)	Developing (tropical)
Objectives	Conservation	Provision of food
	Recreation	Income
Mechanisms	Recreational fisheries	Food fisheries
	Habitat restoration	Habitat modification
	Environmentally-sound stocking	Enhancement through intensive stocking and management of ecosystem
	Intensive, discrete, industrialized aquaculture	Extensive, integrated, rural aquaculture
Economic	Net consumer	Net producer
	Capital intensive	Labour intensive
	Profit	Production

Note: After Welcomme and Bartley 1998a, 1998b

1.2 Stocking as a management tool

Stocking is probably the most widespread tool used by fisheries managers. Most countries report that they conduct stocking to some degree and that this is related to the fact that more conventional approaches to management have failed to control fisheries exploitation.

Stocking is often used to respond to degraded natural fish populations as a result of habitat change or overexploitation of fish, or just to increase the fish stocks in general. In this context, stocking is an attempt to fix a problem, either real or perceived.

Depending on the problem, stocking can be considered to be either a permanent or temporary solution and can, more or less, be divided into five main categories, although a number of terminologies are applied throughout the fisheries sector (Table 2).

[9] Welcomme and Bartley (1998a and 1998b)

Table 2 Range of terms used to describe stocking activities

Term	Definition	Source(s)
Restocking		
Mitigation	Production and release of fish to restore stock to original levels	Radtke and Davis (2000)
Stocking	Supplementing natural recruitment with injection of external material	Ziemann (2001)
Ocean ranching	Releasing of fish to the ocean to be subsequently commercially harvested	Arnason (2001)
Marine ranching	Production of early life-stages of species in a hatchery for eventual release into natural or modified habitats	Bartley (1999)
Stocking recovery	Production and release of fish for intergenerational benefit	Harada and Matsumiya (1992)
Augmentation		
Augmentation	Production and release of fish to complement natural recruitment when available habitat is below carrying capacity	Cowx (1994b), Bartley (1999)
Habitat enhancement	Production and release of fish to (re)colonize new/artificial habitats	Young (1999)
Mitigation	Stocking of fish in new/modified habitats to compensate for a decrease in a fishery	Cowx (1994b), Bartley (1999)
Addition		
Community change	Production and release of exotic fish to create new fisheries	Cowx (1994b), Bartley (1999)
Addition	Stocking of a new species in an area outside of its natural range	Rowland (1994)
Enhance	Production and release of fish to create new fisheries	Petr (1998)
Other terms		
Stocking	Production and release of fish for the public good	Drawbridge (2002)
Sea ranching	Production and release of fish for the common good	Drawbridge (2002)
Stocking continuous	Production and release of fish for intragenerational benefit	Harada and Matsumiya (1992)
Enhance	Production and release of fish to increase stocks above original levels	Radtke and Davis (2000)

Note: Modified from Molony *et al.,* 2003

1.3 Stocking is a widespread practice in Asia

Stocking and/or habitat modifications of waterbodies are widespread in the tropics, with implementation of a large variety of fisheries enhancement measures in public, communal or private waterbodies.[10] Provided that conditions are conducive and the enhancement measures well-designed, these enhancements can be effective in increasing fisheries yields for food or income, or as opportunities for recreational fishing and wider socio-economic benefits. In practice, many enhancements are likely to be ineffective and some have caused demonstrable ecological damage.[11]

For more information on culture-based fisheries (one specific form of stocking) please see *Fisheries enhancements in inland waters with special reference to culture-based fisheries in Asia: current status and prospects*"(Paper 3 in this publication).

[10] Cooke *et al.* (2015)
[11] Cooke *et al.* (2015)

In developed countries attempts to manipulate species composition in rivers and lakes to correspond to the preferences of sport fishermen led to an early adoption of enhancement techniques orientated around stocking coupled with habitat maintenance. Production facilities are generally isolated in carefully controlled fish farms and the inland waters are destined mainly for aesthetic and recreational uses. This means that enhancement of the system is now tending to be accomplished more by rehabilitation and restricted access. Ideally, in this view, stocking programmes are limited to low numbers of large fish in support of native species or restoration of endangered ones.

Stocking practices also now emphasize protection from undesirable genetic effects.[12] Exceptions to this general trend exist in some lakes where capture fisheries are supported by large-scale stockings with target species and in some recreational fisheries that are still highly intensive and are maintained by high stocking rates with smaller fish.

In developing countries the emphasis is on food security and inland fisheries are being called on to maximize the supply of protein for human consumption. Since most inland water systems have now reached their maximum potential natural production, rising demand is now pushing managers to maximize yields in tropical waters through enhancement. In many countries this process is now advanced with the infrastructure to cope with the required production of fingerlings for stocking highly developed. In other areas, lack of funding and infrastructure is delaying the process despite there being adequate physical potential.

Capture and culture fisheries are often closely integrated through the extensive and semi-intensive management of man-made waterbodies and rice paddies. The latter, commonly termed culture-based fisheries, is becoming increasingly prominent in developing countries and the practice is used to maintain catches from fisheries that are usually subject to high levels of exploitation.

Aquaculture production from inland waters has increased progressively from about 260 000 tonnes in the early 1950s to 42 million tonnes by 2012[13] and at least part of this has been achieved through increased stocking of open waters, rice fields and other aquatic environments, besides aquaculture ponds and cages. Unfortunately it is difficult to separate how much fish seed is produced for stocking into open waters for enhancement purposes. This is an important issue that needs addressing, and mechanisms for collecting data on hatchery production destined for stocking is required.

1.4 Evaluation

Recently, however, there have been concerns about the potential risks associated with stocking and introducing fishes, particularly with respect to ecosystem functioning, changes in community structure and losses of genetic integrity.[14] Indeed, the Global Invasive Species Programme listed eight fish species, including two salmonids, among the "world's worst invasive alien species".[15]

Although the stocking and introduction of species has had obvious benefits, they are not without cost, and the whole issue of introducing fish species is highly controversial. Most stocking activities, both deliberate and accidental, have had negative effects on indigenous fish communities and other fauna through predation, competition, introduction of pathogens and change in ecosystem dynamics.

The effects of hybridization, loss of genetic integrity and reduction in biodiversity are also issues that must be considered.

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[12] Carvalho (1993); Ryman and Laikre (1991); Ryman *et al.* (1995); Coates (1998).
[13] FAO FishstatJ (available at http://www.fao.org/fishery/statistics/software/fishstatj/en).
[14] Cowx (1997); McGinnity *et al.* (1997; 2003); Cowx and Gerdeaux (2004); Casal (2006); Eby *et al.* (2006); Gozlan *et al.* (2010); Hutchings (2014)
[15] Cambray (2003)

Of particular concern are shifts in food-web structure and trophic status that may occur, and the impacts that these could have on indigenous flora and fauna. In addition, stocking or introductions may lead to competition with or predation on indigenous biota.[16] This can have serious implications for waterbodies that are part of designated sites or support protected plant or animal species.

It should be recognized that without precise information of stocking activities it is not possible to predict the likely impacts of particular management techniques on specific waterbodies.

Indeed, "the impact of alien invasive sport fish is for the most part unpredictable in time and space, with the introduction of relatively few species having resulted in many extirpations of indigenous fish species worldwide."[17]

The impacts of particular management techniques will be site specific, because of the inherent differences in ecosystem dynamics between waterbodies.

A major weakness of many stocking programmes is failure to evaluate fully the outcomes of the activity. In some cases, success of a stocking project has been claimed even though evaluation only lasted a relatively short period of time,[18] or was simply based on the numbers of fish produced and stocked.[19]

Rigorous post-stocking evaluations are rare[20] and many programmes do not include evaluation, or the evaluation ceases prior to recruitment of the released animals into a fishery. The success or failure of all projects should be evaluated and reported. This requires assessment until released animals commence recruitment to the fishery,[21] which may take several years depending on the life history characteristics of the stocked species,[22] or longer[23] if increases in reproductive biomass, genetic risks, or ecosystem effects are to be quantified.[24] On this basis, some projects previously considered successful show no long-term benefit when reassessed.[25]

In terms of the latter issue, it is important to recognize that evaluation goes beyond simply quantifying the recapture rates of stocked and wild fish.[26] Evaluation must also examine the long-term impacts of stocking on ecosystem functioning, population dynamics and genetic integrity of the stocks, since reduced productivity[27] and loss of genetic diversity, or even extinction, are known to occur.[28]

More difficult to measure is the displacement of wild stock by the release of reared fishes,[29] although this may be investigated using estimates of numbers of wild fish before and after releases of reared fish.[30]

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[16] Hickley and Chare (2004); van Zyll de Jong *et al*. (2004); Lorenzen (2014)
[17] Cambray (2003), p. 217
[18] For example: Leber *et al*. (1995); McEachron *et al*. (1998); Cook and Sweijd (1999); Fielder *et al*. (1999); Dibden *et al*. (2000)
[19] Blankenship and Leber (1995)
[20] Bartley (1999)
[21] For example: Bannister and Addison (1998); Walton and Walton (2001)
[22] Cook and Sweijd (1999); Burton and Tegner (2000)
[23] Heggberget *et al*. (1993)
[24] Brand *et al*. (1991); Hilborn and Winton (1993); Dao *et al.* (1999); Burton and Tegner (2000)
[25] For example: Burton and Tegner, 2000)
[26] Ishino (1999); Burton and Tegner (2000); Bert *et al*. (2003)
[27] Arnason (2001)
[28] Brannon (1993); Hershberger (2002)

These issues are discussed in the literature, but it is worth highlighting the reasons for differing opinions over the impacts and benefits of stocking activities.

The primary reason for deliberate stocking activities is to enhance yield and output either in controlled (aquaculture) or natural (commercial and recreational fisheries) systems. The gain is generally measured in economic terms for the fisheries but does not consider cross-sectoral impacts, particularly conservation status and social and cultural aspects in the fishing communities that are difficult to quantify.
Any beneficial effects of stocking activities usually occur immediately and are short-lived, whereas the harmful effects are often delayed. Thus managers are frequently faced with political and economic pressure to embrace short-term benefits at the cost of the long-term well-being of an ecosystem.
There is often a failure to evaluate objectively if the desired objective of the exercise has been achieved. Paucity of baseline information on the fish communities and ecosystem dynamics of the recipient system before the stocking activities take place, plus inadequate long-term post-stocking monitoring to evaluate the impact on ecosystem dynamics, mean the success or otherwise of the actions are not measured.
Many recipient ecosystems have been degraded and stocking activities are seen as a short-term option for the rehabilitation of the waterbody to increase fish production. Consequently, it is often difficult to isolate the impact of the stocking activity from other anthropogenic activities, e.g. habitat degradation and the consequent introduction of generalist species.
Absence of a precise definition of the success of stocking activities to allow a better evaluation of the positive status of an activity.

In view of the many concerns that exist about stocking activities, a responsible attitude towards the activity is essential. Mechanisms must be put in place to minimize the prospects of any degradation of fish communities and ecosystems as a result of stocking activities. It should perhaps be stated that if the need to stock fish species into natural systems arises, existing management has probably failed in its overall objective to maintain the stocks.

Consequently, before stocking activities are considered, alternative strategies for rehabilitating the fisheries[31] should be evaluated. Such strategies include use of indigenous fish, improved water resource management (quality and quantity), habitat protection and rehabilitation, and use of sterile fish (see Section 4.2 and *"Alternative strategies for enhancement of fish stocks"* (Paper 2 of this publication).

1.5 Stocking in the Lower Mekong Basin freshwater fisheries

The Lower Mekong Basin (LMB) contains some of the world's largest and most productive inland fisheries. They are of enormous importance to more than 60 million people who live in the LMB. The basin's fisheries production represents about 20 percent of the world's inland capture fish production. Approximately 70 percent of the basin's communities are rural and rice farming and fishing are the main occupations of most people. Fisheries resources, including fish and other aquatic animals, make a vital contribution to regional food security and nutrition, cash income and employment, and have

[29] Leber *et al*. (1995)
[30] Butcher *et al*. (2000)
[31] see Cowx and Welcomme (1998)

strong cultural and religious significance. Per capita consumption of fish in the LMB is generally high, with the regional average of 46 $kg.capita^{-1}.year^{-1}$, with national figures varying by about 20 percent. This LMB figure is similar to the Southeast Asian rate of 51 $kg.capita^{-1}.year^{-1}$ and significantly higher than the world rate of 24 $kg.capita^{-1}.year^{-1}$. In the lowland areas of the LMB, protein from fisheries resources ranges from 40 percent to more than 80 percent of the total animal protein intake.[32]

Fish production from inland capture fisheries and aquaculture in Southeast Asia is progressively increasing, but it is subject to multiple pressures. Despite the importance of inland fisheries, there are clear warning signs of approaching overexploitation. Water development works such as agriculture irrigation, hydropower dams, and the likely impact of climate change pose serious threats. Although the overall catch is apparently stable, there is a decline in the landings of large, late-maturing species and the average sizes of several other commercial species are now smaller than previously.

Stocking through formal stocking programmes is generally recognized as an important tool to compensate for the loss of productivity and diversity, and is widely implemented in the LMB as an essential element in increasing or maintaining fish production in the region (see country summaries in Annex 1 of this paper).

Current weaknesses in how this takes place, however, pose problems for contributions to fish production for food security and as a provider of employment and income to rural economies (see comments in summary reports from each country in Annex 1). There are questions regarding the long-term effectiveness, sustainability and impacts of stocking. Most of these programmes are associated with ceremonies, awareness raising, or a variety of other socio-cultural events.

In general, there is no post-assessment of these stocking activities, except in Thailand. As a consequence, it is not known how well the stocking programmes succeed in terms of diversity and production increase or maintenance. There are also concerns over species introductions to promote aquaculture and fisheries production. There are also risks of further introductions of non-native fishes to the region.

[32] Statement by Mekong River Commission (MRC) Fishery Programme to the 32nd Session of the Asia-Pacific Fishery Commission (APFIC), 2012

2 PURPOSE OF THESE GUIDELINES

Fisheries managers need to be aware of the possible impacts of stocking programmes, both in terms of the effects on ecosystem functioning and the likelihood of improvements in stocks. Unfortunately, information on the impacts of stocking programmes is sparse, largely because of a lack of systematic monitoring and dissemination of information on the outcomes. Furthermore, although large sums of money have been invested in stocking activities, relatively few stocking programmes have been properly evaluated and there is little evidence to suggest that stocking exercises lead to tangible long-term benefits.[33]

Weaknesses in the success of many programmes appear to result from indiscriminate stocking without well-defined objectives or prior appraisal of the likelihood of success. Nevertheless, if stocking programmes are designed to achieve defined objectives and to be implemented following best-practice guidance, it should be possible to improve success rates and minimize or mitigate any detrimental effects. It should also be possible to identify situations when, because of risks to the wider ecosystem, it is inappropriate to undertake stocking programmes.

In the industrialized world, the most successful stocking programmes have typically been associated with put-and-take and intensively stocked fisheries in lakes, reservoirs and ponds. The stocking of river fisheries has been less successful except perhaps where stocking has been used to establish populations or accelerate recovery.[34]

The most successful enhancement programmes in developing countries have usually been associated with reservoir fisheries that have been heavily stocked to increase yield. It should be noted that these are artificially created environments and usually do not have established biodiversity and often rely on the adaptation of species found in the area prior to flooding, many of which become extirpated.

Consequently, there is a need to develop guidelines that accommodate risk and uncertainty, as well as enhancing protocols associated with other aspects that require decision-making. This is to ensure that stocking programmes are carried out in an environmentally friendly, socially acceptable and economically justified manner.

LMB countries have recognized this issue, and the requirement for comprehensive policy instruments to cover stocking activities in inland fisheries (and aquaculture). They have also carried out workshops and assessments through the Mekong River Commission (MRC)[35] and the Asia-Pacific Fishery Commission (APFIC).[36]

These present guidelines provide an overview of the state of knowledge on fish stocking around the world, and present step by step guidance on the process for designing, implementing and evaluating a stocking initiative. The goal is to avoid the negative impacts and maximize the benefits of species introductions and stocking.

This guidance is deemed necessary to facilitate responsible stocking in the inland fisheries and aquaculture sectors because more and more non-native species are being used to support the continuous global expansion of aquaculture production and increased exploitation of inland fisheries.[37]

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[33] Cowx (1998a); Arlinghaus *et al*. (2002); Lorenzen (2014)
[34] For example: Cowx (1994a; 1994b; 1999)
[35] MRC Stocking Consultation Meeting, Vientiane, 17-18 August 2010
[36] Miao *et al*. (2010)
[37] Cowx *et al.* (2009); De Silva and Funge-Smith (2005) ; De Silva *et al*. (2006 and 2009); Lorenzen (2014)

3 STEP-BY-STEP DECISION SUPPORT GUIDE FOR STOCKING

The previous sections have outlined the range of activities that constitute stocking and the threats and issues posed by stocking activities, especially when these are poorly managed or uncontrolled.

A number of issues arise that need to be addressed if stocking programmes are to be carried out in an ecologically acceptable, socially responsible, technically feasible and cost-effective manner. In particular, the threats posed by fish stocking programmes are especially insidious because few management measures exist to overcome any adverse effects.

Furthermore, many stocking programmes appear to have been unsuccessful because of poor project planning and poorly defined objectives.[38] Consequently, there is a need to adopt a strategic approach to fish stocking activities to improve overall success and minimize impacts on the ecological functioning of recipient waterbodies.

It is recommended that all stocking programmes are properly formulated and planned before implementation to avoid indiscriminate and often futile stocking activities.

3.1 Global normative and technical documents on stocking

There are a number of global normative and technical documents that cover movements, introductions, assessment methods and codes of practice that are available to inform the development of guidelines. These include:

Codes of practice and guidelines	
Code of practice and manual of procedures for consideration of introduction and transfer of marine and freshwater organisms	EIFAC (1988)
Code of conduct for responsible fisheries (CCRF)	FAO (1995)
IUCN/SSC guidelines for reintroductions	IUCN (1998)
Asia regional technical guidelines on health management for the responsible movement of live aquatic animals	FAO/NACA (2000)
Manual of procedures for the implementation of the Asia regional technical guidelines on health management for the responsible movement of live aquatic animals	FAO/NACA (2001)
Code of practice for introductions and transfers of marine organisms	ICES (2005)
Code for alien species in aquaculture	IUCN (2006)
Guidelines for environmentally sound practices for introductions and translocations in aquaculture (IMPASSE)	Cowx *et al*. (2009)

Regulations and resolutions	
Resolution by the parties to the convention for the conservation of salmon in the North Atlantic Ocean to minimize impacts from aquaculture, introductions and transfers, and transgenics on the wild salmon stocks	NASCO (2003)
Regulation (EU) No. 304/2011 of the European Parliament and of the Council of 9 March 2011 amending Council regulation (EC) No. 708/2007 concerning use of alien and locally absent species in aquaculture (IMPASSSE)	European Union (2006)

Codes of practice and technical guidelines are generally voluntary in nature and mostly focus on the risks associated with stocking and introductions.[39]

[38] Cowx (1994a, 1994b and 1999)
[39] For example, see EIFAC (1988); ICES (1988 and 2005) and IUCN (1987 and 1998)

There are a number of general global technical reviews and some technical reviews specific to the Asian region. Several of these are products of regional technical workshops and review various aspects of stocking, introductions and movements including regional consultation on issues and best practices for stocking:

Global technical reviews	
International measures for the control of introductions of aquatic organisms	Welcomme (1986)
International introductions of inland aquatic species	Welcomme (1988)
Stocking strategies	Cowx (1994b)
A responsible approach to marine stocking	Blankenship and Leber (1995)
Inland fishery enhancements	FAO (1998)
An appraisal of stocking strategies in the light of developing country constraints	Cowx (1999)
Review of existing guidelines: advantages and constraints. Report to EC, 46 pp.	Angelopoulos *et al.* (2008)
Responsible approach to marine stocking: an update	Lorenzen *et al.* (2012)
Guidelines for stocking of fish within designated natural heritage sites	Cowx *et al*. (2012)

Technical workshops and reviews specific to Asia	
An evaluation of floodplain stock enhancement	MRAG (1997)
A review of stock enhancement practices in the inland water fisheries of Asia	De Silva and Funge-Smith (2005)
Regional expert workshop on "Inland fisheries resource enhancement and conservation in Asia", Pattaya, Thailand, 8–11 February 2010	FAO and NACA
Inland fisheries enhancement and conservation in Asia	Miao, De Silva and Davy (2010)
Workshop on fisheries enhancement, Vientiane, Lao PDR, August 2010	MRC Fishery Programme
Consultation on development trends in fisheries and aquaculture in Asian lakes and reservoirs, Wuhan, PR China, September 2011	Institute of Hydrobiology
Regional study on fish introductions in Central Asia and the Caucasus	FAO
Regional workshop "Synthesis of regional and national fish stocking practices and recommendations for the mitigation of the impacts", Hanoi, 2–5 September 2014	FAO and MRC Fishery Programme
General aspects of stock enhancement in fisheries developments	Ingram and De Silva (2015)

3.2 A framework for responsible management of stocking

The guidelines listed usually present a logical review and decision process for the holistic evaluation of introductions, integrating ecological, fishery and aquaculture benefits, socio-economic considerations, through to the final implementation. Their structure is typically broken down into a number of key components, summarized in Figure 3, but organized into three phases:

1. What to consider before attempting stocking (establish clearly whether restocking or stocking).
2. How to ensure an optimal stocking programme.
3. What to assess, evaluate to monitor/optimize the stocking (or restocking).

Unfortunately, the advice provided is often general and insufficiently detailed to support fishery managers. No guidance on how to assess the consequences of stocking is provided. Importantly, these guidelines tend to focus on biological risks (such as the ecological, genetic, and pathological impacts of introductions) and do not provide guidance on the economic and social aspects of the fisheries enhancement programme.

As a consequence, there is often a need to adopt a precautionary approach to stocking and introductions of aquatic organisms because insufficient information is available to make informed decisions, as recommended by FAO[40] under such circumstances.

The framework for the management of stocking programmes covering seven steps presented in Figure 3 below, provides a logical review and decision process for the holistic evaluation of stocking exercises, integrating ecological, fishery, socio-economic and implementation considerations. The tool covers an evaluation of: the relative benefits and cost effectiveness of stocking with fish at different life stages and at different times of the year; whether stocking actually contributes to improved stock status;[41] and guidance to ensure that stocking and introductions are conducted in the most effective manner to maximize the success of the activity.

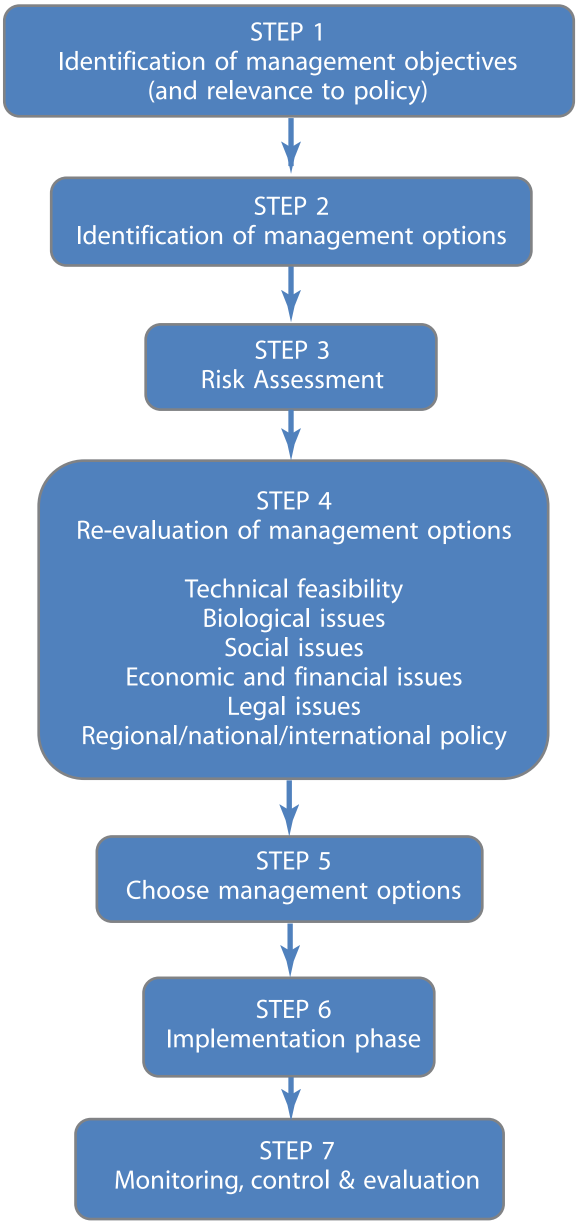

Figure 3 Framework for responsible stocking of living aquatic organisms

[40] FAO (2005)
[41] Aprahamian *et al.* (2003)

The underlying principle for the management of stocking should stipulate that once the objectives for stocking have been set through a thorough assessment of the status and limitations of the fishery, a specific stocking strategy should be developed to achieve the desired objective. This is equivalent to identifying the bottlenecks constraining the potential performance of the fishery.

Once the fishery has been confirmed as potentially requiring enhancement, scenario overviews must assess the critical bottlenecks to the fish population or fishery performance and, through these, determine whether stocking of the species is a viable option for enhancement. It should then be evaluated against ecological and environmental risk criteria, and a cost-benefit analysis should be carried out.

Finally, the overall feasibility of the action assessed in terms of environmental and ecological risk, bio-economic gain and practicality should be evaluated. If at any stage of these assessments the risks, costs, feasibility or potential benefits are deemed unacceptable, the programme should be rejected and alternative strategies considered.

4 SET CLEAR OBJECTIVES (STEP 1)

Although most stocking activities can be categorized into the broad objectives outlined in Table 2, the potential for a successful outcome is often limited because the specific objectives of the exercise in relation to perceived problems and available resources are not fully appraised from the onset or the enhancement project attempts to rectify issues beyond the ability of stocking to address.

Many projects are ill conceived and do not fully address the issues that underpin the requirement to improve the fishery and possible constraints on the enhancement procedures adopted. Furthermore, they often have little consideration for wider cross-sectoral and environmental issues, particularly in relation to long-term impacts.

The main problem lies in poor or improper planning and evaluation of the proposed stocking activity. Before investment of resources, a full prefeasibility study should be carried out, and the stocking programme should be linked to the sectoral objectives, not just the fishery objectives.

Clearly defined objectives (including measurable success criteria) will assist in the design and implementation of robust sustainable stocking initiatives. These objectives should be linked to measurable indicators (see STEP 7).

4.1 Stocking initiatives often underperform or fail because of poorly defined objectives

In the past, many stocking programmes were based on the assumption that the release of fish into the wild will increase stock abundance, and thereby harvest levels would increase.[42]

Few clear objectives were ever set for such programmes.[43] Unfortunately, this practice still continues,[44] and where objectives are set they are difficult or impossible to test.

Weak, objective difficult to measure	Clear, measureable objective
The main goal was to ”investigate the possibility of enhancing an oceanic cod stock”[45]	“to investigate whether captive bred fish could survive in the wild, grow to a size that could enter the recreational fishery and whether they could be caught by recreational fishers”[46]

Stocking projects that have clearly defined objectives in relation to the recovery of adult populations generally have a better chance of success.[47]

A similar problem arises because the end-points of stocking programmes are not clearly defined,[48] thus pressure is often exerted to continue stocking indefinitely[49] even if the project is not effective or necessary.[50]

[42] Winton and Hilborn (1994); Hilborn (1999); Leber (2004)
[43] Cowx (1994b; 1999)
[44] For example: Courtenay (1995); Svåsand (1998)
[45] Fjallstein and Jákupsstovu (1999)
[46] Lenanton *et al.* (1999)
[47] Heppell and Crowder (1998)
[48] For example: Svåsand (1998); Svåsand *et al*. (2000)
[49] Leber (2002)
[50] For example: Hoffmann (1990); Morán *et al.* (1991); Kitada (1999); Svåsand *et al*. (2000); Saltveit (2006)

If end-points are not established, there is no measure against which to assess the success of the project, and the risks of a negative outcomes increase because the programmes continue *ad infinitum*. Under such circumstances, poorly planned and performing stocking projects are simply redefined and continued, despite being ineffective and expensive.[51] Although the implications for many of the above have been understood for many years, stocking has generally failed to become more rigorous or scientific.[52]

4.2 Answer the question "Why does the fish stock need enhancement?"

From the sectoral perspective, the objectives of stocking are a compromise between conservation and protection of the ecosystem, positive economic return, and food security and/or employment.

A fundamental question that is often neglected before a stocking programme is undertaken is "Why does the fish stock need enhancement?"

This question is rarely answered before stocking programmes take place, because it is often a reflection of poor management of the environment or the fish stocks themselves. Stocking is frequently required because the fishery is overexploited or has suffered some environmental perturbation.

In many instances, the issues addressed are removal of the constraints acting on the fishery and enhancement of the fishery based on natural production. Even when fishing pressure has been identified as the major reason for stock decline, reduction in exploitation is not always implemented in conjunction with stocking,[53] thereby limiting the potential success of stocking.[54]

Sometimes stocking is employed instead of doing nothing,[55] instead simply arguing that stocking increases abundance and therefore believing the problem has been addressed.[56] Indeed, there are many cases where stocking has been inappropriately promoted as a solution to declining fishery resources.

There are also examples where stocking has been seen as condoning unsustainable management practices of habitat loss, overfishing, or avoiding the introduction of drastic fishery regulation or other unpopular measures[57] as stocking was seen as an alternative to good management. Without mitigating the underlying causes of stock decline, stocking will have little or no success.

Under such circumstances, stocking programmes need to be used in conjunction with other fisheries management tools.[58] Stocking projects that are planned in conjunction with other management tools imply a better understanding of an ecosystem and the causes of a stock's decline,[59] and have greater chances of success.

Removal of any recruitment bottleneck associated with environmental degradation also needs early evaluation. If mitigating action against the factors causing the poor recruitment to the fishery is not taken at an early stage, stocking will become a recurring action that does not address the problem.

[51] For example: Svåsand *et al.* (2000); Saltveit (2006)
[52] Cowx (1994b ; 1999); Leber (1999 and 2002); Leber *et al*. (1998)
[53] Ackefors *et al*. (1991)
[54] Beattie (2003)
[55] Bartley (1999)
[56] For example : Lenanton *et al*. (1999); Dibden *et al*. (2000)
[57] Van Vooren (1995); Hilborn (1998); Burton and Tegner (2000)
[58] For example: Brand *et al.* (1991); Heppell and Crowder (1998); Hilborn (1998); Blaxter (2000)
[59] Beal (1993); Robinson (1994); Walton and Walton (2001)

This typically occurs when, for example, the decline is caused by man-made interruptions to riverine passage[60] and is thus beyond the ability of stocking to rectify. Although stocking may initially appear a cost-effective option in the long term, recurrent costs and resource needs to meet any criteria for stocking can become a problem, especially if the focus of financial support and political/economic conditions change.

Short-term stocking programmes do not address the long term fundamental issue of environmental impacts or other underlying factors that are causing the decline in fisheries potential.

To address the fundamental causes for the poor status of the fish stocks in the first instance has added benefit because a stocking programme is more likely to succeed if bottlenecks to natural recruitment are removed. Without such action, any benefits accrued from the stocking programme are likely to dissipate quickly and stocking will have to be done on a continuous basis.

4.3 Define clear objectives for the stocking initiative/programme

It is essential that the objectives of stocking initiatives are formulated and prioritized clearly. This allows the selection of appropriate management and technical strategies and enables objective evaluation of whether the objectives have been achieved or not. It is likely that there will be more than one objective of this stocking, although one may be more important than the others (Table 3).

Table 3 Typical objectives for stocking, covering a range of environmental and human benefits

Objective	Value
Enhanced food/fish production	Compensating for shortfalls in catch in overfished systems or those damaged by changes to the environment caused by other users of the resource – Primary objective is increased yield – Stocking to achieve higher levels of output than fisheries based on wild stocks alone – Significantly increase production beyond what is naturally possible in a waterbody
	Stocking of waterbodies that are recruitment-limited – Primary objective is increased yield – Increasing productivity of seasonal waterbodies – Compensating for overfishing of broodstock – Maximizing yields of stocked species
Enhance/diversify livelihoods	There is often an implicit assumption that enhancements provide opportunities in particular for resource poor sections of inland and coastal aquatic resource users This may be the case and there are positive examples. Equally, there are examples where the impact has not been felt or secured by poorer resource users because of issues with elite capture, exclusion by a core group of users or inability to pay the additional costs (e.g. fees, change of gear) to effectively exploit the improved fishery – Primary objective is improved benefits to households or fishery stakeholders – Increase income from catches (more catch, more marketable species) – Increase household food security – Compensate for declining catches resulting from environmental perturbations – Additional livelihoods benefits
Rehabilitation of degraded systems	Stocking to sustain general (food) fish catches, especially of species whose breeding or recruitment potential is threatened by changing environmental conditions (e.g. pollution, water quality, water flow) or loss of habitat – Primary objective is environmental improvement – Returning natural productivity and population structure to a pre-assessed state – Mitigation strategy in situations where environmental conditions have been irreversibly altered by other human interventions

[60] Ackefors *et al.* (1991); Will *et al*. (2002)

Table 3 *(continued)*

Objective	Value
Conservation	Similar to the above but more focused on endangered species or ecosystems. Stocking to sustain catches, especially of species whose breeding or recruitment potential is threatened by changing environmental conditions or loss of habitat – Primary objective is environmental stability/resilience – Retaining natural productivity and population structure
Increased recreational opportunities	The recreational potential of a waterbody can be enhanced by regular stocking. In this case the primary objective is not maximizing food production and the species stocked may be chosen for sport fishing characteristics rather than for yield. Such species may also tend to be top predators. – Recreational value – Economic value

4.4 The choices of objectives for stocking

The most recent typology recognizes five different enhancement system types[61] and these are outlined in Table 4. Each of these systems has a different primary purpose and involves quite different management practices.[17]

Table 4 The five types of fishery enhancement system that involve stocking

Enhancement type	Primary purpose(s)
Culture-based fisheries and ranching	Increased fish production
	Creation of recreational fisheries
	Bio-manipulation
Stock enhancement	Sustaining and improving fisheries in the face of intensive exploitation
	Sustaining and improving fisheries in the face of habitat degradation
Restocking	Rebuilding depleted populations
Supplementation	Reducing extinction risk
	Conserving genetic diversity
Re-introduction	Re-establishing a locally extinct population

4.4.1 Stocking for mitigation or compensation

This encompasses stocking with fish carried out as a voluntary exercise or statutory function to compensate for a disturbance caused by human activities against lost production, such as a reservoir construction, land drainage works or similar habitat perturbation.

Stocked fish may be released into unaffected parts of the waterbody, and the impact on the wild stocks in these areas must be considered.

Many of the traditional, long-term stocking programmes are carried out for mitigation or compensation. In such cases, stocking is often viewed as a permanent solution (i.e. it must be done on a continual, usually annual, basis) and is unlikely to lead to the establishment of a self-sustaining natural population because the underlying reason for the stocking has not been addressed.

The degree to which the fishery is dependent on stocking depends on the extent of ecosystem modification and can range from "total", where the native stock would disappear without support, to "partial", where the stock would be reduced to a proportion of that which might be expected if the system was not impacted.

[61] Lorenzen *et al.* (2012)

4.4.2 Enhancement stocking

Enhancement stocking is the principal method used to maintain or improve stocks where production is actually, or perceived to be, less than the waterbody can potentially sustain.

Often, the reasons for the poor stocks cannot be identified and/or removed, or there is a desire to increase populations (usually for exploitation) to levels greater than those that can be achieved naturally. Typically, this type of stocking is used where those exploiting the fishery have expressed dissatisfaction with the quality of fishing, or to enhance stocks in sections of a river where access is restricted by in-stream barriers.

It also includes activities carried out to strengthen the quality and quantity of the spawning stock of a given species so as to improve natural reproduction potential. This can be for improvement of yield from a fishery or for conservation purposes where the natural breeding component is considered inadequate to maintain the stock at sustainable levels (see below).

The majority of stocking in the past probably falls into this category and it is driven by complaints about the status of the fishing or desire to improve output from a particular waterbody. However, in many cases the assessment of the state of the stock has been unduly pessimistic, resulting from natural fluctuations that can have a profound effect on some fish populations, or merely that the estimates of potential production have been unrealistically high. If production is already limited or driven by natural population cycles, it is unlikely that stocking will have a beneficial long-term effect.

When stocking for enhancement is considered a permanent, on-going, solution, it can be defined as culture-based or "ranching" (supplementing natural juvenile recruitment through the growth of stocked fish) or, in the case of recreational fishing, "put-and-take" (stocking of fish into a waterbody for the express purposes of catching and removing for consumption). As a permanent solution, the strategy requires continuous application to maintain the desired fishery. This strategy is particularly favoured in situations where it is not considered desirable to introduce a permanent element to the fauna and where stocks would eventually die out without new material being added. Typical of this is the stocking of rainbow trout, *Oncorhynchus mykiss,* and the stocking of Indian major carps (rohu) or Chinese carps (grass, bighead and silver carps).

4.4.3 Stocking for restoration

Stocking for restoration is carried out after a limiting factor on stock recovery or improvement has been removed or reduced.

An example may be a long-term improvement in water quality, habitat improvements, the easing of passage for migratory fish or a reduction in fishing pressure. All restoration stocking must be based on reliable evidence that such populations existed in that catchment, or waterbody, in the past.

Restoration stocking should generally not take place until defined limiting factors have been removed or ameliorated. However, situations may exist where it is necessary to initiate stocking in parallel with other habitat or fisheries management actions. Used in parallel, this can accelerate the stock recovery and/or to secure continued support for the restoration.

Stocking programmes of this type should be a temporary measure and require a more active management strategy for the aquatic ecosystem and its fish populations. The ultimate objective is to create a fish stock and aquatic ecosystem that is self-sustaining.

4.4.4 Culture-based fisheries are typically undertaken for a narrower set of objectives

Much of the stocking that takes place in the Asian region can be more narrowly classified as culture-based fishery. Culture-based fisheries and ranching systems are used to maintain stocks that do not recruit naturally. The typical objectives for culture-based fishery stocking activities are presented in Table 5.

Table 5 The range of objectives of culture-based fisheries in Asia

Purpose of culture-based fishery	Objectives
Promote or increase a commercial fishery	To increase yield of the fishery
	To increase fishers' incomes or the value of the fishery
Support a recreational fishery	To increase the number of fish that can be caught by recreational anglers
	To replace the fish that are taken out of the fishery by recreational fishers
Bio-manipulation	To reduce the level of an unwanted species in an ecosystem (often invasive or pest species)
	To alter the trophic web of an ecosystem to restore or improve water quality (e.g. in the case of weed/phytoplankton control) or another ecosystem feature

4.4.5 Stocking to create new fisheries

To an increasing degree, introductions into natural waters are an accident through escape, colonization or establishment of an introduction made for aquaculture.

Where introductions are made as a management tool for commercial and recreational fisheries, the aim is to insert a new element into the community of fish for one of the following reasons:

- ***Establish new fisheries*** that are more resistant to fishing pressure or have greater market value than fisheries comprising only native species. In recreational fisheries new species are introduced to improve the variety available to anglers or insert a species of particular trophy or sporting value into an area. Stocking fish into a newly-created water, e.g. a redundant gravel pit, also falls into this category.
- ***Fill a vacant niche*** where existing fish species do not fully utilize the trophic and spatial resources available. In some natural waters evolutionary isolation has resulted in there being few native species, (e.g. United Kingdom and Ireland where fauna have been wiped out through glaciation).

More commonly, the need for introductions arises as a consequence of human activities. Many new reservoirs lack native species capable of fully colonizing lentic waters and there is interest in developing commercial fisheries through species introduction (e.g. the case of the introduction of *Limnothrissa miodon* in Lake Kariba[62] and the icefish,[63] *Neosalanx taihuensis,* which has been introduced to many Chinese reservoirs). In many river basins, regulation of flow by dams has eliminated or drastically reduced the native rheophilic fauna leaving the waters open to colonization by introduced species.

[62] Marshall (1995)
[63] Liu *et al.* (2001)

4.4.6 Stocking for conservation

Many fish species are under considerable threat from extinction and stocking can be used to maintain these species.

This is generally confined to those fish species or populations that are considered rare or threatened, mainly salmon and eel. This is allied to mitigation stocking but is usually more preservationist in its intent.

Stocking may take place into habitat refugia or other areas not subject to the threat of species endangerment, but often the species has to be maintained in areas where the threat still exists through continuous inputs of new material from hatcheries.

Conservation stocking is used also to enhance populations of other fauna that depend on fish stocks. Fish can also be stocked to provide food for other rare or threatened fauna, e.g. piscivorous fauna such as otters and waterbirds.

5 TECHNICAL REQUIREMENTS AND METHODS FOR STOCKING (STEP 2)

Stocking is probably the most widespread (and abused) management tool used in fisheries today.[64] Most countries report stocking of freshwater and/or marine fisheries as more conventional approaches to management have failed to control fisheries exploitation or reduction in stock biomass through environmental degradation, or in attempts to increase fishery yield.[65] The scale of stocking in inland waters is extensive.

For example, in China state and private entities operate fisheries enhancements in over 80 percent of the country's vast area of reservoirs, yielding over 2.5 million tonnes of fish annually.[66] Similarly, rural people in the rice-farming landscapes of Southeast Asia implement a plethora of fisheries enhancement measures in public, communal or private waterbodies.[67]

However, the literature suggests that most programmes have not met their objectives or not lived up to project expectations, despite some such projects operating for many years.[68] There are six fundamental reasons:

- stocking too many or too few fish;
- stocking inappropriate species;
- stocking poor quality, unconditioned or unfit fish;
- inappropriate or stressful release strategy;
- poor cost-benefit analysis resulting in low economic returns; and
- failure to take into account potential governance and social issues.

This step is primarily concerned with identifying the technical requirements and methods to ensure successful stocking once the objective of the stocking has been clearly defined.

5.1 Determine the most biologically and economically effective stocking densities

One of the greatest concerns with respect to stocking programmes is that they rarely consider the capacity of the recipient system to support the enhanced stocks. If too many fishes are present, increased mortality rates through predation and starvation, reduced growth rates and increased dispersion, generally follow. Although stocking and introduction may produce large increases in fish numbers at certain times or in localized areas, it is still the case that no more fish will survive than the resources will allow.

In worst-case scenarios, overstocking can lead to reductions in the performance of fisheries below that prior to the introductions. For fisheries already subjected to stocking activities, reducing stocking densities should reduce the potential for competitive interactions between native and stocked fishes, as pressure for finite resources is reduced. Reducing stocking densities should also minimize any detrimental impacts on the ecosystem as a whole.

[64] Cowx (1998b); Coleman *et al.* (1998); Petr (1998); Howell *et al.* (1999); Lorenzen (2014)
[65] Petr (1998); Lorenzen (2014)
[66] Li (1999); Miao (2009)
[67] Garaway *et al.* (2006); Amilhat *et al.* (2009a and 2009b)
[68] Svåsand *et al.* (2000); Lorenzen (2014)

Determination of optimal stocking densities should be based on assessment of the carrying capacity of the receiving waterbody, and be commensurate with the risk and scale of the stocking programmes. For lakes, the optimal density can be determined from the relationships between environmental parameters such as shoreline development and water depth and fish biomass.[69] This has been further developed[70] to estimate optimal stocking density for culture-based fisheries. Unfortunately this model relates to fisheries where stocks are exploited.

The number of fry needed to stock a body of water can be obtained by inverting the standard mortality formula:[71]

$$N_0 = N_c e^{z(t_c - t_0)}$$

Where N_0= number to be stocked; N_c = number desired at age-of-capture c; z = total mortality (m for the age group).

Table 6 Some indicative yields from reservoirs in three countries

Area (ha)	Yield (kg/ha)				
	Mexico	China	Sri Lanka	Indonesia (Lakes)	Indonesia (Reservoirs)
100		746			
200		576	17–120		1 500–2 000
400		444	10–60		1 300
600		381			750–1 500
800		342	10–60		1 300
1 000		315		150	600–1 000
2 000		243	10–15	70–80	
3 000	331	209	5–10	40–60	
4 000	267	187		40–60	
5 000	226	172		180–240	500–700
10 000	135	133		120–150	400
20 000	80	103		120–130	
30 000	59	88		120–130	
40 000	48	79			
50 000	40				
60 000	35				
70 000	31			50	
80 000	28			50	

Note: Calculated from Welcomme and Bartley 1998b, Kartamihadja, 2015

Numbers to be stocked should also be related to the potential productivity of the waterbody (Table 6). Several systems have been used for this ranging from generalized equations such as the Morpho-edaphic index to specialized indexes based on benthos of zooplankton densities. These can be incorporated into the general formula as follows:

$$S = \left(\frac{qp}{\overline{\overline{W}}}\right) e^{z(t_c - t_0)}$$

[69] Welcomme and Bartley (1998a)
[70] Lorenzen (2005)
[71] Welcomme and Bartley (1998b)

Where S = number to be stocked; p = natural annual potential yield of the waterbody (MEI or alternative estimator); q = the proportion of the yield derived from the species in question; w = mean weight at capture; T_c = age at capture; t_0 = age at stocking; z = total mortality rate.

Worked example 1: In a small, fertile reservoir fishery, where the stocked fish are 70 percent of the catch (q = 0.7) and the expected yield is 500 kg/ha of fish (p = 500) weighing on average 500 g (w = 0.5), one year after stocking (T_c = 1). The mortality rate is 0.8 (z = 0.8 total mortality rate). The stocking density (of 2 month fingerlings t_0 = 0.167) would be 1 363 fish per hectare:

$$1\,363 = \left(\frac{500 * 0.7}{0.5}\right) e^{0.8(1-0.167)}$$

Worked example 2: In deep oligotrophic reservoir fishery with low natural recruitment, where the stocked fish are 80 percent of the catch (q = 0.8) and the expected yield is 50 kg/ha of fish (p = 50) weighing on average 500 g (w = 0.5), one year after stocking (T_c = 1). The mortality rate is 0.8 (z = 0.8 total mortality rate). The stocking density (of 1 month fingerlings t_0 = 0.08) would be 219 fish per hectare:

$$219 = \left(\frac{50 * 0.8}{0.5}\right) e^{0.8(1-0.08)}$$

More empirical expressions are used by Chinese reservoir fishery managers for arriving at the number of fish for stocking,[72] for instance:

$$d = \frac{F}{WS}$$

Where d = annual stocking density (fish/ha); F = annual fish productivity (kg/ha) as estimated from food organism abundance; W = average weight if fish at harvest (kg) and S = return rate.

Worked example: For a very fertile shallow reservoir fishery, where the expected yield is 1 000 kg/ha of fish weighing on average 350 g (0.35 kg) and a 40 percent return rate (based on post stocking survival, natural mortality and rate of recapture), the stocking density would be 7 142 fish per hectare:

$$7\,142 = \frac{1\,000}{0.35 * 0.4}$$

Food biomass indicators are used to establish the productivity and carrying capacity of the water to be stocked in both China and Russia.[73]

Empirical figures could be used in place of biomass indicators, based on the general fertility, depth and nature of the waterbody. In many developing country contexts, the stocking rates are derived on the basis of experience of repeated stocking events. However, this does assume that there is a relatively effective monitoring of the capture rates in the fishery to inform the estimate of stocking numbers. Table 7 provides some indicative stocking rates and yields for Chinese reservoirs.

[72] Li and Xu (1995)

[73] Li (1988); Berka (1990)

Table 7 Stocking and production characteristics of reservoirs of different sizes in China

Area of Reservoir (ha)	Stocking density number/ha	Fish yield kg/ha
Small (<70)	3 000 to 7 500	750 to 3 000
Medium (70 to 670)	1 500 to 3 000	450 to 750
Large (670 to 6 670)	750 to 1 500	225 to 450
Super (>6 670)	450 to 750	150 to 225

5.2 Increasing survival and performance of the fish to be stocked

5.2.1 Assess if the fish will "fit" in the ecosystem and perform as expected

Aquatic systems are characterized by complex inter-relationships between society and the environment. In addition, different fish species have well-defined habitat requirements that need to be met by the recipient environment if stocking programmes are to be successful.[74]

For example, most fish species have complex life-history migrations, habitat requirements, and, in some cases, local adaptations to individual sections of rivers.[75]

This complexity is almost impossible to fully predict, but failure to recognize the importance of matching fish population ecology and dynamics to ecosystem functioning is likely to result in reduced stocking success or even failure.[76]

It is also important in ensuring that key variables such as natural mortality[77] or limits on carrying capacity or productivity[78] are taken into account, when assessing the likely performance of the stocking activity.

In the Asian context, the most typical approach is to review the performance of a fish species that has been stocked into a similar habitat. This empirical method does not assist in the case of the stocking a fish species that has not been previously used.

5.2.2 Avoid species with known traits that will cause negative impacts

The impacts of stocking programmes on the recipient waterbodies depend partly upon the species of fish released.[79] For example, there is evidence that piscivorous fishes can have significant impacts on fish populations.[80]

Stocking may also lead to undesirable changes in habitat that may impact on the populations of indigenous species the programme is designed to enhance. For example, the introduction of grass carp may greatly reduce the growth of aquatic macrophytes that may be reflected in the productivity of other species that use the vegetation either directly or indirectly. Moreover, by selectively feeding on soft-leaved species, grass carp can lead to an increase in the biomass of tougher (ligneous) species that may be more of a nuisance than the macrophytes originally targeted for control.[81]

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[74] Brannon (1993)
[75] Heggberget *et al.* (1993); Wiley (1995)
[76] Walters and Hilborn (1978); Giske *et al.* (1991); Blaxter (2000)
[77] Stoner and Glazer (1998)
[78] Wiley (1995)
[79] see Cambray (2003); Gozlan *et al.* (2010)
[80] Gozlan *et al.* (2010)
[81] Wells *et al.* (2003)

The stocking or introduction of piscivorous fishes can initiate trophic cascades that decrease phytoplankton biomass and increase water clarity.[82] However, if stocked or introduced fishes are zooplanktivorous, increased zooplanktivory may decrease the abundance of large-bodied zooplankton (e.g. *Daphnia* spp.) and result in an increased biomass of algae and lower water transparency.

The selection of fish species to stock or introduce should therefore be based upon knowledge of their likely impacts on native fishes and the ecosystem in general. Species that are ecologically similar to native fishes are most likely to compete for resources, whereas dissimilar species may potentially alter ecosystem functioning through occupation of vacant niches.

Stocking triploids has the potential to avoid inter-breeding between stocked and native fishes. This is of particular importance for waterbodies that support unique strains of species. However, triploids may interfere with the post-spawning recovery of wild fishes.

5.2.3 Improving the survival of fish to be stocked – pre-conditioning and acclimatization

Pre-conditioning fishes to prevailing conditions in the receiving waterbody potentially improves their survival.[83] Fish reared in a hatchery environment tend not to be exposed to the diversity of environmental conditions they will experience when released to the wild. The hatchery lacks both the structural complexity and the wider variation in environmental characteristics (e.g. temperature, flow velocity, salinity) typically found in the natural habitat. Consequently, the fish are less tolerant of the physical conditions they will experience in the wild.

In these situations, the fish are not only exposed to natural temperature and light fluctuations and more complex habitat structure; they are also exposed to limited supplies of live prey and avian predation pressure. Indeed, many authors[84] have suggested that simple measures such as increasing flow rates within raceways to match natural conditions, providing dark backgrounds, semi-natural streambeds, submerged structures and overhead cover could improve survival rates upon release.

Exposure to natural conditions not only increases the fitness of the individual fish, but providing submerged structures creates visual isolation amongst potential competitors allowing the establishment of territories through improved visual references, leading to lower levels of aggression and improved growth rates.[85]

The reduced opportunity for exercise in hatchery conditions leads to a reduced ability to flee from predatory strikes.[86] Fish that are farm-reared or are to be transferred from still to running water should be exposed to running-water conditions for an extended period before their release. This exercises the red-muscle tissue in the fish, increasing their ability for sustained swimming. Brief exposure to such conditions prior to release can improve post-stocking survival.[87]

This process of acclimation and conditioning is often referred to as "soft release" in the conservation biology literature, and broadly refers to the provision of any kind of training or preparation for release.[88] Soft release enables the fish to become accustomed to the prevailing environmental

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82 Geist *et al*. (1993); Frankiewicz *et al*. (1996 and 1999); Dörner *et al*. (1999); Dörner and Benndorf (2003); Radke *et al*. (2003); Skov *et al*. (2003); Skov and Nilsson (2007)

83 For a comprehensive review see Brown and Day (2002)

84 Leonard and Cooper (1941); Ritter and MacCrimmon (1973a and 1973b); Leon (1975); Butler (1981); Howell and Baynes (1993); see Maynard *et al.* (1995) for a review; Johnsson *et al.* (2014); Roberts *et al.* (2014)

85 Mesick (1988)

86 Howell (1994)

87 Johnsson *et al*. (2014)

88 Pre- or post-release conditioning: Scott-Brown *et al.* (1986)

conditions (temperature and chemical composition of the water, for instance), familiarize themselves with local landmarks for orientation and navigation, recover from transportation, and develop cohesive social bonds wherever appropriate.[89]

Allowing an acclimatization period prior to liberation should, therefore, result in substantial reductions in post-release mortality. The exact period of acclimatization required to maximize survival is likely to be species- or case-specific, but several studies suggest that holding fish in cages or enclosures for one to seven days prior to liberation substantially increases survival rate, increases growth rates and improves recapture rates,[90] all desirable attributes of successful stocking.

It is recognized, however, that pre-conditioning and acclimatization may not be possible in many situations. However basic measures can be taken:

- increase water flows in hatcheries to "train" fish to flowing water (where relevant); and
- acclimate fish in pens or bags in the waterbody before release.

Holding the fish prior to release also helps alleviate the stress caused during transportation of hatchery reared fish to the release site.

5.2.4 Improving the survival of fish to be stocked – life skills, predator avoidance, feeding

Hatchery-rearing techniques have advanced considerably in recent years, but survival of stocked fish of captive origin remains low.[91] Considering most species are reared in captivity for extended periods and released between six months and two years of age, their survival relative to wild stocks in terms of age-specific mortality is very poor.[92] Even when age-specific mortality is not considered, survival of stocked fish from eggs to catchable sizes is still lower than their wild conspecifics; most mortality occurs in the first few days following release[93] and is indicative of predator-mediated mortality.

If hatchery-reared fish survive their first few weeks in the wild, their chance of long-term survival is greatly increased.[94] The relatively poor success rate of stocking in wild fisheries, coupled with various other issues (e.g. loss of genetic integrity of wild stocks discussed in Section 1.4) question the value of hatchery supplementation programmes.[95]

It is worth noting that hatcheries now tend to consider the choice of broodstock more carefully to avoid genetic "pollution" of the resident wild stock.[96] Ideally, a large number of mature individuals should be sourced from the target population every year.

Arguably, the two most important factors likely to cause the poor survival are compromised ability to feed on natural food sources and vulnerability to predation, to a lesser extent this also includes the ability to interact socially, the ability to tolerate conditions in the receiving environment (see previous Section 5.2.3) and the ability to orientate and navigate in a complex environment. Many of these behaviours require some degree of learning,[97] which can only come about by repeated exposure to appropriate stimuli.

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[89] Brown and Day (2002)
[90] For example: Jonsson *et al*. (1999)
[91] Nickleson (1986); Beamish *et al.* (1992); Pearcy (1992); Coleman *et al*. (1998); Blaxter (2000)
[92] Reisenbinchler and McIntyre (1977); Chilcote *et al.* (1986); Leider *et al*. (1990); McNeil (1991); Salvanes (2001)
[93] Howell (1994); Blaxter (2000); Svåsand *et al*. (2000)
[94] Kanid'hev *et al.* (1970); Brown and Smith (1998)
[95] See Winton and Hilborn (1994) for further discussion
[96] Ryman (1981); Ståhl and Hindar (1988); Allendorf (1991); Bergan *et al.* (1991); Doyle *et al.* (1991 and 2001); Utter (1998); Hindar *et al.* (1991); Waples (1991); Hindar (1992); Cowx (1999)
[97] See McLean (1997) for a review of learning and relevance to conservation reintroductions

Hatchery-reared fish are routinely reared on a diet of manufactured, pelleted foods and this means fish are not exposed to the natural range of foraging behaviour because there is little variation in the timing, location, abundance or type of food on offer. When food is added to the hatchery enclosure, limited searching is required to discover it, thus providing no opportunity for the fish to develop natural foraging behaviours.

It appears that individual fish are reliant on learning from prior experience or from contemporaries[98] to improve prey recognition, attack skills and handling efficiency.

When foraging in the wild, where distribution, abundance and trophic value of prey are variable, it is particularly important to improve foraging efficiency by adjusting foraging behaviour to match the new circumstances.[99]

Stocked fish exhibit limited prey choice, take fewer items and are very slow to switch between prey types compared with wild fish,[100] depriving them of essential nutrition to aid survival.[101] Furthermore, stocked fish often fail to disperse, are less aggressive and frequently found in higher densities, thus competing for limited resources.[102]

As with foraging skills, hatchery-reared fish tend to have poorly developed anti-predator skills, because they have little opportunity to interact with predators prior to release.[103] This increases their susceptibility to predation[104] and is the principal cause of mortality among released hatchery fish.[105] For example, hatchery reared fish tend to exhibit more risk-taking behaviours,[106] have poorer predator recognition skills[107] and have weaker anti-predator responses[108] than wild-reared fish.

It is suggested that it is "critical . . . to develop methodologies for hatcheries to improve post-release behavioural performance."[109]

Captive-rearing programmes could address this need by providing some form of experience to the captive animal, to stimulate the learning acquisition of foraging or anti-predator skills.[110] This has been termed life skills training.[111] It has been suggested that foraging and predator avoidance training regimes could be implemented at the scale required for hatcheries.[112]

The pattern of post-release mortality observed in released fish implies that pre-release training occurs relatively quickly, since those that do survive the early post-release period must have rapidly acquired the necessary life skills to survive. Even a single exposure to predators may make a substantial difference to the behaviour of prey on subsequent exposures.[113]

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98 For example: Paszkowski and Olla (1985); Stradmeyer and Thorpe (1987a and 1987b); Reiriz *et al*. (1998)
99 Hughes *et al*. (1992)
100 Sosiak *et al*. (1979); Ersbak and Haase (1983)
101 Paszkowski and Olla (1985); Usher *et al*. (1991)
102 Olla *et al*. (1998)
103 Suboski and Templeton (1989); Kieffer and Colgan (1992); Olla *et al.* (1994); Dellefors and Johnsson (1995)
104 Berejikian (1995); Dellefors and Johnsson (1995); Shively *et al.* (1996)
105 Howell (1994)
106 Dellefors and Johnsson (1995); Johnsson *et al.* (1996), Fernö and Järvi (1989)
107 Berejikian *et al*. (2003); Hawkins *et al*. (2004)
108 Järvi and Uglem (1993); Alvarez and Nicieza (2003)
109 Olla *et al.* (1994)
110 For example: Berejikian (1995); Griffin *et al*. (2000)
111 Suboski and Templeton (1989); Suboski (1990); Brown and Laland (2001); Johnsson *et al*. (2014)
112 Suboski and Templeton (1989); Brown and Laland (2001)
113 Olla and Davis (1989); Pyanov (1993); Hossain *et al*. (2001)

For foraging, two key behaviours are important to improving foraging efficiency:

- prey recognition; and
- prey handling (attack response and ingestion).

Three behaviours are important to reduce predator-induced mortality:

- avoidance strategies that reduce the probability of encountering predators (e.g. avoiding dangerous microhabitats, cryptic behaviour or cryptic colouration);
- predator recognition and detection; and
- anti-predator response (schooling, flight to refuge).

It would be relatively easy to stimulate foraging behaviour in fish by repeated exposure to different prey types.[114] Live prey can be introduced into the holding facility periodically or just prior to release to provide the fish with limited foraging experience at little time or financial cost. This would improve prey recognition, handling and selection.[115]

More complex foraging behaviours such as weighing up the costs and benefits associated with foraging under different levels of predation threat[116] and selective foraging based on trophic value and abundance can also be improved with experience.[117]

Like foraging behaviour, there is ample evidence that anti-predator behaviour improves considerably with experience.[118] It has been suggested that captive-rearing programmes could rectify this deficiency by providing some form of predator experience to stimulate acquisition of anti-predator skills,[119] thus potentially improving the viability of restocking procedures.

In this context, numerous authors[120] found that prior exposure to a predator increased survival rates substantially on subsequent exposure.[121] Fish may even show improved survivorship simply by interacting with predator-experienced individuals.[122]

Predator-naïve animals can acquire recognition through releaser-induced recognition learning,[123] whereby a novel stimulus (predator cue) is paired with an aversive stimulus, leading to learned aversion to the predator cue under laboratory conditions.[124]

It has been found that anti-predator responses improved in hatchery-reared Atlantic salmon exposed to cod either behind a partition and when allowed to interact directly with the hunting predator.[125] However, this approach has met with limited success for salmon stocked into the wild[126] and needs further development.

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[114] Godin (1978); Ringler (1979); Paszkowski and Olla (1985); Stradmeyer and Thorpe (1987a); Reiriz *et al*. (1998)
[115] Ware (1971); Croy and Hughes (1991); Hughes *et al.* (1992)
[116] Dill and Fraser 1984; Metcalf *et al*. (1987); Gotceitas and Godin (1993)
[117] Hughes *et al.* (1992); Provenza and Cincotta (1993); Reiriz *et al*. (1998)
[118] Kanayama and Tuge (1968); Fraser (1974); Olla and Davis (1989); Csanyi and Doka (1993); Järvi and Uglem (1993); Berejikian (1995); Brown and Smith (1996); Mirza and Chivers (2000); Hossain *et al.* (2001)
[119] For example: Ellis *et al*. (1977); Berejikian (1995); Griffin *et al.* (2000)
[120] For example: Olla and Davis (1989); Magurran (1990); Kieffer and Colgan (1992); Järvi and Uglem (1993); Berejikian (1995); Brown and Smith (1998); Brown and Warburton (1999)
[121] See also Hossain *et al.* (2001)
[122] See Patten (1977); Suboski and Templeton (1989); Brown and Laland (2001)
[123] Suboski (1990)
[124] Mirza and Chivers (2000); Berejikian *et al.* (2003)
[125] Järvi and Uglem (1993)
[126] Thompson (1966); Kanayama (1968); Berejikian *et al*. (1999)

5.3 Select the most effective release strategy

5.3.1 Establish a protocol for timing and method of release

There is a growing body of evidence to suggest that the timing and nature of release are critical to the survival of stocked fish. It is important that fish are stocked at a time when they will be able to adjust to the new environment quickly and thus learn to forage on natural foods with minimal delay. It is important therefore that abundant food resources are available.

Unfortunately, many fish are stocked when the fish are available from the hatchery, often at the end of the growing seasons when food resources are on the wane or depleted. Thus the fish probably not only have to survive the rigours of competition and aggression from wild fishes but they also have to survive on their body's nutritional reserves (e.g. lipids and fats). If the reserves are low, chances of survival are equally low. Thus, the preferred period of stocking should match an abundance of natural food resources such as that typically found in the spring as temperatures are warming up.

As previously indicated (Section 5.2.3) acclimatization is important to allow the fish to adjust to their environment. However, this should be coupled with a release pattern that minimizes the stresses on the stocked fish. There are three mechanisms for releasing fishes:[127]

- **spot planting** (releasing all the fish in a single batch);
- **scatter planting** (simultaneously releasing batches of fish at several locations); and
- **trickle planting** (releasing batches of fish over an extended time period).

Releasing large numbers of fish at a single spot not only leads to aggression between the individuals, but also to competition for food resources in the immediate vicinity of the stocking point until the fish have dispersed. Consequently, survival is also related to whether the fish stocked at one locality, scattered around the waterbody, or trickle stocked in a range of locations over a period of time.

Spot planting can lead to competition amongst released fishes and with native stock, and in rivers is often associated with downstream displacement of fishes.

Scatter planting minimizes the potential for competitive interactions by reducing over-dispersion of released fishes.

Similarly, trickle planting minimizes the potential for competition, but is often constrained by lack of manpower, finance and available stock.

Evidence suggests that in terms of stocking success, scatter and trickle planting should be preferred over spot planting.

5.3.2 Choose the correct release site

The importance of choosing the right location and the time of year to release captive-reared fish is well established especially with reference to flow rates, habitat quality (including stream-bed structure), prey, predator and competitor abundance.[128]

Nevertheless, many programmes ignore these issues and fish are stocked either when they are available or where good access to the waterbody is possible, irrespective of the potential impact on

[127] Cowx (1994a)
[128] Leber *et al*. (1996); Jokikokko (1999); see Cowx (1998a and 1999) for reviews

survival. Furthermore, often no consideration is given to the existing stocks in the receiving water and the potential competition, predation or social interaction between stocked and wild fish.[129]

Part of the problem arises because it is virtually impossible to assess the carrying capacity of the receiving waters or the existing stock size. Consequently, fish are stocked at pre-defined densities based on resources available. In some cases this can lead to overstocking and reduced survival success. Evidence suggests that lower densities of fish can produce better quality fish and enhance survival.

The provision of habitat enrichment during rearing at the hatchery may provide the key to the development of more natural social behaviours that could potentially alleviate some of the social inadequacies displayed by hatchery fish. Conversely, the low abundance or absence of existing populations of fish may be indicative of an inappropriate stocking location, e.g. one that is environmentally degraded or under extreme fishing pressure.

In these cases, it may be more appropriate to address the habitat bottlenecks prior to the stocking to improve the likelihood of stocking success (see Section 4.2).

5.3.3 Determine the appropriate size of fish for release

Selection of the size of fishes to be stocked requires knowledge of their likely impacts on native fishes and the ecosystem in general, together with a cost–benefit analysis. The significance of the size or age of fishes released is most apparent for species that undergo size-related or ontogenetic shifts in feeding behaviour or habitat use. For instance, many fish species are initially planktivorous, but switch to piscivory or benthivory with development. The size or age of fish released therefore determines the position they occupy in the food web and hence their impacts upon ecosystem functioning and trophic status. Many piscivorous species consume zooplankton and benthic macro-invertebrates when young, but may become increasingly piscivorous as they grow and this may have implications for ecosystem functioning. Releasing fishes at small sizes should reduce the incidence of piscivory and aggressive behaviour towards wild fishes.

In principle, the size that optimizes the yield (benefits) from stocking in relation to cost of the activity should be preferred. The optimum size to give the maximum benefit should be determined for all stocking programmes. In fisheries where exploitation is well managed, and the fishes allowed to achieve a reasonable size before being exploited, the optimum size is probably somewhere in the early juvenile period. However, if fisheries are poorly managed and the exploitation of young fishes is intense, this point is probably in the larval period because the production costs of the stocking material are much lower.

A general trend is that migratory and anadromous fishes are usually stocked at young life stages (fry) to allow them to acclimate to the natal river and prepare for migration as their size increases. Cyprinids and other non-migratory forms are generally stocked at an older stage (fingerlings ~12 cm) as they are often supplementing a failure in natural recruitment. These fishes are expected to grow on to a large size based on the natural productivity of the stocked waterbody.

Although there is a theoretical overview[130] of the implications of stocking different sized individuals, few studies have assessed this in real terms. This is despite there being general agreement that survival rates are higher for fish stocked at larger sizes.[131]

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[129] Fenderson and Carpenter (1971); Bachman (1984); Welcomme and Bartley (1998a and 1998b); Deverill *et al.* (1999); Lorenzen (2014)
[130] Cowx (1999); Lorenzen (2005)
[131] For example: Tsukamoto *et al.* (1989); Masuda and Tsukamoto (1998); Svåsand *et al.* (2000)

As a result of this size-correlated mortality, hatcheries tend to grow fish destined for stocking for extended periods prior to release, although economic constraints usually prevent fish being grown to very large sizes in captivity before release; the longer the fish remains in captivity the greater is the cost of feeding and husbandry.[132]

These extended grow-out periods also have strong adverse effects on the behaviour of the fish (see above). Therefore, a balance must be found between the benefits of long-term captivity on mortality, the disadvantages of behavioural deficits and the cost-benefits derived from stocking many small fish against fewer larger individuals.

Pre-release conditioning may address this problem (see 5.2), but still adds considerable work and complexity if this is to be applied on a large scale.[133]

5.4 Undertake a cost-benefit analysis

In terms of cost-benefit, two main factors influence the size chosen for stocking material: cost and survival. The release of fishes at smaller sizes risks higher mortality, but the cost of stocking material increases exponentially with fish size, especially in slow-growing species, because fewer fishes are needed to obtain the same amount of additional catch from stocking when the size of released fishes is increased.

The costs of using larger fish for stocking must be balanced against the uncertainty in fishery yield and hence the economic yield from stocking, which decreases as a function of fish size.

It is generally thought that there is a transition size (juvenile bottleneck) after which the yield from stocking is changed from unpredictable to predictable and the uncertainty is lowered considerably.

The actual size chosen depends on an empirically determined balance between these two factors and is a trade-off:

- The more fish stocked (that survive) the better the yield from the fishery, but only up to point. After that, the stocking does not increase the fishery yield and is a waste of money.
- Larger fish have greater chance of survival and so the certainty of stocking improves with increasing size.
- Larger fish cost more, so with a fixed budget you have to stock less.
- Small fish are cheap and you may stock a lot, but their survival rate can be very low.
- The optimal profitability balances these factors of size and number of fish stocked.

5.5 Evaluate and mitigate potential adverse governance and social issues

5.5.1 Institutional weaknesses

Most stocking strategies generally concentrate on fishery-related aspects such as size of fish, density or biomass of fish to be stocked.[134] However, there are many wider issues and constraints that also need to be overcome before a stocking activity can take place or will be effective, particularly where fisheries are maintained by regular stocking, i.e. commercial put-and-take, catch-and-release or culture-based fisheries. These can be broken down into provision of stocking material and management of the fisheries.

[132] Behnke (1989)
[133] Järvi and Uglem (1993); Brown and Smith (1998); Brown and Laland (2001)
[134] See Cowx (1994a) for details

In many cases, failure to maintain fish stocks at adequate levels arises because of lack of suitable stocking material. A recurring problem is that fish are not available at the ideal time or in the numbers required. The problem can be traced back to the source of supply of the seed or fish for stocking.

Fisheries stocking initiatives are based on stocking material from either the wild or fish farms. Seed from the wild are often subject to huge natural fluctuations, which inevitably effects availability. If the fishery is dependent on this source, and stocks are limited, the stocking programme can fail. Similarly, supply of stocking material from fish farms or hatcheries can also have inherent problems. These only have limited capacity and increasing demand for stocking material can outstrip supply. Furthermore, hatcheries and farms are often in central locations and access to the fishery is difficult and creates transportation and logistical problems.

5.5.2 Ownership

In waterbodies where the boundaries can be defined (e.g. put-and-take and still-water fisheries) ownership is rarely a problem. In open systems, such as large rivers, lakes or coastal regions, the ownership is less well defined. In these systems stocking is more akin to ranching and the dispersion of stocked fish outside the area of jurisdiction of those carrying out the stocking programme puts considerable question on ownership and exploitation rights. In many instances the stocked fish become a common property resource and any stocking programme will probably have to sustain any external exploitation.

The reason many ranching programmes do not succeed on a strictly financial basis is because the return on investment is dissipated and not accrued by the primary owner. Under such circumstances the programmes generally have to be run by a central institution, and if the objective is to run an economically viable fishery, a levy or license fee needs to be paid by those exploiting the fishery to cover the costs.

Alternatively, if the objective is food security then the institution may accept the cost, but the fishery will probably require some form of regulation to prevent overfishing. Community-based or cooperative arrangements for management with official recognition and/or a licensing system are the best strategies for achieving some regulatory control.

5.5.3 Ignorance of social and economic considerations to set reference points

Stocking programmes are frequently unsuccessful, curtailed or even abandoned because the wider political, social and economic issues associated with fisheries management are ignored. This is particularly true in developing countries where the overall fisheries sector objectives are different from those in the developed regions of the world. In developed countries stocking strategies are targeted towards ecological goals, particularly the enhancement of recreational fisheries, and more recently conservation and protection of species diversity.[135]

In developing countries the goals are economically driven, focusing on food security and income generation. The differing goals mean that the issues and constraints acting on fisheries enhancement activities in developing countries are very different and the strategies formulated for these regions need adapting to the prevailing circumstances in developing countries. Stocking or culture-based fishery initiatives should therefore:[136]

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[135] Cowx (1998b); Arlinghaus *et al*. (2002)
[136] FAO (2015)

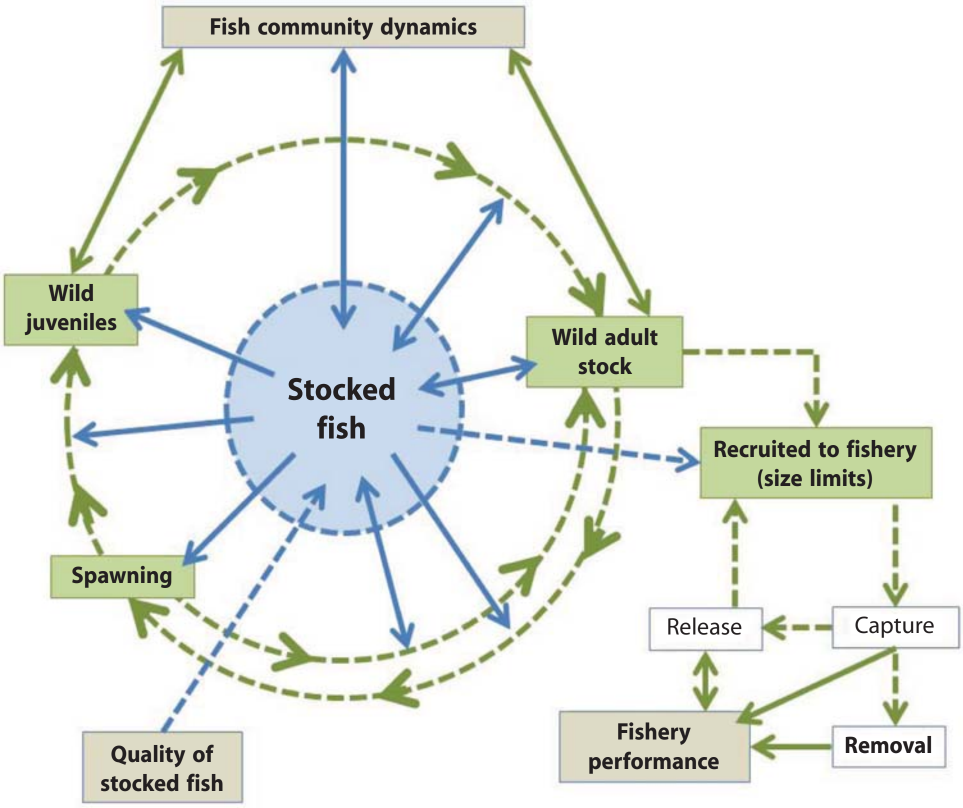
- not become a source of conflict;
- not damage or negatively impact ecosystem services unless a specific mitigation or compensation mechanism is in place;
- strive for equitable arrangements over access and rights to the fishery and the empowerment of stakeholders including women; and
- take into account, the rights of poor, vulnerable or marginalized groups using the guidance found in the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (VGSSF) and the Voluntary Guidelines on the Governance of Tenure.

6 RISK ASSESSMENT (STEP 3)

6.1 Identification and assessment of hazards and risks of stocking activities

Stocking is a widespread practice that has been undertaken for many decades. Despite this, the long-term ecological effects of these stocking activities are not well understood. Evidence suggests that, where natural recruitment is not limiting, stocking has negative effects on the growth and survival of resident fish populations. The hazards of stocking are linked to the interactions of five key elements (Figure 4):

- quality and condition of stocked fish;
- the wild fish population dynamics of the recipient waterbody (specifically the natural production cycle);
- fish community dynamics of the recipient waterbody;
- the environment of the receiving waterbody (carrying capacity for different size classes); and
- the existing fishery.



Note: Potential interaction and hazards are identified by solid arrows.

Figure 4 Scheme of interactions between stocked and wild fish indicating possible interactions with hazards to wild stocks

It is the potential interactions between these elements that may pose risk to the status of the wild stocks. Interactions and potential hazards within this cycle are summarized in a hierarchy from species-specific risks up to ecosystem-wide risks (see Table 8).[137]

[137] This has been reviewed by Gozlan *et al.* (2010)

Table 8 Potential detrimental impacts associated with stocking activities in a hierarchy from species-specific to ecosystem-wide outcomes

Outcome	Relative risk	Certainty	Source(s)
Increased intraspecific competition: because of an increased abundance of the species by the addition of hatchery-reared fishes	M	M	Ackefors *et al.* (1991); Rowland (1994); Su and Liao (1999)
Shifts in prey abundance: changes in the abundance of prey species because of increases in fish predator abundance as a result of stocking	L	M	Blaxter (2000)
Prey-switching by wild predators: changes in the targeted prey of wild predatory species, usually to focus on hatchery reared (naïve) fishes because of large numbers released	L	L	Warburton *et al.* (1998); Wilhelm *et al.* (1999); Willette *et al.* (2001)
Starvation/food limitation: because of overstocking	L	M	Dushkina (1991); Ackefors *et al.* (1991)
Exceeding the carrying capacity of an ecosystem (swamping): because of continued stocking after recovery	M	M	L'Abee'Lund (1991); Leber *et al.* (1998); FAO (1999); Blaxter (2000)
Interspecific competition: competition between hatchery-reared fish and other species with similar ecological requirements. May lead to a reduction in abundances of competing species and prey species	H	M	Rowland (1994); Wiley (1995); FAO (1999)
Displacement of wild stock: by hatchery-reared conspecifics, although there are no well-documented examples	M	L	Blaxter (2000); L'Abee'Lund (1991); Leber *et al.* (1995); (1998); Bannister and Addison (1998); Butcher *et al.* (2000)
Introduction of diseases and parasites: especially because of poor hatchery management and husbandry	H	H	Fjälling and Fürst (1987); Heggberget *et al.* (1993); Loneragan *et al.* (1998); Wootten (1998); FAO (1999); Burton and Tegner (2000); Lee *et al.* (2001)
Genetic bottleneck: because of lack of genetic management of broodstock within the production system	H	H	Rowand (1994); Busack and Currens (1995); Compton (1995); Loneragan *et al.* (1998); Penman and McAndrew (1998); Utter (1998); Wootten (1998); Cross (1999); FAO (1999); Hershberger (2002); Lester (2002)
Loss of genetic diversity and fitness: certain alleles of wild fish may become rare because of the release of hatchery-reared fish with a low genetic diversity. This is of higher risk where the wild stock is reduced to very low levels prior to stocking	M/H	L	Leary *et al.* (1995); Penman and McAndrew (1998); Skibinski (1998); Utter (1998); FAO (1999); Burton and Tegner (2000); Lee *et al.* (2001); Lester (2002); Aprahamian *et al.* (2003)
Extinctions: the loss of species because of increase in the abundance of released fish and ecosystem shifts	M	L	L'Abee'Lund (1991); Utter (1998); McDowell (2002)
Ecosystem shifts: shifts in the distribution of biomasses or other species, possibly resulting in the loss of other ecosystem values	M	M	White *et al.* (1995); Crowe *et al.* (1997); Fielder *et al.* (1999); Arnason (2001); Lee *et al.* (2001)
Physical environmental damage: because of stocking operations	L	H	Lee *et al.* (2001)
Hindrance of difficult management decisions: (e.g. reduction of effort) because of the perception that stocking will allow fishing activities to continue unabated	H	H	Burton and Tegner (2000)
Diversion of management resources from other activities: for example, other management strategies	M	H	Burton and Tegner (2000)

Note: Modified from Molony *et al.* (2003)

6.2 Risk assessment

To assess the scale of risk, with the degree of uncertainty, of any stocking programme, there is the possibility of undertaking a risk assessment. When applied, these procedures should be weighted into the overall assessment. The risk assessment process addresses the major biological and environmental impacts (Table 9), and if necessary the benefits to the region's economy.

With stocking, it should provide a standardized approach for evaluating the risk of genetic and ecological impacts as well as the potential for introducing non-target species, especially pathogens, which might impact on the native flora and fauna of the proposed receiving waterbody.

Risk assessment is used to determine the likelihood that an event may occur and what the consequences of such an event will be. A risk management framework operates by establishing the context (i.e. stocking event), identifying the risks for the existing situation (consequence and likelihood), assessing the risks and treating the risks.

A measure of risk is typically derived by multiplying *likelihood* by *consequence*. A risk matrix is used to determine the level of risk (Table 9). The ratings refer to the probability (*likelihood*) of the impact (*consequence*) occurring if a species is stocked in a waterbody based on attributes of the ecology of the species and the environment into which the species is being released.

Table 9 Example of a risk matrix for use in stocking

LIKELIHOOD	CONSEQUENCE				
	Insignificant	Minor	Moderate	Major	Significant
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost certain	N	M	E	E	E

Note: N = negligible; L = low, M = moderate; H = high; E = extreme

The *likelihood* of an event occurring according to the ratings in Table 9 is defined in Table 10.

Table 10 Likelihood rating

Likelihood	Description	%
Rare	Event will only occur in exceptional circumstances	<5
Unlikely	Event could occur but not expected	25
Possible	Event could occur	50
Likely	Event will probably occur in most circumstances	75
Almost certain	Event is expected to occur in most circumstances	>95

The *consequence* refers to the scale of the potential impacts based on knowledge of ecological interactions between the species to be stocked and those in the receiving waterbody. The ratings are, where possible, based on scientific evidence; otherwise expert judgment is required. The latter introduces a level of uncertainty into the assessment procedure that must be accounted for. As a consequence, there is a need to introduce a further layer to the matrix that accounts for uncertainty in the knowledge base or processes in nature (Table 11).

Where knowledge is deficient or uncertainty high, the precautionary principle should apply to prevent unforeseen impacts. It should also be recognized that the risks associated with stocking can be reduced by mitigation actions such as quarantining or stocking with reproductively sterile fishes (e.g. triploids). If applied, these procedures should be weighted into the overall assessment.

Table 11 Weighting to account for uncertainty about potential risks from stocking

Degree of certainty	Description	Weighting
High	Well-established knowledge from existing stocking programmes	0.5
Medium	Knowledge from limited stocking programmes supported by documented ecological and environmental studies	1.0
Low	Little or no previous knowledge from stocking programmes and little or no supporting ecological and environmental studies	3.0

Note: Weightings are arbitrarily defined in this example and should be set to reflect the scale of risk likely to accrue from the event.

6.3 Fish introductions and the associated risk

The introduction of fish species, especially into fresh waters, is commonplace around the world with a list of 1 673 introductions of 291 species into 148 countries by 1992.[138] Since that date some 1 000 more introductions into inland and marine environments have been reported.[139] An overview of the main species introduced into the Asian region[140] includes species from both within the region and from other parts of the world (Table 12).

Table 12 Species used directly in stocking practices and those that are directly and or indirectly impacted through inland fisheries enhancement programmes/activities

Species	BGD	CHN	IND	INS	MYA	NEP	ROK	SRL	THA	VIE
Anabas testudineus	+		+	+						+
Anguilla japonicus		+					+			
Hypophthalmicthys nobilis	+*	+	+*		+*	+*		+*	+*	+*
Barbonymus gonionotus	+			+*					+	
Clarias gariepinus				+					+	
Carassius auratus	+*	+	+		+*	+*	+			+*
Catla catla	+		+		+	+		+*	+*	+*
Chana striata				+	+					+
Chitala chitala				+	+					
Cirrhinus mrigala	+		+		+	+		+*	+*	+*
Ctenopharyndogon idellus	+*	+	+*	+*	+*	+*		+*	+*	+*
Cyprinus carpio	+*	+	+*	+*	+*	+*	+	+*	+*	+*
Eriocheir sinensis		+					+			
Heteropneustes fossilis	+			+	+					
Hypophthalmichtys molitrix	+*	+	+*	+*	+*	+*		+*	+*	+*
Labeo rohita	+		+		+	+		+*	+*	+*
Leptobarbus hoevenii				+					+	
Macrobrachium rosenbergii	+		+	+	+			+	+	
Mastacembelus armatus	+		+		+					
Morulius chrysophekadion				+*					+	
Mylopharyngodon piceus		+								+
Neosalanx spp.		+**								+*
Oncorhynchus mykiss#						+				+
Oreochromis mossambicus#	+		+	+	+			+	+	
Oreochromis niloticus#	+		+	+	+	+		+	+	+

[138] Welcomme (1992)
[139] Welcomme (1996)
[140] Miao *et al.* (2010)

Table 12 *(continued)*

Species	BGD	CHN	IND	INS	MYA	NEP	ROK	SRL	THA	VIE
Osteochilus hasselti				+					+	
Pangasianodon				+*	+				+	
Probarbus jullieni				+*					+	
Salmo gairdneri#		+		+					+	+
Salmo salar#		+		+						
Salmo trutta#		+		+					+	+
Salmo richardsonii#					+	+				
Tor douroensis			+	+						
Tor putitora			+			+				
Tor tor			+		+	+				
Trichogaster pectoralis				+*	+*				+	
Trionyx sinensis		+					+			

Notes: Recorded for at least 2 countries (Miao *et al.* 2010)# alien to the region; * alien to the country; ** translocated across watersheds within a country for stocking; BGD = Bangladesh; CHN = PR China; IND = India; INS = Indonesia; MYA = Myanmar; NEP = Nepal; ROK = Republic of Korea; SRL = Sri Lanka; THA = Thailand; VIE = Viet Nam

The frequency of introductions into individual countries varies considerably. The countries that have introduced the greatest number of species tend to be characterized by tropical and eastern location or a degree of isolation from diversity hotspots, e.g. island or peninsular countries, which tend to have impoverished fish fauna. It should be noted that data on introductions only provide a basic picture of the scale and diversity of introductions and translocations. Records, particularly of translocations, are inadequate considering the importance of the activity over the past century.

The principal reasons for introductions are aquaculture (19.8 percent) and improvement of wild stocks (46.6 percent). Introductions for aquaculture have always been relatively important but came to the fore in the late 1900s with the development of salmonid culture and again in the 1960s and 1970s with the emphasis on tilapia and Chinese carp, the latter especially in Asia. Both have led to a high number of escapes from aquaculture installations and the establishment of natural breeding populations.

Improvements of wild stocks were primarily to establish new fisheries (37.7 percent) or enhance existing fisheries (5.4 percent). These have been both for commercial and recreational development as demand for fishery products and recreational access has increased.

Perhaps the category that causes greatest concern is accidental introductions. Nearly 8 percent of introductions are accredited to this mode. Although not specified, escape from aquaculture installations is probably a main cause and this in turn has led to dispersion. With the extensive development of intercatchment transfers of water resources that now takes place, it is inevitable that dispersion of species by this mechanism will increase in the future.

Accidental introductions alongside other species being deliberately imported or release of bait species are problematic situations. More recently, introductions have taken place to control unwanted organisms, especially mosquito fish *Gambusia affinis* for mosquito control, grass carp *Ctenopharyngodon idella* for macrophyte control and silver carp *Hypophthalmichthys molitrix* for controlling phytoplankton blooms.

Although these introductions appear to have been highly successful, particularly relative to more costly and environmentally unacceptable alternatives such as insecticides and herbicides, the impact on the recipient ecosystems has yet to be fully evaluated.

6.4 Use a precautionary approach to stocking

It is recommended that the precautionary approach should be adopted with regard to the stocking and introduction of species. It is further recommended that a strategic planning approach to stocking is adopted, using an approach similar to that provided in these guidelines.

This draws the attention of the fishery managers and owners to the many problems that must be resolved within a wider fisheries sector context before stocking programmes are likely to achieve their objectives. As part of this approach, a number of aspects should be considered at an early stage and these are listed in Table 13.

Table 13 Precautionary considerations prior to stocking

Whenever stocking or introduction of fishes is being considered, the aims and specific objectives of the exercise must be clearly defined and adhered to. The potential economic and environmental advantages should also be demonstrated, although it is recognized that in some situations (e.g. applications to stock or introduce fishes for conservation purposes) there may be no economic imperative. These should be matched against the disadvantages or problems that may ensue
Before stocking programmes are undertaken a thorough evaluation of the reasons for the action should be examined. Alternative approaches to stocking should be considered/discounted (e.g. habitat improvements or better fisheries management).
If it is possible to remove or minimize the causes of declines in fisheries, this course of action should be taken, such that the fishery may then recover without stocking. Habitat improvement is the most desirable alternative because it should lead to long-term sustainable improvements with minimal deleterious ecological impacts.
The wider issues and constraints that are likely to affect the long-term success of stocking programmes should be reviewed and considered in the design of stocking projects.
Stocking activities should be considered mainly for systems that have been altered by human activity. For example, where original fish communities have been disrupted or eliminated and there is no possibility for restoration of the habitats and enhancement of the community based on residual or relict stocks.
When evaluating stocking as a possible management tool, the relative benefits and costs of all options should be considered. The "do nothing" option should not be disregarded but should be considered as fully as any of the other options under discussion, despite possible public pressure to stock
Regulatory bodies must consider the potential long-term implications of stocking activity on the ecosystem, and should not be guided solely by short-term economic gains. The entire catchment and any adjacent waterbodies must be taken into account when considering the proposals.
The potential for proposed stocking programmes to introduce new parasites or diseases into recipient systems should be assessed through risk assessment protocols. This should also take into account the current capacity to detect, manage or control aquatic disease to minimize risks of transmission
The strategy for any programme of stocking, translocation or introduction should be carefully tailored to suit the species in question. This should take into account its entire suite of ecological prerequisites, so as to maximize the chances of success.

Table 13 *(continued)*

The potential adverse impacts of stocking in terms of environmental, genetic and ecological interactions should be considered fully. The precautionary principle should be adopted where foreseen adverse impacts cannot be mitigated, particularly in the case of designated natural heritage sites. Species that might be sensitive to the proposed introductions should be identified in the receiving rivers and waterbodies. Special consideration should be given to rare species or those most ecologically similar to the species proposed for introduction.
Introductions should be considered mainly for waterbodies that are sufficiently isolated to prevent the uncontrolled spread of introduced species. Since most problem waters are not isolated, the best alternative is to evaluate the potential effects of introductions on all connected waters, no matter how distant. Nearby unconnected waters should also be evaluated, as they will be at increased risk of illegal fish transfers.
Significant new stockings or introductions should be evaluated by an independent review. Ideally, this is a panel of scientists familiar with ecological principles and aquatic systems. It is important not to be hasty with introductions, as most effects are irreversible.
All projects should have in place the methodology to enable adequate monitoring of progress and, ultimately, evaluation of success or failure. This should include a mechanism of disseminating the outcomes to minimize the risks of any unforeseen adverse effects in future exercises.
A series of guidelines should be produced for all species that are stocked or introduced. These guidelines should clearly define the most effective protocol for deciding whether or not stocking should take place, how it should be implemented and the potential impacts of such activities.

Note: Expanded from Li and Moyle (1993) and Cowx and Godkin (1999).

7 RE-EVALUATION OF THE MANAGEMENT OPTIONS (STEP 4)

Once the steps 1 to 3 are concluded, it is time to re-evaluate the options for stocking and whether to proceed. The ideal stocking strategy will:

- clearly meet the identified policy objectives;
- be environmentally and socially responsible;
- be cost-effective;
- be practical/feasible to implement; and
- have a reasonable likelihood of success.

7.1 A decision tool for stocking

To support this decision, a decision support tool is presented in Figure 4. This allows evidence-based decision-making for stocking proposals and identifies the different needs for information and/or data collection and analysis that are required to support such decisions. This decision support framework presents critical decision levels with some relevant questions and is presented in Figure 5. Details regarding each box are provided in the following text.

7.2 Decision box 1: Review of management policy

The first step when considering any stock improvement activity must be to ensure proper clarification of the management policy and objectives. It is only then that the project proposal can be properly formulated to achieve the desired effects. Part of this exercise includes establishing whether the stock is below optimum production level or whether the quality of the stock (e.g. in terms of age or size distribution) could be improved. This requires not only an assessment of the status of existing stocks, but an appraisal of the condition of the waterbody, and the natural and artificial factors that may limit production.

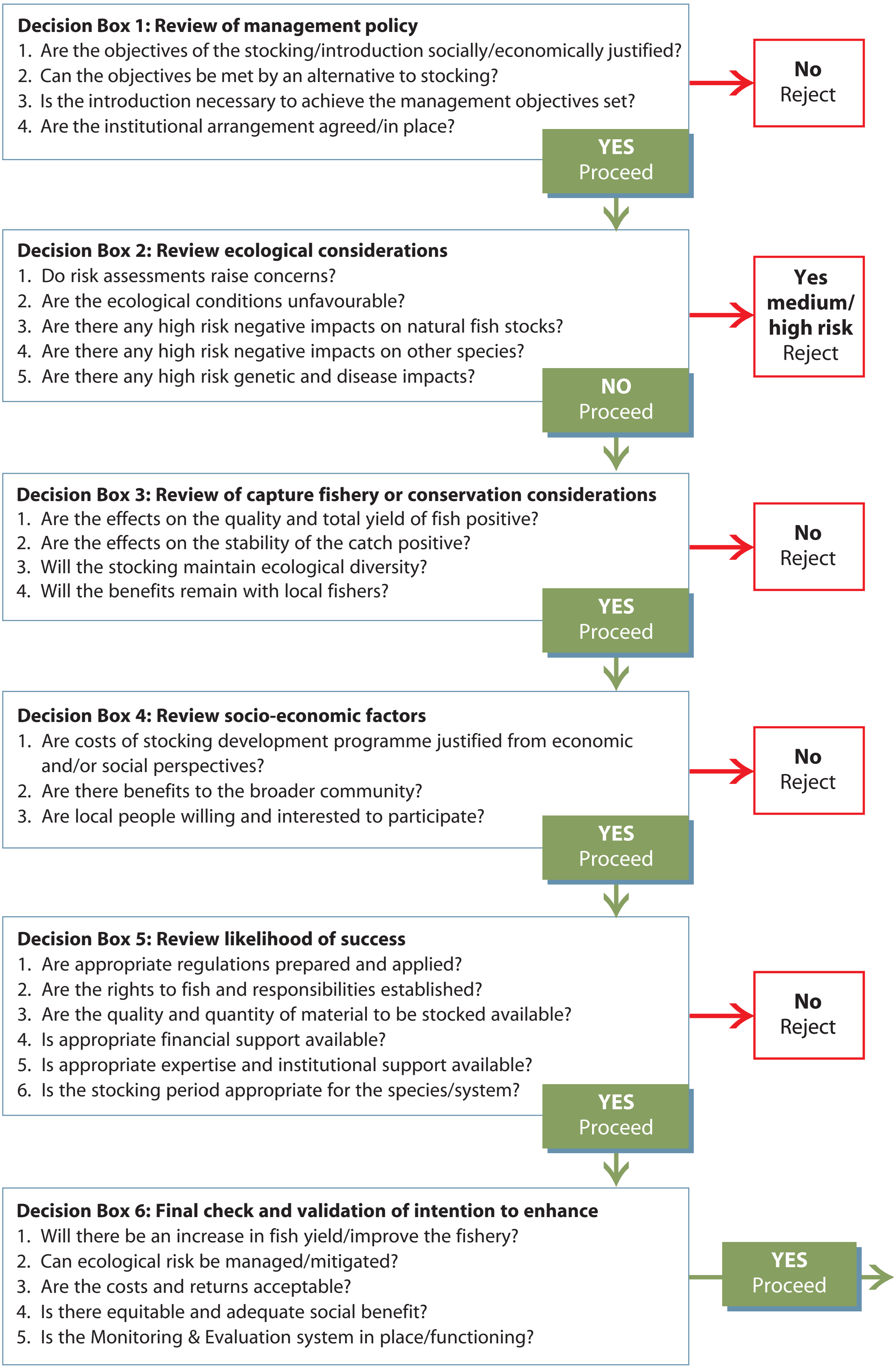
Where the recruitment of wild fishes has been reduced by anthropogenic disturbance or the fishery is underperforming, the requirement to protect the residual stocks from genetic impacts of non-native fish remains, and it is unlikely that such species will be the favoured tool for mitigation. In these scenarios, mitigation through habitat rehabilitation and associated short-term assisted breeding programmes of existing, indigenous stocks is likely to be the preferred option. The use of non-native fish species in this case may have negative effects on the mitigation activities.

The use of non-native fish species should be restricted to fishery enhancement scenarios with the objective of maintaining or enhancing the stocks of fish for capture rather than establishing new populations.

Where enhancement of the stocks is considered necessary, a number of approaches are available in addition to enhancement stocking: these should be explored first. There are a number of options available to improve fisheries that do not (negatively) impact on the environment or fisheries:

- Alter the ecosystem, to improve both the fisheries and the conditions for exploitation.
- Adopt traditional management measures that regulate catches and access to the fisheries, to manage exploitation pressure.

Of course, the introduction should be rejected if answers to the questions are unacceptable.



Note: Modified from Cowx (1998a).

Figure 5 Suggested protocol for evaluating a stocking programme to minimize the potential risk, maximize the potential benefit and monitor the success of the project.

Where there are economic or practical constraints preventing alternative strategies, enhancement stocking may be desirable to boost performance. Where the limiting factor(s) can be isolated, efforts should be made to resolve the problems before resorting to stocking. If remedial action cannot be taken, because it is either impractical or not cost effective, then mitigation stocking could be considered. This is unlikely to lead to a sustainable population, however, and fish may have to be stocked on a regular basis and appropriate risk assessment should be undertaken.

Remove or minimize the causes of declines in fisheries if possible and the fisheries may then recover without stocking. Habitat improvement is the most desirable option because it should lead to long-term sustainable improvements with minimal deleterious ecological impacts.

This approach can also be an efficient use of resources in the medium-to-long term because it may have greater long-term benefits than enhancement stocking and also other conservation and ecological benefits (e.g. improved primary or secondary production).

In cases where natural recovery may be ineffective because, for example, spawning stocks have been reduced to an apparently critically low level, restoration stocking may be appropriate to promote stock recruitment.

7.2.1 Decision box 2: Review ecological considerations

Before any stocking programme is implemented, a thorough assessment of the risks associated with the exercise must be undertaken as described in Section 2.4. This takes the form of a series of steps to review the possible ecological, genetic and disease interactions that may arise from the stocking or introduction.

ECOLOGICAL IMPACTS: Before a stocking (or introduction) is undertaken, the suitability of the recipient habitat should be assessed. Details of physico-chemical factors and environmental tolerances of the proposed species to be released should be included in the evaluation.

Unsuitability of the receiving water habitats may be grounds for rejecting the proposal.

If the proposal is to be implemented, the risks of ecological disruption must be assessed, together with levels of uncertainty. Issues to be examined include interactions through predation and competition, disruption of habitats, whether there will there be niche overlaps with native species and whether there will there be negative impacts on species of high commercial or conservation value. This would essentially provide an overview of the possible interactions among native and stocked/introduced species. If major gaps in knowledge emerge from the above exercise, further research on the system should be conducted.

This assessment is largely redundant where the species is being stocked to supplement existing stocks but may be of relevance where a species has been stocked previously.

GENETIC IMPACTS

Genetic impacts through hybridization, inbreeding and loss of genetic integrity can hamper the outcome of stocking programmes. Evidence suggests that stocking, especially of farm-reared fishes, is a threat to the genetic integrity of wild populations through reproductive interactions. The release of fishes should aim to minimize genetically based changes and to conserve genetic resources.

If there is a possibility of inbreeding, hybridization or loss of genetic integrity the programme should be rejected or procedures such as stocking with triploids should be adopted to minimize the risk.

DISEASES AND PARASITES

The acts of stocking and introduction, irrespective of whether they involve the transfer of pathogens, can elevate the risks of fish disease. Hence, it is equally important to identify the disease potential of stocks in the receiving waterbody and whether and how this might change as a result of stocking.

Minimizing the risks of disease and parasite transference is one of the main criteria that must be achieved to maximize benefits. Impact should be quantified by quantity of fish and monetary value then the decision-making authority can understand how important this point is. There is major concern over the spread of diseases and parasites through stocking, and there is a need to protect natural environments from unwanted pathogens. Stocking materials should be free of disease and parasites. All stocking material should preferably be from disease-free certified sources, although this is possibly overly optimistic, as it is unlikely that disease-free status is attainable. Nevertheless, fishes stocked into open waters should be checked for a range of parasites and symptoms of clinical disease (the protocol operates at a set level of confidence of detection).

The presence of any major pathogen or significant evidence of clinical disease are grounds for rejecting a proposed stocking operation.

In the absence of basic disease detection capacity, health checks or quarantine facilities, the precautionary approach is to reject the stocking proposal.

7.2.2 Decision box 3: Review of capture fishery or conservation considerations

Typically, the sorts risks described below should be identified during the risk assessment phase. However, not all outcomes can be predicted. Less tangible effects (e.g. impacts/effect on food webs and ecological niches) may not be picked up during a risk assessment and may only emerge during the evaluation phase of the stocking initiative.

The assumption of any stocking exercise is that the stocked fish will contribute to the fishery in a positive manner and increase the yield. Clearly, if this does not occur then the stocking activity needs to be re-evaluated and the technical aspects of the management strategy adjusted to correct the failing. This may be relatively simple in the case of high post-stocking mortality, where technical measures can be adjusted to improve survival.

If the situation cannot be corrected through modification of the stocking strategy, the stocking activity should be abandoned.

If the impacts on the ecological diversity are negative then the modification of the stocking strategy may be more complicated. This can arise from the high mortality of stocked fish as a result of natural predators. Alternatively, stocked fish may predate other wild fish, resulting in low yields. This situation is rather uncommon in Asian stocked fisheries, where the stocked species are almost universally omnivorous/herbivorous. There may still be issues with predation on eggs and larvae of other wild/non stocked species that can impact ecological diversity.

Changing the species stocked may reduce negative impacts on habitats or negative interactions with wild species. If such impacts as become apparent are significant and cannot be managed the stocking activity should be abandoned.

An important consideration of any stocking initiative is that it should ultimately benefit the primary stakeholders. In the case of most Asian fisheries, this is assumed to be those who are currently engaged in fishing. The stocked fish are intended to increase yields and available food to the broader community. In some cases, a stocking activity can increase the value and yield of the fishery to the point where an elite group or individual, take control of the fishery monopolizing the benefits. The result is marginalization or even displacement of the original fishers, who were the target of the initiative. This negative impact is seen in developing country contexts where weak governance and tenure rights can lead to this situation. If there is evidence of the displacement, marginalization or inequitable treatment of fishers, the stocking initiative will require significant reform. Typically this would involve allocation of user rights or tenure guarantees to the vulnerable fisher group.

If the reform cannot be undertaken or the impacts mitigated the stocking initiative should be abandoned.

7.2.3 Decision box 4: Review socio-economic cost and revenue factors

When assessing the viability of stocking programmes an evaluation of the most cost-effective options in relation to expected benefits should be undertaken. All too often the strategy is to make do with existing circumstances, whereas a little forward planning may improve the outcome considerably.

In any proposal, the overall costs and benefits of the stocking programme should be evaluated to ensure that the outcomes are justified in terms of benefits to the locality or region. The typical economic costs incurred are listed in Table 14.

Table 14 Typical economic costs for stocking programmes that need to be reviewed for inclusion in cost-benefit analysis

Fixed costs	Lease value
	Costs of physically modifying the environment (creation of bunds, embankments, creation of spawning and shelter habitats, construction of artificial reefs, etc.)
	Cost of physically intervening to maintain the environmental quality (e.g. draining reservoir, dredging)
	Labour costs involved in management
	Taxes and insurance
Preparation, stocking	Fertilizer, weed removal, liming, cost of removal of unwanted species
	Stocking materials (this often accounts for between 40 percent and 70 percent of total costs)
	Costs of genetic manipulation and genetic resource management will increase cost of stocking material (e.g. selective breeding, hybridization, polyploidization, gene transfer, or sex manipulation)
Production and management	Fertilization
	Feeding
	Patrolling/enforcement
	Energy costs (if any)
Harvesting	Draining
	Cost of harvesting

Economic analysis, coupled to an assessment of benefits/impacts (Table 15) is critical to ensure benefits accrue to the local economies commensurate with the risks to the environment. A simple assessment of this nature should also highlight stocking programmes that have little tangible benefit and so reduce the number of unnecessary stocking events.

Analysis of this type is critical because the cost of stocking may not result in the benefits expected, and in some cases lead to deterioration in the fishery, e.g. when the fishery is overstocked, growth rates and survival of the stocked material are compromised.

Calculating the costs of stocking any life stage should include identification of the stocking location and (often) specialist equipment and transport. Eggs and larvae are apparently the least expensive option, but there are doubts about cost-effectiveness because of the relatively high levels of mortality during these early life stages. Growth and mortality are key issues in estimating economic returns.

A simple economic assessment will also allow the rapid identification of stocking programmes that have few tangible benefits and facilitate the decision to abandon unnecessary stocking activities.

Table 15 Table of typical quantitative and qualitative benefits to be taken into account relating to the outcomes of stocking events

Prior to stocking	Before stocking baseline production yields/revenues
	Opportunity of employment
	Fishery status
Post stocking	Harvested yields
	Increased revenues
	Employment
Secondary impacts	Support to the fish farms producing stocking material
	Change of fishery status, e.g. supporting recreational and commercial fisheries
	Recreational benefit for people (income, employment).
	Conservation of endangered species
	Benefits to society by allowing alternative uses of water (e.g. hydro-electric generation, transportation)

7.2.4 Decision box 5: Review likelihood of success

Stocking is an important tool in the management of fisheries, but the feasibility or practicability of proposed stocking programmes must be assessed, commensurate with the size of the stocking programmes and/or the associated risks before they are allowed to go ahead. Assessments should be based on a brief study that examines whether the objectives and defined outcomes of the stocking programmes are achievable within socially acceptable, environmental, genetic and ecological levels of risk.

In essence, the proponents of stocking programmes should provide a summary report that includes basic information about the recipient waterbody, physico-chemical information about flash and normal flooding time, duration, water level, water and soil conditions, waterbody management system, inlet and outlet channels, fishermen access trends, fish community structure and abundance, fish migration routes and any conservation-related issues.

This information should be used to appraise the potential benefits and impacts and associated risks from stocking on the receiving ecosystem and associated biota. In cases where the potential risks and uncertainty about the impacts and benefits are high, an independent appraisal should be conducted. Much of the data can be provided in a generic form once the initial stocking or similar event has been appraised.

Generally, it would be expected that all stocking programmes should be economically viable and contribute to the well-being of the stocks. Unfortunately, financially driven enhancement programmes are rarely successful because the returns in terms of increased yield (revenue) do not usually cover the costs of the stocking programmes. The precautionary principle should be adopted if any adverse impacts are foreseen.

If the decision-making authority approves the proposal, an executive plan (working plan) should be produced to implement the enhancement programme.

All projects should have in place the methodology to enable adequate monitoring of progress and, ultimately, success or failure. This post-stocking appraisal should include a mechanism of disseminating the outcome to minimize the risks of any unforeseen adverse effects in future exercises.

7.2.5 Decision box 6: Final check and validation of intention to enhance

Stocking of fish is practised for many reasons and evaluated by different stakeholders in various ways. Generally, there has been a lack of objective criteria in defining what actually constitutes success, particularly in an economic context.

Several countries have included the enhancement of inland fisheries in their national plans and actively use stocking as a major management tool. The real costs and benefits of stocking, in economic, social, biological and environmental terms, are mostly unknown. Armed with such knowledge, and economic valuations of fisheries, fisheries managers will be in a stronger position to make informed decisions in the face of complex management objectives and strategies.

There is a need for comprehensive cost-benefit analyses of stocking operations, as well as other enhancement activities. Generally, stocking is perceived as being the least-cost option in comparison to habitat restoration schemes, which have been compared to motorway construction in terms of their cost per kilometre.

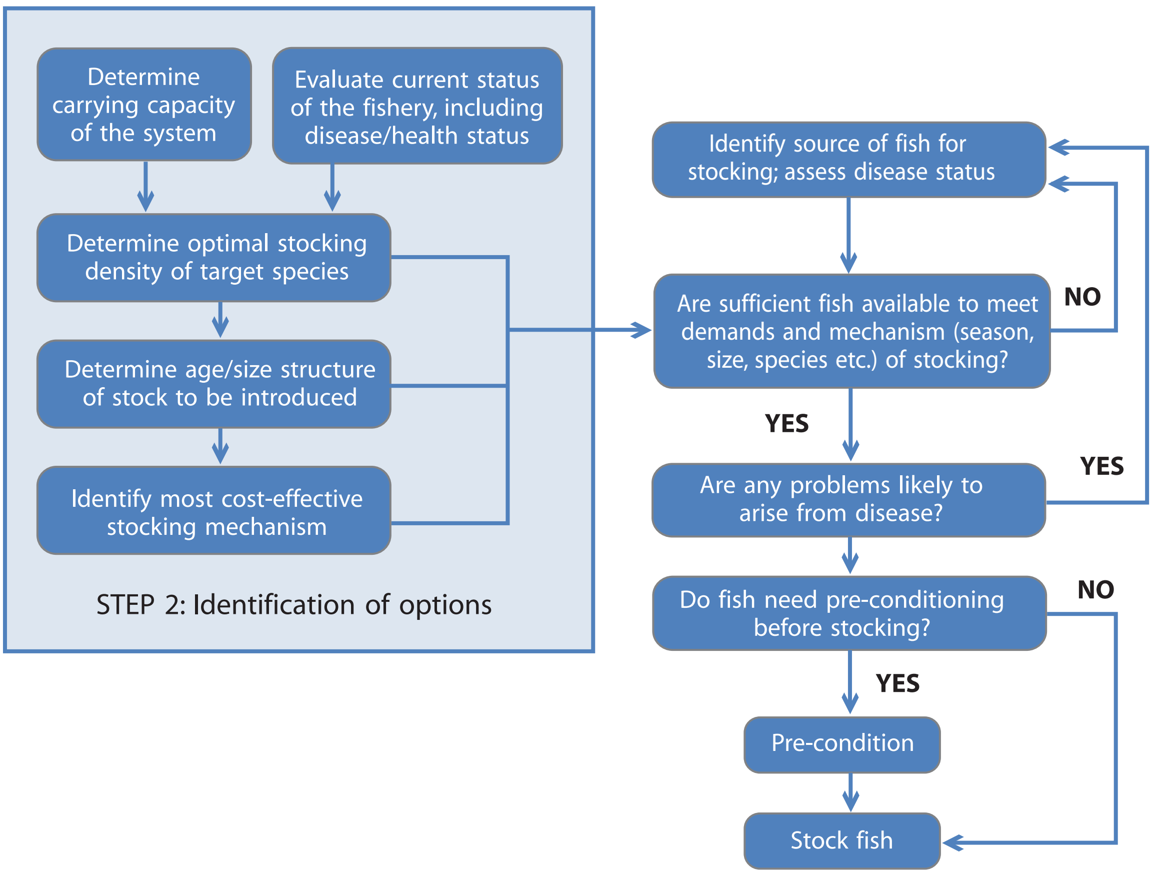
8 IMPLEMENTATION (STEP 6)

Guidelines for the act of stocking fish are available for many countries and focus on appropriate techniques to maximize post-stocking survival and to minimize the risks of disease. The issues that must be considered include:

- Source of fish
- Size of fish
- Stocking densities
- Species of fish
- Mechanisms and timing of release
- Pre-conditioning and acclimatization
- Handling and transportation.

All these aspects must be taken into account and documented at the planning stage of the exercise to maximize the benefits and minimize any potential risks. These are often species-specific or relate to particular types of waterbodies. Most of these planning aspects are addressed in Step 2. However, the sourcing of fish for stocking and the assurance of the health status and quality are essential aspects of this step. Transportation stresses and failure to acclimate at the point of stocking will all contribute to low survival and poor overall performance.

A number of important considerations that relate to the implementation of the stocking activity that need to be addressed to ensure successful stocking are detailed in Figure 6.



Note: Adapted from Cowx (1994b).

Figure 6 Flow chart illustrating the considerations that must be addressed when implementing fish stocking

8.1 Identify the source of fish for stocking

This is often the greatest challenge to a responsible and successful stocking initiative as the quantity and quality of fish to be stocked is highly dependent upon the hatcheries producing the fish for stocking. This is a typical bottleneck in developing countries and the result is that undersized, poor quality, poor health or inappropriate species of fish are stocked. Material for stocking comes from five main sources.

(i) Government hatcheries

These may be operated exclusively for production of stocking material. There may not be a programme for ensuring adequate genetic diversity of the fish for stocking. This is a particular issue when using indigenous species that may interact with wild stock.

(ii) Private hatcheries and farms

These may supply fish for stocking and for consumption. Again, the main purpose may be for aquaculture operations and the genetic diversity of the fish for stocking may be quite narrow.

(iii) Dedicated hatcheries/farms

These may be built to produce stocking material to compensate for human interference with the natural fishing production. These purpose-built operations ought to be designed to deliver the exact specifications of fish required for the stocking purpose. All too often, however, they are designed along the same lines as aquaculture hatcheries and have limited broodstock holding capacity and are unable to produce larger size fingerlings.

(iv) Transfer of stock cropped from one water body to another

This source of fish is usually from waterbodies that have an excessive stock produced deliberately or naturally and cropped as a management intervention. Some fish come from dewatering, fish rescues, change in the status of the fishery, maintenance of specialist fisheries or general movement of fish as commercial ventures. Although these are typically wild stock, there may be health issues related to disease, or stressors during capture and transport. Reconditioning or nursing before stocking may improve survival.

(v) Imported stock

A final source of stocking material is imports. There is a significant market for the import of specimen-sized fish to support specialist fisheries. This mode of supply is one of the root causes of the spread of parasites and disease in fisheries. Although the fish should be certified disease-free, veterinary inspection is weak and several potentially lethal pathogens have been introduced via this route.

8.2 Transport and transfer

Much of the success of a stocking initiative depends upon the quality of the fingerlings that are stocked. The quality of fish is related to the care in the hatchery, degree of acclimation and the amount of stress encountered during transport.

Dedicated packaging, transportation and release protocols should be developed for each specific stocking initiative.

Some basic guidance is provided in Table 16 below. Further information on the indicators of optimal conditions is provided in Table 20.

Table 16 Generic guidance on protocol for hatchery, packaging, transportation and release of fingerlings

Hatchery	The fish are well fed and have energy reserves
	The fish are free of parasites and major non-specific diseases of nutrition and water quality or pathogens specific to the species
	The physical shape and condition of the fish are good, there is no fin damage or scale loss
	Fingerlings show active swimming behaviour (not upside down or dying fish at the bottom of the tank)
	Acclimation (temperature, pH, or feed changes etc.) should be commenced several days prior to transportation
Packaging	The fish are starved before transport to reduce pollution of transport bags and reduce oxygen consumption
	Packaging should take place early in the morning, ideally at dawn (it is difficult to pack in the dark)
	The fish are packed at the correct density for their size. The density of fingerlings varies according to size – small fingerlings can be packed more densely. For long journeys or for larger fingerlings the densities should be reduced 3 cm fingerlings: 100–150/litre; 4 cm or 5 cm fingerlings: 50–70/litre
	The transportation container is aerated or has oxygen added (in the case of bags). The volume of water in the transport container should be sufficient for the fingerlings to be transported (see above) – Plastic bags: 1/3 water 2/3 oxygen (not compressed air) – Plastic bags are kept in styrofoam boxes during the whole of the transport
Transportation	Transportation should start as early in the morning as possible so as to take advantage of cool night/dawn
	Transport containers should be insulated and shaded. For short transport times to destination open containers can be placed under shaded transport
Release	Fish are acclimated to temperature and water quality of receiving waters
	Release strategy and location follows decisions made in Section 5.3.1 and 5.3.2
	Fingerlings are nursed/acclimated in hapas or other impoundments before release to main waterbody

9 MONITORING AND EVALUATION OF STOCKING (STEP 7)

Stocking is an important tool in the management of fisheries, whether for commercial, recreational or conservation purposes. However, the threats posed by fish stocking programmes, especially introductions, are particularly insidious because few management tools to overcome any adverse effects are available.[141] The expected outcome for particular stocking exercises should be compared with wider fisheries sector objectives and constraints that are likely to prevent a successful outcome should be considered in all appraisals.

9.1 All stocking initiatives should incorporate a post-stocking monitoring programme to measure impacts and outcomes

It is recommended that existing and proposed stocking programmes should be independently assessed to ensure that the wider environmental, ecological and socio-economic issues have been thoroughly reviewed.

Any measure of the success of a stocking programme will depend on the extent to which its objectives are realized. These may vary: for instance, when stocking commercial (capture) fisheries the usual measure is the extent to which the financial value of the catches is improved, whereas in recreational fisheries the criterion is a more elusive one of angler satisfaction.

Whichever criterion is used, data on the stocking programme, including economic costs and benefits, are needed. Post-stocking monitoring programmes should also include fish health monitoring when the fishes are captured and species-specific harvesting data recorded by number and weight (Cowx, 1998a).

After implementation, it is desirable to evaluate stocking programmes on the basis of ecological, economic, genetic, disease and parasite risks and social aspects. In this context, an evaluation plan, proportionate to the scale and potential impacts of the stocking programme should be prepared and executed. This should run over a period of three to five years at least, preferably longer where intensive stocking or predatory species are concerned, and should include technical, ecological, genetic and social considerations.

The long-term holistic approach will assist in identifying and addressing:

- impacts on the habitats (e.g. loss of aquatic vegetation, changes in the composition of aquatic vegetation, increases in dissolved solids and turbidity) of recipient ecosystems;
- impacts on the trophic dynamics of recipient ecosystems (e.g. changes in the quality and quantity of plankton communities, increases in single age groups of particular fish species, changes in the quality and quantity of benthic organisms);
- changes in the genetic integrity of stocked/resident fish species (e.g. the presence of hybrids, deformed fishes, fish maturing earlier or later than conspecifics in similar waterbodies, egg quality, survival of larvae and juveniles);
- impacts of latent disease and parasites that were not detected during quarantine;
- changes in species and catch composition;
- changes in growth performance of stocked/resident fish species;
- changes in production trends of stocked/resident fish species; and
- changes in the socio-economic conditions of people related to the fisheries.

141 See Britton *et al*. (2011)

This post-stocking appraisal should include a mechanism of disseminating the outcomes to highlight the risks of any unforeseen adverse effects in similar exercises.

9.2 Use holistic evaluation criteria

In order to ensure that the monitoring and evaluation of stocking is conducted holistically, there is a need for some clearly defined criteria and indicators to measure performance. Such criteria and indicators must be based on the objectives of the stocking, as determined in the earlier steps of the decision-making process. These are summarized in Table 17.

Table 17 Holistic criteria for the evaluation of stocking

Biological and environmental	**Technical/biological effectiveness**	Impacts on survival, production/yields
	Environmental impacts and/or benefits	Ecological effects Impacts on habitats, invasive species, disease Environmental externalities Impacts on target and non-target species
Social and economic	**Economic effectiveness and efficiency**	Cost recovery Financial sustainability Cost-benefit
	Social and livelihoods benefits and/or impacts	Impact on fisher incomes and livelihoods Influence on social cohesion
Governance	**Rights and equity**	Impacts on access to fishery, tenurial aspects Creation or resolution of conflicts
	Institutional sustainability/effectiveness	Sustainability of (institutional) arrangements Enforcement and compliance with harvest/management measures

Ideally, the criteria used would seek to evaluate the stocking across the range of issues that influence the outcomes of stocking actions.

Using a broad range of criteria also provides greater scope for the development of management solutions to problems and can assist in the development of mitigating actions or trade-offs when there is no direct solution.

More detailed evaluation criteria are elaborated in Table 18, which also provides suggestions for the type of indicator that could be used to evaluate performance under each of the criteria.

Table 18 Recommended criteria and associated indicators for the holistic evaluation of stocking

Biological and environmental criteria	**Criteria**	**Indicator(s)**
Technological effectiveness/ efficiency	Efficient use of natural productivity	Fish yield, fish size at harvest, recapture rates
	Minimized mortality at stocking	Post-release survival
	No significant genetic or health impacts	Genetic quality and health status of seed
Environmental impacts and/or benefits	Ecosystem services within target area maintained (e.g. food, water, energy) according to objectives	Provisioning, regulating, supporting and cultural ecosystem services indicators through measurement of changes to: – Physical habitat – Water quality – Trophic structure – Biodiversity
	Biodiversity not impacted negatively	Abundance of key species and habitat
	Surrounding ecosystem (external to target area) and watersheds not adversely impacted	Habitat disturbance Presence of undesirable species
Social and economic criteria	**Criteria**	**Indicator**
Economics and economic efficiency	Increased revenue from production, processing or distribution of target species (or from the whole fishery)	Improvement of household incomes;* related businesses/services; total value of the fishery
	Economic/financial sustainability** and reduced dependence on external financial support	Income or revenues meet the costs of stocking and are sufficient to sustain the stocking activity Change in level/regularity of financial support
	Positive economic impact within the broader community directly resulting from the fishery and related activities	Community infrastructure built by fishery or taxes or license fees collected from fishery Human development index in community
	Economic opportunities from existing ecosystem services are sustained or compensated	Value of appropriate ecosystem services
Social and livelihoods benefits and/ or impacts	Livelihoods of people in the community improved as a result of the stocking and related activities	Income from fishing activities Employment from fishing activities
	Livelihood options increased in target area	Time allotted to fishing and other activities (i.e. changes in labour patterns)
	Nutritional and food security increased in community	Fish consumption and nutritional status (e.g. stunting, growth rate)
	Community development and social cohesion increased	Development of social activities and community infrastructure Migration to/from community Community groups and fishing associations
	Women and marginalized and vulnerable groups engaged in stocking and related activities	Participation in stakeholder consultations and in production, harvest, processing, distribution and marketing activities
Governance criteria	**Criteria**	**Indicator**
Rights and equity	The distribution of benefits from the intervention are equitable considering multiple objectives	Benefits*** for individual/household for specified stakeholders and target beneficiaries Impacts on non-target beneficiaries
	Appropriate**** tenure/access ensured for resources (water, land etc.)	Access to resources (water, land etc.) for stakeholders Tenure arrangements, consideration of the impact of external factors

Table 18 *(continued)*

	Mechanism in place to reduce and resolve arising conflicts	Incidence/severity of conflicts Policy and legal frameworks for conflict resolution
	Recognition and respect of users' rights and rights of traditional users	Incidence of rights violations
Institutional sustainability	Coordinated institutional mechanism(s) between water management, environment agency and government arrangements/agencies responsible for assigning rights facilitates the establishment of responsible stocking initiatives	Institutional mechanism(s) or lack of coordination impedes development of legitimate stocking initiatives
	Fishery stakeholders empowered to lead management, monitoring and decision-making processes, leading to community management or co-management and consequent reliance on government institutional support for this	Fishery management groups Fishery co-management arrangements capable of developing regulations and implementing monitoring, control and surveillance (MCS)
	Effective enforcement and compliance with regulations	Incidence of non-compliance Effective management action taken in the case of non-compliance
	Stocking initiative is effectively integrated into the existing wider fishery and does not compromise effective fishery management and/or maintenance of habitat integrity	Impacts or conflicts in the wider fishery or environment resulting from the stocking activity Fishery management plan in place, with considerations for stocked fish

* Improvement in incomes assumes that incomes are equitably distributed and not subject to elite capture by a limited group.

** Note that economic sustainability and cost recovery may not be an objective in a rural development or livelihood support programme. Equally, a conservation objective may not have an economic objective as it is a public good. Sustained resourcing or financing may be secured via government support.

*** Benefits may be defined according to the system and context: quantitative (food, catch, financial, income, savings) or qualitative (livelihood opportunities, social capital).

**** Including women, and marginalized and vulnerable groups.

9.3 Use cost-benefit analysis

Stocking is generally regarded as being an effective management tool under the correct conditions, and indeed has proved effective in intensively managed fisheries in lakes and reservoirs. There is some dispute as to its effectiveness in running waters, particularly in large river systems, and also with regard to the most effective life history stages at which to stock.

Interrogation of the literature relating to stocking, however, indicates that evaluations of stocking programmes in inland waters are drawn from very few countries, most of these being developing nations with commercial and subsistence fishing practised on a large scale. Generally, there are few existing studies and those available concentrate mainly on the biological parameters and constraints of stocking, with evaluations of success being based around volume of stocking materials and *apparent* recapture rates.

Very little economic evaluation work has been undertaken and that which does exist is inclined towards a simplified account of costs such as the market value of the yield and costs of stocking material. Economic analysis that includes broader societal and environmental benefits and impacts is recommended.

Where economic analyses have been performed on stocking programmes, many were found to be economically unviable,[142] inconclusive[143] or did not fully account for all costs involved.[144] Indeed, several studies suggest that the maximum cost-benefits are derived when no stocking occurs.[145] This is largely because the costs of stocking are relatively high,[146] especially at the initial stage of any project,[147] for example to account for the costs of hatcheries.[148] In some cases, individual fish are valued in tens of dollars[149] up to hundreds of dollars each.[150]

Even in Asia, where stocking is considered cost-effective in culture-based fisheries in reservoirs and ox-bow lakes,[151] closer examination suggests this is not the case. For example, carp fisheries in Thai reservoirs based on heavy stocking are worth USD2 million each year, but the relative contribution of the stocked fish to the fishery has not yet been evaluated.[152] Only the chum salmon, and perhaps the red sea bream (*Pagrus major*) release programmes in Japan appear to have been economically successful, primarily because the cost of production is so low, although the salmon success may have resulted from improvements in oceanic conditions.[153]

Consequently, to be successful, stocking programmes to replenish freshwater (or marine) ecosystems must be driven by economics, i.e. the costs of rearing fish prior to release must be justified by the value of that fish in terms of return from the fishery.[154] A range of economic tools is now available to meet this need for cost-benefit analyses of any stocking project.[155]

Cost-benefit analyses and bio-economic modelling are also available to determine the most cost-effective numbers, stage and/or size of fish to be produced,[156] allowing the most cost-effective stocking programmes to be designed.[157] In reality, such evaluation should be as important in the decision-making process as biological and environmental considerations.

The move towards self-reliance raises the issue of cost-effectiveness of the stocking programme. Generally, it would be expected that all stocking programmes should be economically viable and contribute to the well-being of the stocks.[158]

Unfortunately, financially driven enhancement programmes are rarely successful because the returns in terms of increased yield (revenue) do not usually cover the costs of the stocking programmes. This is evident from the numerous stocking programmes that have been abandoned.[159] Perhaps the exception to this is put-and-take fisheries and intensively stocked sport fisheries where people pay high fees to guarantee to catch fish.

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142 Hoffmann (1991 and 1993)
143 Knapp (1999)
144 White *et al*., 1995
145 For example: Herrmann (1993)
146 Hilborn and Winton (1993); Bannister and Addison (1998); Hilborn (1998); Moksness *et al*. (1998); Arnason (2001)
147 Butcher *et al.* (2000)
148 Loneragan *et al*. (1998); Moksness *et al*. (1998); Arnason (2001)
149 Butcher *et al*. (2000)
150 Hilborn and Winton, (1993)
151 Welcomme and Bartley (1998b)
152 Welcomme and Bartley (1998a)
153 Bigler *et al*. (1996)
154 In the case of conservation, one might have to ascribe existence values to the fish.
155 For example: Herrmann (1993); Radtke and Davis (2000)
156 Fjälling and Fürst (1987); Miyakoshi *et al*. (2001)
157 For example: Kitada *et al*. (1992); Blaxter (2000)
158 See Langton and Wilson (1998); Welcomme (1998)
159 Cowx (1999)

9.4 Assess performance for several objectives using a success matrix

A stocking programme may have more than one objective and each of these objectives can be assessed using more than one indicator of success/failure. A "success/failure matrix" allows several objectives to be aligned according to the objectives of the stocking initiative (i.e. the fishery management plan).

In the examples provided in Table 19 below, the direction of change for a number of criteria is used to evaluate the success/failure of the intervention. Since there may be different primary objectives for stocking programmes the performance would be judged according to different criteria.

Table 19 Success/failure matrix for evaluating stocking activities with multiple objectives

	PERFORMANCE ACCORDING TO EVALUATION CRITERIA				
PRIMARY OBJECTIVE	**Economics**	**Institutional sustainability**	**Livelihoods**	**Environment**	**Technological effectiveness – efficiency**
Enhance food/fish production	+	=	=	=	+
Enhance/diversify livelihoods	+	=	+	=	+
Rehabilitate degraded systems	=	=	+	+	+
Conserve species or environment	=	=	=	+	+
Increase recreational opportunities	+	=	=	=	+

Legend: +: a positive impact/benefit is expected or necessary to achieve the primary objective; = no change/effect is expected. A negative rating in any criteria requires corrective action or mitigation.

There is a potential for the application of this "success/failure matrix" to the evaluation of fishery management plans that have multiple objectives.

This evaluation approach can support decision-making and the review of fishery management plans by indicating areas of weakness against priority management objectives. It also allows the identification of secondary issues that may be related to additional benefits or threats. Some indicators for determining optimal and sub-optimal performance are provided in Table 20.

Success is based on a positive result under the main criteria used to evaluate the intervention according to the primary objective. All other criteria ought to be unaffected or could also be positively impacted (which would indicate even greater success).

If any of the criteria is judged to have been negatively impacted, this would indicate a problem that required correction. A negative rating for a criterion that ought to be positive is an indication that the intervention has serious problems or has failed to meets its primary objective.

Negative impact on the other criteria may still indicate serious problems or the need for corrective action to mitigate the impact. There may be situations where several of the evaluation criteria are given negative ratings (failed) and/or the cost of assuring the improvement of failed criteria is too high or unrealistic. Under these circumstances, the recommended management action would be to phase out the stocking intervention and develop an alternative strategy aimed at achieving a similar outcome (e.g. other fishery management actions, habitat modification/rehabilitation or at restoring the system to a natural/initial state).

Table 20 A checklist of indicators for optimal and sub-optimal performance (biological and environmental criteria)

Biological and environmental criteria	Optimal conditions	Sub-optimal conditions
Technological efficiency	Risk based pre-evaluation of the activity Precautionary approach applied	No pre-evaluation of the activity Precautionary approach is not applied
	Optimal use of inputs within given constraints – Infrastructure and technology is tailored or fits the intended purpose – Seed for stocking is produced efficiently at appropriate cost	Sub-optimal use of inputs/lack cost-effectiveness – Inefficient use of infrastructure or over-capitalization, inappropriate placement of hatcheries/landing sites – High cost seed from inefficient production facilities
	Good fishing technology used by experienced fishers – Efficient gears targeted to stocked species – Stock is fished to intended level	Poor fishing technology and expertise – Lack of suitable gear to target stocked species – Overfishing and/or stock caught at appropriate size
Technological effectiveness	Environmentally suitable waterbodies selected – Waterbody characteristics fit for the intended purpose	Inappropriate waterbodies selected, with consequent failure to achieve objectives of stocking
	Stocking strategy developed to maximize the potential productivity of the waterbody – Carrying capacity known, may be based on yield models – Correct choice of species	Ad-hoc, unplanned stocking, waterbody carrying capacity unknown – Other activities impacting on waterbody cannot be controlled – Inefficient use of natural productivity
	Stocking takes place during the optimal season – Relating to weather/seasons – Water level, hydrology of the waterbody	Stocking was badly timed – Water levels wrong for habitat needs – System dries out too soon – Flooding or spillage lost stock
	Where relevant or feasible waterbody or habitat was prepared properly	Poor preparation led to predation or other impacts on survival of the stock
	Proper handling and transportation procedures were used	Stress, and damage to seed prior to release – Increased mortality post release as a result of prior handling
	Healthy (disease free) stock were introduced	Transmission of diseases, introduction of exotic parasites and pathogens
	Appropriate genetic stocks were introduced	Released stock inter-bred or introduced inappropriate genetic material to the system

Biological and environmental criteria	Optimal conditions	Sub-optimal conditions
	Immediate post stocking mortality was minimized – Acclimation of stock prior to release – Use of nursing pens/hapas prior to release – Optimal size at stocking (links to success post stocking), e.g. do not use fry and larvae – Correct habitat or location for release, to avoid immediate predation and maximize survival/feeding – Staggered stocking and multiple release locations to ensure distribution and survival	High-post stocking mortality – Poor/no acclimation – Seed too small – Inappropriate release locations – Single locations, single release
	Appropriate numbers released/stocked – In accordance with the size, type and productivity of the waterbody – Using appropriate stocking models for guidance	Inappropriate stocking levels reduce effectiveness – Overstocking leading to small sizes and slow growth – Understocking leading to low yield and inefficient use of the resources
Environmental impacts/ benefits	Ecosystem services known and valued either quantitatively or qualitatively	Ecosystem services not known and valued either quantitatively or qualitatively. The intervention has negative impact on other ecosystem services
	Impacts on biodiversity known, and considered acceptable with no unplanned changes in biodiversity	Impacts not known with decreased biodiversity or changes in species assemblage or structure
	Surrounding ecosystem (external to target area), watersheds, not adversely impacted	Surrounding ecosystem (external to target area), watersheds impacted

Table 20 A checklist of indicators for optimal and sub-optimal performance cont. (social and economic criteria)

Social and economic criteria	Optimal conditions	Sub-optimal conditions
Economics and economic efficiency	Cost recovery – catch/income revenue compensates cost of stocking (including costs of enhancement research and management costs) – sustained through license revenues/tax	Cost of stocking not returned, costs not recovered (see footnote **)
	Total value of production increases (more total catch)	Total value of production does not increase
	Total value of production of target species increases (more catch of target species)	Total value of production of target species does not increase
	More valuable marketable catch/species (size and species)	Lower value, less marketable species/catch
	Reduced household expenditure/costs for fish within community	Increase in price of fish excessive and people can't afford to buy fish as often as before
	Harvesting strategies avoid oversupply and consequent price drops Post-harvest or marketing innovations maintain price or increase marketability	Fish oversupply, gluts and price instability
	The total economic value of fishery increases (including also recreational fishing)	The total economic value of fishery decreases (or in some instances does not increase)
	The value of existing benefits from ecosystem services (e.g. wild fish harvesting, nutrition) maintained or compensated by economic revenue from target species	The value of benefits from ecosystem services are not maintained or compensated by economic revenue from target species Loss of economic opportunity resulting from impacts to ecosystems services arising from the stocking activity
	Fishery adds value to ecosystem services provided by waterbody	No value addition to ecosystem services Fishery water requirements add to overall water costs or restrict water availability Water storage for flood control reduces fishing efficiency
Social and livelihoods benefits and/or impacts	Stakeholders and key beneficiaries identified and engaged in the process	Only a sub-section of society engaged; rural poor, and/or women marginalized
	Communication mechanisms exist to facilitate community engagement	Communication only among wealthy or within a privileged sector
	Social acceptance of fishers as valuable sector of society	Fishers viewed as "foreign" and external to community and discriminated against
	IUU fishing reduced	IUU fishing prevalent because of lack of governance and enforcement
	Nutritional benefits from fishing and its contribution to food security increased in community	Nutritional benefits from fishing decreases leading to decreased food security

Table 20 A checklist of indicators for optimal and sub-optimal performance cont. (governance criteria)

Governance criteria	Optimal conditions	Sub-optimal conditions
Rights and equity	Mechanisms, agreements or instruments exist to ensure fair and equitable distribution to main target beneficiaries	Benefits distributed from the intervention usurped/monopolized by fraction of stakeholders (e.g. elite capture)
	Tenure arrangements appropriate and respected by community	The access to resources and the tenure arrangement are not appropriate or not respected
	Conflicts (originating from the intervention) are reduced and arising conflicts are resolved	Increase in conflicts that are not resolved
	User rights are enshrined in policy, law or traditional practice and are known and respected	The rights of certain individuals or groups have been violated User rights not well defined, not known and/or not respected
Institutional sustainability	Adequate institutional arrangements exist or established to allow regulation of use by, and flow of benefits to, the primary stakeholders	Institutional arrangements do not allow regulation of use by, and flow of benefits to, the primary stakeholder
	Increased empowerment of stakeholders in the decision-making, management and compliance arrangements of the stocking programme and fishery	Institutional and management regimes have continued over-reliance on government institutional support Institutional and management regimes vulnerable to inconsistent/ inadequate government support/policy
	Effective communication exists among water management, environment agency and agencies responsible for assigning rights, facilitates establishment of responsible stocking and enhancement initiatives, e.g. water allocation and water management	Poor communication and lack of coordinated mechanisms obstructs/ impedes the establishment of initiatives Enhancement initiative poorly integrated into broader water management frameworks resulting in negative impact on intervention (e.g. timing and volume of water)
	Fishery regulations are fair and equitable and well-known by stakeholders	Fishery regulations are unjust and/or not well known Ineffective enforcement and/or lack of compliance with regulations
	Fishery managers, groups responsible for stocking fish and hatchery operators have a forum for coordination and cooperation	Enhancement initiative poorly integrated into the production chain with no mechanism for coordination and cooperation

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ANNEX 1 – STOCKING IN THE LOWER MEKONG BASIN

The following reports are summarized from full papers submitted from the four riparian countries of the Lower Mekong Basin.

Cambodia[160]

This report is mainly a literature review. It attempts to put all together the available information from the stocking into the inland waters of Cambodia. Cambodian fisheries resources play a very important role in contributing to national food and nutritional security, national economy and people's livelihoods. In Cambodia, inland fisheries and aquatic animal species are under threat from habitat degradation and overexploitation. In many instances, the Fisheries Administration has attempted to bolster wild stock by releasing mature wild brood fishes and fingerlings, as well as crustaceans from hatcheries, into the wild. Fisheries restocking programmes have primarily fronted these attempts through the National Fish Day, stocking and releasing of brood fishes in open community areas and sanctuary zones, the stocking and release of tagged migratory fishes in the Mekong and Tonle Sap areas, the stocking of giant freshwater prawn, the release of endangered Canto's giant Mekong soft shell turtle, the development of the community fish refuges ponds, the application of culture-based fisheries and some trial stocking in reservoirs. In addition, a substantial number of endangered species recover programmes also rely on the release of broodstock fishes and hatchery reared individuals to ensure long-term population viability and enhancing inland fisheries production.

Despite the considerable fish stocking activities, the greatest benefit to the communities comes from the development of fish refuge ponds and the application of culture-based fisheries in small reservoirs. In addition, the Fisheries Administration is awaiting the outcomes of the first trial stocking of giant freshwater prawn in the flooded plain of the Tonle Sap river. The greatest concerns are the need to promote a responsible approach in stocking including using the optimal size of stocked individuals, the best species combination, stocking densities, time at release, genetic resources management, community participation, the advantages of using hatcheries and biodiversity issues.

Fisheries scientists have known about the behavioural deficit displayed by hatchery-reared fish and the resultant poor survival rate in the wild and their relative contribution, and it is clear that significant improvement could be made by rethinking the way in which hatchery fish are reared to the optimal size before being released. The focus of fisheries research must also shift from simple husbandry to improving both the genetics of broodstock management and post-release behavioural performance.

Apart from these, socio-economic dimensions are a major concern because enhancement of waterbodies is mostly in rural settings catering to rural populations by providing an affordable source of protein and household income in general. The economic viability and value of stocking practices have yet to be demonstrated properly and the fisheries of such waterbodies, which are dependent on naturally recruited stocks, need to be examined and the optimal stocking practices elucidated.

The effect of stocking on biodiversity is a major cause of concern because of the appearance of some exotic species in Cambodia's inland waters. In this context the government has always encouraged the use of indigenous species. More studies should be undertaken to evaluate the current situation so that remedial steps can be taken without causing serious harm to stocking practice.

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[160] Prepared by Sam Nuov

In summary the issues that need to be addressed are:

a) lack of a clear fisheries management perspective;
b) fishery stock assessments and modelling are integral to exploring the potential of stocking, but are found lacking in most stocking efforts;
c) establishing an institutional framework for enhancements is largely ignored;
d) involvement of stakeholders in planning and execution of stocking programmes is key from the start, but is rarely an integral part; and
e) adaptive management of fisheries is not well integrated into enhancement plans.

Lao PDR[161]

Fish resources from the inland waters of Lao PDR play an important role in providing food for the people in general and income for rural people in particular. Fish supply comes from a variety of waterbodies such as the Mekong river, tributaries, streams, man-made reservoirs (hydropower and irrigation reservoirs), natural ponds, swamps, rice fields and manmade ponds. Until recently, capture fishery production was predominant in rural areas where people rely on fish catches from the wild, which was about 62 percent of the country's total fish production (DLF, 2007). In parallel with the growing population, fish marketing has led to an increased demand for fish. Stocking has been carried out in Lao PDR for many decades to increase inland fisheries production in the natural waters. It is usually done on Lao PDR's national fish releasing day, which is mentioned in the Lao Fisheries Law.

Stocking enhancement is mainly to maintain the fish productivity or to maintain a stable catch, especially for capture-based fisheries. Seven native and seven non-native fish species are preferred for release (Table A1) but the Department of Livestock and Fishery policy requires that only native species can be released into natural waters such as rivers and wetlands and non-native species must only be released/stocked into enclosed waterbodies such as reservoirs, manmade ponds and community fish ponds. Most of the seed supply of non-native species comes from private farms and government fish stations, whereas seed of indigenous fish species mainly comes from government fish stations because of difficulties in producing seed of indigenous species.

The number of fish stocked in the waterbody can be many million each year (30.242 million in 2014, DLF 2014) for the whole country. The main native species stocked is *Barbonymus gonionotus,* which is released into open waterbodies (rivers, swamps, reservoirs, manmade ponds). This species can potentially be produced by both the private sector and government fish stations. Grass carp is the most popular non-native species stocked as it is well adapted to the reservoir environment, especially small-sized reservoirs and grows well in manmade ponds in rural areas.

Table A1 Species preferred for stocking in Lao PDR waterbodies

No.	Native species		Non-native species	
1	Big head catfish	*Clarias macrocephalus*	*Bighead carp*	*Aristichthys nobilis*
2	Sickle fin barb	*Puntioplites falcifer*	*Silver carp*	*Hypophthalmichthys molitrix*
3	Small scale mud carp	*Cirrhinus microlepis*	*Grass carp*	*Ctenopharyngodon idella*
4	Mud carp	*Cirrhinus molitorella*	*Mrigal*	*Cirrhinus mrigala*
5	Black sharkminnow	*Morulius chrysophekadion*	*Nile tilapia*	*Oreochromis niloticus*
6	Giant gouramy	*Osphronemus exodon*	*Rohu*	*Labeo rohita*
7	Thai silver barb	*Barbonymus gonionotus*	*Common carp*	*Cyprinus carpio*

[161] Prepared by Sinthavong Viravong, LARReC, Lao PDR

Thailand[162]

Thai people have long exploited fish as a cheap protein food. Fish was freely harvested from natural waters when the fisheries resources were abundant and the human population was small. Fisheries productive areas can be classified as: 1) rivers and canals; 2) swamps and lakes; 3) large reservoirs; and 4) small waterbodies. Country development coupled with rapid population growth has resulted in habitat alteration and depletion of fisheries resources. Aquaculture development can produce food fish to support the increased demand to some extent. Wild capture fisheries, however, still maintain their crucial function in producing food fish to support the rural poor.

Fisheries stocking can be achieved through traditional law enforcement, habitat rehabilitation and fish stocking. The latter is the most popular approach widely used for stocking. Aquatic animal stocking in general has two main objectives, namely conservation and production enhancement, and a variety of agencies is involved. The Department of Fisheries (DoF), the Tambol Administration Organization, provincial agencies, the Electricity Generating Authority of Thailand, and other private sector groups implement stocking programmes.

DoF is the fisheries competent authority, responsible for fisheries production enhancement. They adequately supply the local demand and also export for income generation. The Fisheries Act B.E. 2490 (1947) is the most important tool used to administer and manage sustainable fisheries production. Alongside law enforcement, aquatic animal stocking is implemented under stocking projects such as: 1) village fisheries projects; 2) school fisheries projects; 3) *bamrung phan pla pracha-arsa* projects (participatory voluntary fish stocking projects); 4) small waterbodies rehabilitation for fisheries projects; 5) large waterbodies fisheries development projects; and 6) seed production for stocking.

Stocking is more intensified when fisheries stations are able to produce large amounts of fish seed. Under DoF stocking programmes, a total of more than 1 333 million fingerlings of 59 aquatic animal species were stocked into natural waters in 2013. Out of the 59 species stocked, 53 species were freshwater fish, 6 were frogs and the freshwater giant prawn.

DoF has followed up and assessed the impact of stocking programmes since 1985. Positive impacts were apparently found with freshwater giant prawn stocking. The recapture rate of this species was 3 percent with a more than sixfold increase in the rate of return on investment. Recapture rate of stocked fish is five to ten percent with a total production of 20 000 tonnes and valued at about USD30 million.

Stocking can be achieved through a number of approaches depending on conditions of the particular water. Law enforcement on illegal fishing is an important lesson learnt in the Yom river basin; stocking large numbers of freshwater giant prawn has been successful at the Pak Mun reservoir; and community-based fisheries management has been effective at the Ubol Ratana reservoir. These are important stocking lessons learnt in Thailand.

Fisheries production, particularly capture production, varies depending on many challenges including habitat alteration, overfishing, genetic alteration, outdated fisheries act and climate change. Deterioration of capture production will definitely adversely impact on the livelihoods of those entirely reliant on the resource. Stocking by various approaches will be effective only when all challenges concerned are taken into account and properly managed.

[162] Prepared by Suchart Ingthamjitr and Boonsong Sricharoendham, consultants, Bangkok, Thailand

Viet Nam[163]

In Viet Nam, stocking began in the 1960s and was concentrated mainly on reservoir fisheries. As of 2008, there were about 1 055 reservoirs with a total area about 332 190 ha with potential for aquaculture in Viet Nam. After impoundment, most reservoirs in Viet Nam were stocked with fingerlings but only a few have been successful. The return rate from stocking has been from two to ten percent of total stocked fingerlings. Nowadays, aquaculture is implemented in more than 40 percent of the total reservoir area, mainly in small and medium-sized reservoirs. The major species stocked include silver, bighead, grass, and common carps, tilapia, and Indian carp. In principle, the stocked fish depend on natural food.

At present, reservoir fisheries management systems in Viet Nam are of three main types, namely state-controlled management, community management and private control. The major gears used include gillnets, liftnets, lighted liftnets, integrated nets, castnets, longlines, and seines. Reported yields from reservoirs range from 20 to 700 $kg.ha^{-1}.yr^{-1}$.

In Viet Nam, "The national plan for reservoir fisheries towards 2020" was approved in 2013, and included a stocking strategy for reservoirs. However, the official guidelines for stocking have not been published yet. Some policies for reservoir fisheries have been applied but the results have not met expectations. In recent years, the central government has not invested much in reservoir fisheries, so they tend to be underdeveloped. However, some particular reservoirs have had successful stocking projects, including Ajun Hạ (3 700 ha – Gia Lai province), Easoup (240 ha – Daklak province), Eakao (210 ha – Dak Lak province), Nui Coc (2 500 ha – Thai Nguyen province).

[163] Prepared by Phuc Dinh Phan, Research Institute for Aquaculture No. 3

PAPER 2: Alternative strategies for enhancement of fish stocks

Robin Welcomme, Simon Funge-Smith, Ashley Halls and Ian Cowx

CONTENTS

1 INTRODUCTION

The intensive use of water and aquatic environments for human purposes other than fisheries is increasing the number of conflicts within the fisheries sector and between the fisheries sector and other users of the resources. The cost-benefit resolutions to such conflicts are rarely explored, but are crucial to future management decisions regarding mitigation of environmental impacts and fisheries practices such as stocking.

Rehabilitation and mitigation are expensive in terms of manpower, funds or space and should be considered in the long term as part of a holistic management strategy for individual rivers, lakes or river basins. Unfortunately, formal and informal mechanisms needed for such resolutions are rare, and the basic data required to reach conclusions are all too frequently lacking.

Stocking and culture-based fisheries are valid management practices for compensating for shortfalls in catch in overfished systems or those damaged by changes to the environment caused by other users of the resource. Stocking may also achieve higher levels of output than fisheries that are based on wild stocks alone.

The current trend in stocking of open waters in Asia tends to be pursued uncritically with limited evaluation of its impact, both in terms of cost-effectiveness, environmental consequences and social impact.

A hectare of land under aquaculture generates at least 43 percent higher income than a hectare of land under crop cultivation.[1] Consequently the importance of stocking is growing and stakeholders are exploring alternative approaches to enhancing the productivity of stocking.

Retaining natural productivity and population structure, as well as maximizing yields of stocked species may require investment in rehabilitation or mitigation to counter the effect of environmental degradation.

Even taking into account the costs of such enterprises, critical evaluation may well show that careful management of the natural environment through rehabilitation and mitigation techniques may be a more viable option in sustaining fish production from river and reservoir systems than stocking.

This review examines some of the environmental factors that are involved in the process of repetitive stocking and its success or failure, as well as alternative approaches to sustaining inland fisheries yields.

1.1 What is stocking and what is its purpose?

Stocking is the addition of externally derived fish to a waterbody for the supposed improvement of the fishery or its conservation status. The objectives of this stocking are various, ranging from enhanced food production, income generation, rehabilitation or conservation and recreation.

Stocking is an increasingly common practice for managing inland, brackish and some coastal fisheries. The practice of stocking fisheries is often undertaken uncritically, with little attempt to evaluate its effectiveness socially, economically or ecologically. There are also varying objectives and methods for stocking.

[1] Hasan and Taklukder (2004)

1.1.1 Occasional stocking of fish to restore or develop a fishery

The original source of stocking material may be from another fishery location, or may be produced in a hatchery. The stocked fish are expected to become breeding stock and the fishery is sustained by natural recruitment of the stocked fish. This is typically referred to as "stock enhancement". It is typically used to rehabilitate or develop a fishery, or to re-introduce or conserve certain species.

1.1.2 Repeated stocking of a fishery using fish that are produced in a hatchery

Repeated stocking of fish into a waterbody using fish produced in a fish hatchery is a specific form of stock enhancement, referred to as culture-based fisheries. Most culture-based fisheries are typically managed with the primary objective of increasing yields of fish for consumption. There are two principal objectives for repetitive stocking of fish that are found throughout the Asian region:

1. stocking to supplement existing wild stocks to increase productivity; and
2. stocking of waterbodies that are recruitment-limited.

The stocked fish are not expected to provide a sustainably reproducing population. This is typically because the ecology of the waterbody is unsuitable (e.g. incorrect environmental spawning-triggers, lack of water flow, lack of breeding substrates) for breeding of native species. This is common in man-made reservoirs on rivers that no longer have habitats suitable for many of the original riverine species and on dammed rivers where migratory stocks are barred from longitudinal movements.

It may also be because the new species stocked does not form a breeding population. Examples of this are the Indian or Chinese carp and several other commonly cultured species that do not breed effectively in static waters.

Another reason for repeated stocking (especially in small waterbodies) is that the body is drained down regularly because of seasonal drying out or because the waterbody has another function such as an irrigation reservoir.

Furthermore, intensive fishery management of the floodplain by stocking is gaining in popularity in parts of the region. Usually the channel connecting a waterbody to the main river channels is closed, isolating the fish stocks and providing an opportunity for aquaculture type management regimes involving inputs of feed and perhaps fertilizer.[2]

A final reason is that the fish stock in the waterbody is fished to a level that it is not capable of providing adequate recruits to sustain the fishery.

1.2 Does stocking necessarily mean more fish production?

There is often a presumption that low yield in a fishery is the result of insufficient fish, and that adding more fish will increase that yield. This often leads to the promotion of stocking as a means to increase the yield. This assumes that the fishery is recruitment limited (either because of overfishing of broodstock or because fish cannot breed effectively in that waterbody) and that the fish that are stocked will survive to make an appreciable positive impact on the overall yield.

What is frequently overlooked, is that environmental conditions may be more important limitations to the productivity of fish or shellfish stocks than mismanagement of the fishery. In such cases, simply stocking with additional material may not be the most effective strategy and environmental manipulation or management may be more appropriate.

[2] Mustafa and Brooks (2009)

Despite annual fish production being significantly higher for intensive floodplain aquaculture systems, annual net economic benefit per hectare was found to be lower than semi-closed waterbodies (a lake-like wetlands with static water). Lower stocking densities and net income per kg of product were also found to be more effective for semi-closed water bodies.

In situations where a management goal is to increase production significantly beyond what is naturally possible in a waterbody, some modification of the environment is typically required to achieve this.

1.3 Environment has a strong influence on the suitability of species for stocking

The fish species inhabiting the rivers of South Asia and Southeast Asia can be divided into numerous guilds depending on their behaviour and habitat selection.[3] Commonly, these guilds are reduced to three main groups for management:

"Black fish": these represent a group of species, usually relatively small, that inhabit permanent floodplain waterbodies. They migrate little beyond their native waters and are typically resistant to waters with low levels of dissolved oxygen, high temperature fluctuation and high nutrient contents. They are, however, extremely vulnerable to human interventions that dry the floodplain and/or remove dry season refuges. Several species are suitable for culture-based fisheries in poor quality static waters and rice fields, e.g. climbing perch, snakeskin gourami, other gouramis, *Clarias spp.* catfish, snakehead species.

"White fish": these are a wide range of species that are long distance migrants between the main river channels and floodplains. They generally spawn at upstream sites in the main river or tributary channels and often have drifting larvae and fry that later occupy the floodplains during high waters for feeding and growth. They are generally sensitive to poor water conditions including low dissolved oxygen and high nutrient loadings. Because of this sensitivity, and their need to migrate, many of these species are not suitable for stocking in the shallow, static waterbodies common in Asia. They may have some success in very large waterbodies, such as large reservoirs.

"Grey fish": these are intermediate forms, usually occupying main channel fringes and moving to floodplain waterbodies during the floods. Their behaviour and habitat requirements are very flexible with moderate to high tolerance of poor water quality. Their flexibility makes them natural colonizers in the face of major environmental alterations as well as the best subjects for stocking. Several species that have been introduced into the region for aquaculture and stocking belong to this category such as tilapias or the domesticated form of the common carp, which are highly tolerant of poor water quality. There are a number of other species that do well in larger waterbodies where conditions are more stable. These species are also commonly found in aquaculture – examples are Chinese and Indian carp, as well as some of the cyprinid species such as silver barb.

Other species: besides these three general categories of fish, there are other species that may be stocked to form freshwater culture-based fisheries. Possibly the best example is the freshwater prawn (*Macrobrachium rosenbergii*), which has been used in Thailand to enhance existing fisheries (e.g. Songkhla Lake) and to develop new culture-based fisheries (e.g. behind the dam in the Mun river).[4, 5] Their poor tolerance of low dissolved oxygen means that they do well in shallow lakes and rivers, but are less suitable for deep, stratified waters (e.g. large reservoirs).

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[3] Welcomme, Winemille and Cowx (2006)
[4] Sripatrprasite and Lin (2003)
[5] Choonapran *et al.* (2003), cited in De Silva and Funge-Smith (2005)

1.4 Stocking to supplement existing wild stocks to increase productivity

Stocking may be used to supplement existing wild stocks in naturally regulated waterbodies such as floodplain waterbodies, perennial natural lakes and floodplain rice fields. This form of stocking may not always be necessary in these types of waterbody, as the shortfalls in yield may be the result of reversible, human induced and adverse environmental conditions rather than poor fisheries management.

An important consideration is that if the limitation to the productivity is environmental, then stocking is unlikely to sustain an improved yield over what is currently naturally possible. In this situation a critical question must be asked as to whether stocking is a cost-effective solution or whether an alternative strategy to improve yield is required.

Rehabilitation, or mitigation to restore the environment and natural fish populations may be a more viable approach than stocking to sustain catches, where the primary objective is environmental improvement rather than increased yields.

Stocking is a legitimate mitigation strategy in situations where environmental conditions have been altered irreversibly by other human interventions. Examples of this are:

- large reservoirs with partial wild stocks recruitment;
- waterbodies where some wild stocks are unable to recruit because of barriers or unfavourable environmental conditions;
- waterbodies where natural habitat or environmental water regimes have been modified; and
- waterbodies where there is general, heavy fishing pressure.

Supplementing natural production through stocking has the advantage that it benefits from existing natural reproduction by the wild fish present, and enables additional productivity from stocked fish utilizing food niches that the native species are unable to fill.

It is important that, when using this strategy, the environment of the waterbody should be maintained as close to the natural conditions as possible. This is because the native fauna may not be sustained if the fertility, water regime, habitat or other environmental parameters are radically modified. The changed environment may be more favourable to the stocked species and thus lead to displacement of the wild stock.

In Bangladesh stocking is considered as a means of enhancing fish production and single stocking with a low density of carp fingerlings/ha/year with an appropriate species composition ratio did not affect yield and biodiversity of indigenous (non-stocked) species in closed waterbodies.[6] The selection of stocking densities depending upon the available size (length) of fingerlings to maximize profit and return on investment while minimizing risk as large fingerlings have relatively lower rates of natural mortality. The return on investment from a lower stocking density will also be significantly greater than for higher stocking densities because of lower stocking costs.[7]

The supplemental stocking of non-native species may also change the equilibrium of the native fish community as well as the dynamics of the stocked species. There are examples where native species have been out-competed by stocked (non-native) species that have radically changed the predator–prey relationships or trophic balance.

[6] Mustafa (2012)
[7] Halls, Mustafa and Dickson (2007)

A general rule is that non-native (introduced) species are liable to have a far greater ecological impact than stocking with native fishes. Note that even if a stocked species of fish is within its natural range, it may still have a negative impact if it was not previously present in that waterbody.

The extent to which these interactions occur as a result of stocking remains poorly studied and is rarely critically assessed. Often there is limited baseline information of the waterbody prior to the human impacts and subsequent commencement of stocking. This makes a retrospective assessment of impacts or possible beneficial improvements almost impossible.

Production varies greatly between previously stocked and newly stocked waterbodies as the idea and technology for stocking becomes better known to the participants. Stocking performance is generally higher in established fisheries than in newly stocked waterbodies.

There are also concerns with stocking in enclosed floodplain waterbodies that wild species that enter the enclosures may subsequently grow too large to escape. These may form a valuable by-catch but preclude free recruitment of fish into the capture fishery and thus need careful control.[8]

1.5 Stocking of waterbodies that are recruitment-limited

In waterbodies that are not capable of sustaining adequate breeding stock, the addition of recruits through stocking may become the principal source of fish recruitment and are thus clearly culture-based fisheries. This is a typical case in:

- small irrigation reservoirs subject to high water removal and heavy fishing pressure (e.g. irrigation "tanks");
- seasonal, natural or artificial waterbodies (e.g. that completely dry out every year);
- irrigated rice field systems (e.g. fed with reservoir water that contains little recruitment material); and
- artificial waterbodies with limited connectivity to rivers, swamps or other sources of recruitment.

In those systems where fish recruitment is maintained solely by stocking, some environmental solutions may be necessary to maximize survival and growth of the stocked fish. This may include manipulation of fertility, the provision of food or prey for newly stocked fish, or the provision of habitat and shelter to improve survival. These types of enclosed system also provide a greater opportunity for supplementary fertilization or feeding, thereby further increasing the potential productivity of the system.

Waterbodies with less potential in terms of productivity and water extent can be assessed for seasonal stocking with native species. This can enhance the income of the participating communities and provide opportunities for greater involvement of more women in the production process.[9]

[8] Blake and Barr (2005)
[9] LGED-SCBRMP (2011)

2 POTENTIAL ENVIRONMENTAL IMPACTS OF STOCKING

2.1 Effects of stocking on wild, native fish stocks

Only a relatively small number of species are used for stocking. These species are:

- straightforward to mass produce in hatcheries;
- preferred for their resilience and survival; and
- are generally preferred in the market and may have a relatively higher value than many small, wild fish.

Often such species are non-native to the waterbody into which they are stocked (even within a country), and this may have unforeseen ecological impacts. Artificially adjusting natural populations by introducing a new species, or stocking with large quantities of native species, upsets the natural balance of the original species assemblages, often to the detriment of overall productivity.

In some cases, the stocked species may also establish viable breeding populations that continue through time (i.e. an introduction). In extreme cases, where there are clear detrimental impacts on wild fish populations, prey species or other ecological impacts in the waterbody this species would be considered invasive. It is worth noting that many of the non-native cultured species that are stocked into static waters (especially Chinese and Indian carp that require riverine conditions for breeding) do not readily form viable breeding populations.

It is surprising that relatively little research has been done to evaluate the extent of these types of impact and they rarely feature in evaluations of the impact of stocking activities, although multiple stocking with carp fingerlings four to five times a year has seriously affected indigenous species in Bangladesh.[10]

The disturbance of the natural equilibrium of wild fish assemblages is essentially irrelevant in waterbodies or systems that are so perturbed that many elements of the native stock are reduced or even eliminated. Examples of this are some of the impoundments created by damming rivers or disconnecting waterbodies from floodplains or rivers. In such circumstances culture-based fisheries may be the best response to establish or sustain fishery production. Even in extreme cases, rehabilitation or mitigation should be applied if possible to keep any native stock more or less intact.

2.2 Conflicts between fisheries for stocked fish and wild fish

Conflicts may arise where a culture-based fishery is developed within an existing wild fishery. This is usually related to:

- establishment of a closed access regime (either legally or informally), with subsequent exclusion of the fishers previously targeting the wild fish;
- inequitable distribution of benefits, whereby one group has an unfair advantage in catching the stocked fish (e.g. they have boats or gears that enable them to target the stocked fish); and
- where the stocked fish are perceived (rightfully or wrongfully) to be negatively impacting the wild fishery (through competition or predation).

Such conflicts may not arise where culture-based stocking programmes are funded by governments for the benefit of all participants in the fishery. There is another form of conflict that arises when

[10] Mustafa and Mamun (2005)

outside fishers are attracted by the increased potential of the fishery.[11] Their entry to the fishery, legally or not, often causes tension with the existing fishers, especially if the new entrants do not abide by regulations or norms of the fishery (e.g. do not respect gear regulations or closed areas).

The closure of access is possibly the most contentious in developing countries where there is legal allocation of some form of ownership or control over a waterbody to individuals or groups operating in a private funding capacity. In such cases the operator of the fishery incurs expense in terms of stocking material that he wishes to see protected. Effectively this excludes the previous subsistence and artisanal fishermen from the waterbody.

In practice, it is rare to see the complete exclusion of traditional fishermen who may continue to benefit from capture of the residual populations of wild fish. In this situation, it is to support these marginalized fishers that most rehabilitation or mitigation work is advocated.

Careful costing is needed in such cases to determine the viability of the stocked fishery as compared to the previous open access wild fishery and social and economic interventions may be needed to ensure the continued well-being of the former fisher communities.

This underscores the importance of appropriate assessment and valuation of the impacts of culture-based fisheries and of having criteria by which to assess objectively the success or failure of this type of intervention.

This also raises the question whether the objectives for the fishery might be met by the use of environmental interventions rather than stocking. These alternatives to stocking are explored in the next section.

3 USE OF ENVIRONMENTAL INTERVENTIONS TO ACHIEVE MANAGEMENT OBJECTIVES

3.1 The four main purposes of environmental interventions

Environmental interventions are implemented to achieve four principle objectives:

- Protection
- Restoration/rehabilitation
- Mitigation
- Intensification.

For some larger waterbodies (or systems), there may be more than one objective as these may address a range of problems and be specific to different species of fish. They may also be used in conjunction with stocking either occasionally or regularly (e.g. to re-establish a species after rehabilitation of a habitat, or the stocking of fish and fertilization to increase yields).

The choice of intervention depends upon the stressors impacting the fishery, the priority objectives for a fishery (e.g. to sustain wild stocks and biodiversity or to maximize food production) and the degree of modification that is required and/or possible.

Protection: Protection is the prevention of any actions that might change ecosystem functions. The protection prevents or discourages modifications to the structure of the environment, the alteration of hydrological regimes and degradation of water quality.

[11] Mamun and Haque (2008)

This approach is primarily used to sustain natural fish assemblages by ensuring that their breeding, nursery, feeding and refuge habitats remain intact. The total protection of individual habitats is only realistically possible within designated parks or conservation areas. However, even in such protected areas, there can be upstream or downstream effects that can impact the environment and thus the fish assemblage.

Restoration/rehabilitation: These are interventions that aim to return an altered ecosystem to a more functional form by increasing system diversity and connectivity. These types of interventions can be put in place once the activity altering the system has ceased or diminished, and the economic and social conditions allow a focus on restoration and rehabilitation. Rehabilitation is generally costly, although it also typically a one-off activity to re-establish natural ecosystem forces (e.g. engineering to restore water connectivity and flows) as the future drivers of the system. This enables restoration of damaged fish assemblages, although the rehabilitated habitats may also give rise to new species equilibria.

Mitigation: Minimizing the adverse impacts of ongoing environmental change by actions such as fish passes or environmental flows. Mitigation usually involves recurrent expenditures that should be included in any cost-benefit analysis of the fishery, such as the provision of fish passes or actions to minimize nutrient runoff (eutrophication) from agriculture. It rarely achieves complete conservation of the pristine fish fauna but should be viewed more as a mechanism for retaining some fish populations in damaged ecosystems. It usually favours the more flexible black and grey fish species, for which local initiatives suffice, over more sensitive white fishes that generally require a more basin-oriented approach.

Intensification: Altering the environment to increase its productive capacity by creation of habitats (and their subsequent management) that favour preferred species. Ecosystem engineering of this type should be closely adapted to the species to be stocked, as say, the provision of suitable spawning substrates for tilapia, e.g. mapping and protection of shallow muddy substrates for tilapia spawning in large culture-based/enhanced fishery in Myanmar.[12]

3.2 Maintaining the habitat and hydrological function of rivers and floodplains

The high diversity of species in South Asian and Southeast Asian rivers is the result of an extremely varied range of habitats in the main channels of rivers and on the floodplains. Fish typically use a range of habitats for different aspects of behaviour. Separate habitats are used for spawning, as nurseries, as feeding grounds and as dry season refuges. If the species are to thrive, each of these habitats needs to be maintained, as do the pathways (connectivity) between them.

Rivers comprise two main components:

- **River channels:** these are generally permanent features and serve to collect water and conduct it to the sea.
- **Floodplains:** these are lateral expansion areas that accommodate excess flow during the rainy seasons and comprise permanent waterbodies, seasonal waterbodies and inundated land. These are permanently or seasonally connected through river flooding and inundation from monsoon rainfall flooding.

[12] FAO-NACA (2003)

3.3 River channels

In river channels significant habitats, depending on species, include the following: the channel itself; marginal vegetation; point bars; river deeps; slack water anabranches; and rocky rapids. Such habitats are maintained by an active river as part of the continuous erosion-deposition cycle that is basic to river form and function.

Many of these features tend to alter or disappear as the river channels are engineered for navigation or drainage, or when the erosion-deposition cycle is disturbed by dams or abstraction.

Conserving a healthy ecosystem means that changes to ecosystem structure, other than those arising from natural processes, have to be contained. Where the system is already altered, restoration of essential habitats may be carried out by rehabilitation work to restore particular features.

A number of tools have been used for such restoration depending on the nature of the river and the modification needed. In smaller rivers many engineering solutions, including various types of weirs and deflectors, can be installed at reasonable cost. In larger systems such solutions become major public works projects with costs rising in proportion. A variety of engineering solutions are described in technical manuals[13] and detailed treatment here is inappropriate.

Direct stocking into the main channels of large rivers is rare in tropical countries, although it is a regular procedure in the smaller, modified rivers of the temperate zone. The assumption is that the volume of stock required to make any significant impact on a river system is prohibitively expensive.

3.3.1 Restoring or improving connectivity in main channels of rivers

Many of the species inhabiting rivers undertake extensive migrations within the channel usually between feeding, breeding and refuge sites. These migratory species are generally white fish, many of which have larvae that drift downstream during development. Migration pathways are being increasingly interrupted by main channel and tributary dams.

In theory, such adverse impact can be mitigated by various forms of fish pass for all but the highest of dams. However, experience from the Mekong as well as South American rivers with similar migratory species shows that most types of fish pass are poorly adapted to the needs of tropical species.[14, 15] Even if a sufficient number of adult fish are able to ascend the pass to spawn, the drifting juveniles are unable to negotiate conditions in the reservoir upstream and descend the pass. Thus if the economically important white fish are to survive in the system some degree of main channel connectivity must be preserved, at least in parts of the system.

3.3.2 Maintaining water flows and quantity in rivers

The quantity and timing of flows are the major drivers of river morphology and ecology and are crucial to many aspects of river fish biology. First, they have a physiological effect in that they serve as triggers to aspects of behaviour such as migration or breeding. Second, they ensure connectivity and the seasonal flooding of the floodplain. Third, they transport fry and juveniles from the spawning sites to the feeding floodplain areas adjusting the distance travelled accordingly.

Fish assemblages in rivers are closely attuned to the natural flood cycle and changes to this by dams and water abstractions are likely to disrupt many species. Furthermore, changes to flow can adversely

[13] For example: Cowx and Welcomme (1998)
[14] Halls, Hoggarth and Debnath (1999)
[15] Halls and Kshatriya (2009)

affect the downstream drift of fry, causing then to miss the areas of floodplain needed for their survival. Probably the most important mitigation strategy is to ensure that adequate hydrological regimes are maintained in river systems and, in particular, to ensure that the floodplain is flooded.

Water quantity is not enough on its own, the timing and form of the flood are also critical for most fish species and for the agricultural uses of the floodplain.[16]

The most scientific approach to ensuring that adequate water is passed down a river at the most appropriate time is to negotiate environmental flows with those controlling the allocation of water in the river basin. Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them in any particular system.[17] Such negotiations can only be conducted at a high enough administrative level to make adequate representation of the fisheries interests, whether they are natural or stocked.

At a less scientific level, periodic releases can be negotiated with the operators of individual dams. There is evidence that such releases have a positive effect on fish assemblages for the lower river reach of the Pak Panang river below the Uthokawiphatprasit dam.[18] Positive results were also felt on the reproduction of individual species, such as the shark catfish (*Helicophagus waandersii*) in the Mun river below the Pak Mun dam, Thailand.[19]

3.4 Floodplains

In floodplains the major part of the plain is submersed seasonally but remains dry for the rest of the year. The plain itself may be forested or cleared for agriculture and is interspersed with permanent or semi-permanent lakes, channels and swamps.

Floodplain features may disappear because they no longer flood because of upstream dams, they become deforested or the plain is drained for agriculture. The floodplain may also be dried or segmented by embankments and bunds, and through construction of all-weather/floodproof roads and the development of irrigation and drainage structures.

Floodplain waterbodies are equally complex environments. Some take the form of permanent lakes whereas others are seasonal, persisting on the floodplain for some time after the floods have subsided, but eventually drying out. Whatever the type, they vary considerably in extent throughout the year, and during the floods usually coalesce into the general sheet flooding of the plain.

Essential features of floodplain waterbodies include vegetated riparian fringes that serve as nurseries, feeding areas and refuges for many species of small fish. In forested floodplains fringing woodlands are often important habitats, especially during the flood season. The most important feature that can be engineered to improve the capacity of the waterbody is some form of deep that provides permanent water throughout the year and that can act as a dry season refuge for fish. In some Asian and African systems artificial deeps are used as refuge traps, serving to concentrate fish throughout the dry season for fishing towards the end of the season.

Floodplain waterbodies are used widely for stocking, especially where insufficient fish enter the floodplain naturally during the floods because of overfishing or engineering activities (e.g. earthworks, roads, polders and drainage systems) that disrupt connectivity between dry season refuges for floodplain fish, swamps and water channels in the floodplain.

[16] See for example: Welcomme and Halls (2004)
[17] Halls and Welcomme (2004)
[18] Jutagate, Lek, Sawusdee, Sukdiseth, Thapanand-Chaidee, Thongkhoa, Lek-Ang and Chotipuntu (2009)
[19] Jutagate, Thapanand and Tabthipwan (2007)

In the Lower Mekong Basin alone there are more than 14 000 small dams, sluices and irrigation weirs.[20]

It seems inevitable that floodplain stocking will result in increased fishing pressure in floodplain areas outside of the stocking projects, as people are no longer allowed to fish within the impounded stocked area during the growing season. Furthermore, the scale of duck-rearing has been reduced because the snails, which used to form an important food source for ducks, are no longer as abundant after the stocking of floodplain waterbodies.[21]

3.4.1 Connectivity in floodplains

Similarly, both white and grey fishes depend on connectivity between the river channels and the floodplain to complete their life cycles. Silting or human induced filling of the channels that supply and drain the floodplain and its lakes is detrimental to the repopulation of floodplain waterbodies by natural processes. One of the simplest methods to ensure that natural populations of fish are retained in floodplain waterbodies is to ensure that the canals connecting the waterbodies to the main channel are kept open.

Similarly, many tropical floodplains are intersected by embankments that carry roads or railways, which may isolate portions of the floodplain into enclosures. The embankments are often pierced by simple culverts to enable water to enter and leave the enclosure, whose placement is made rarely to coincide with the needs of fish. New culverts (or retro-fitted ones) should be designed with fish passage in mind.

The most extreme form of control of floodplain hydrology is the complete containment of individual floodplain areas within embankments or bunds. These normally contain an area of floodplain with a view to controlling the entrance and exit of water through sluices for rice cultivation. When the entrance and exit of water is employed solely for rice considerable harm to the migratory fish populations can result, although it has been shown that with appropriate schedules the hydraulic regime can be adjusted to improve the abundance and size of some migratory species.[22, 23]

Sluices can also be used to block passage of water through the channels draining floodplain waterbodies. Such control structures may be formally engineered "hard" structures or softer options such as removable earth plugs. When properly used, they can delay the outflow from the waterbody to increase the area and depth of water retained in the waterbody, thereby increasing the time available for growth of fish and improving survival rates.

The operation of a sluice gate for water regulation, which hinders the movement of juvenile fish from river channels into the depression areas of the floodplain, also influences species diversity. The impacts of such operations mainly depend on the production cycle of the species inhabiting these depression areas. These are already being heavily harvested, despite being linked with the river during the monsoon season, so there is a lack of juvenile fish.[24]

3.5 Rice fields

Rice fields are wetlands modified by humans. They are often derived from floodplains and mimic natural floodplain environments. River flooded paddy fields can collect similar black fish assemblages to natural plains and these mainly support subsistence fisheries.

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[20] MRC Fishery Programme (2014)
[21] Gregory and Taufique (2007)
[22] Halls, Payne, Alam and Barman (2008)
[23] Hoggarth, Halls, Dam and Debnath (1999)
[24] Mustafa and Brooks (2008)

The effectiveness of rice fields for fish production can be increased by the creation of sump ponds and canals that perform similar functions to those of natural floodplain waterbodies in conserving fish stocks during the dry season. These can be relatively small and be engineered into individual paddies, or within connected paddy systems (e.g. Cambodia dry season community fish refuges).[25] The smallest refuges are literally a metre wide and constructed from buried concrete rings forming small sumps in the paddy[26] (e.g. Cambodia "CARE" rings in rice fields).

Rice fields can also be stocked to enhance their productivity. This can greatly enhance the level of fish production. There is however, a trade-off between the increased production of fish and the potential loss in rice harvest by devoting portions of the paddy fields to fish retention. Furthermore, where flooding of enclosures is practised, the yield of rice may be sub-optimal if reasonable levels of fish harvest are to be sustained.

3.6 Improving habitats and water management of man-made waterbodies

3.6.1 Small natural lakes, artificial waterbodies

Natural lakes are not a significant feature of inland water ecosystems in South Asia and Southeast Asia. The numbers of small-medium static waterbodies have been increased over the past four decades by the creation of numerous man-made, small dams that have been developed for irrigation and domestic water supply over much of the continent.

These waterbodies are mostly managed by stocking with introduced tilapias, some of which may have formed self-sustaining populations within the lake. Populations of native species may also become acclimatized, although these are mostly riverine in origin and appear to be less effective in using lacustrine systems.

3.6.2 Large reservoirs

Large reservoirs have been formed behind major dams across major river systems, usually installed for power generation and irrigation. Fisheries have been developed or enhanced in these waterbodies through stocking:

- introduction of tilapias, some of which may have formed self-sustaining populations within the lake (e.g. Sri Lankan irrigation tanks); and
- enhancement with native species capable of establishing breeding populations (e.g. stocking of indigenous species into large hydro-electric/irrigation reservoirs in Thailand.

Populations of native species may also become acclimatized, although these are mostly riverine in origin and appear to be less effective in using lacustrine systems.

3.6.3 Enhancing the suitability of reservoirs

The productivity and effectiveness of stocking into dams appears to be associated with lake area and depth; the smaller the lake, the greater the productivity and the more effective the stocking.[27, 28]

The suitability of reservoirs for breeding and sustaining fish populations can be increased in some ways. Many reservoirs are steep sided, as they have been created by damming and flooding river

[25] Joffre, Mam, Kura, Sereywath and Thuok (2012)
[26] Innes-Taylor and Sengvilaykham (2010)
[27] Welcomme and Bartley (1998)
[28] Welcomme and Bartley (1997)

valleys. This form is particularly sensitive to drawdown of water; as the shoreline is relatively featureless, there is little habitat diversity for fish.

The provision of shallows to form spawning grounds can help sustain acclimatized populations of tilapias or common carp, or a variety of indigenous species. Increasing the variety of shoreline vegetation may also improve reproductive success, with swampy vegetated areas (reeds/grasses) as well as riparian trees.

Generally, there is little connectivity downstream through dams for the resident populations or stocked material. Some local species though may be able to breed upstream in tributary rivers. The presence of small streams and rivers entering large reservoirs is associated with the establishment of breeding populations of riverine species, which can still take advantage of this flow to breed (e.g. Nam Ngum reservoir in Lao PDR). If viable populations of the species are to be retained in the reservoir, it is important that habitat diversity and connectivity be maintained within such streams and between the streams and the reservoir. Clearly, where cascades of dams are installed such connectivity becomes limited and fish production in the reservoir will rely increasingly on stocking.

3.6.4 Discharge control and conservation of water in dams

Clearly, the more water that can be retained in a reservoir for longer periods increases the efficiency of the reservoir for fish production. This is especially important in smaller dams many of which may dry out completely towards the end of the dry season. Retention of adequate water enables native stocks to reach a higher potential and increases the survival and growth of stocked fish in culture-based fisheries. In smaller dams that desiccate, seasonally repeated stocking may be necessary, although sump areas may be created that may retain some fish throughout the year. The pattern of discharge is also important because overly fast drawdown can dry out shallow water nesting and nursery areas causing failures in reproduction and increased juvenile fish mortality. In all cases, where water is retained for fisheries purposes there is likely to be conflict with the original purpose for which the waterbody was created (irrigation or power generation) and this is more severe the smaller the waterbody is. Ideally, fisheries managers should discuss possible discharge scenarios with dam operators to secure a better deal for the fishery.

3.6.5 Discharge controls

Discharge control has a cost to the intended beneficiaries of the reservoir, be it for the maintenance of downstream fish populations through the provision of environmental flows, or the retention of water in upstream reservoirs to improve the growth and survival of the lacustrine stocks. Some sacrifice is called for either in loss of power generated, smaller amounts of water for irrigation or reduced capacity for flood control. The costs of these losses should be carefully weighed against any gains to the natural or stocked fish populations so that some long-term, integrated policies can be developed to the mutual benefit of all sectors.

4 CONCLUSIONS

Stocking and culture-based fisheries are valid management practices for compensating for shortfalls in catch in overfished systems or those damaged by changes to the environment caused by other users of the resource. It may also achieve higher levels of output than fisheries based on wild stocks alone. However, current trends in stocking tend to be pursued uncritically with little regard for the cost-effectiveness of the practice or its environmental consequences. Floodplain stocking has been credited with increasing fish production and fishers' incomes, but concerns have been raised about its implications for ecological and social equity, as well as its cost-effectiveness and sustainability.

Retaining natural productivity and population structure, as well as maximizing yields of stocked species may require investment in rehabilitation or mitigation to counter the effect of environmental degradation. Even taking into account the costs of such enterprises, critical evaluation may well show that careful management of the natural environment through rehabilitation or mitigation techniques may be a more viable option in sustaining fish production from river and reservoir systems than stocking.

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PAPER 3: FISHERIES ENHANCEMENTS IN INLAND WATERS WITH SPECIAL REFERENCE TO CULTURE-BASED FISHERIES IN ASIA: CURRENT STATUS AND PROSPECTS

Sena S De Silva

CONTENTS

1 INTRODUCTION

The global per capita fish consumption has increased from 6 $kg.yr^{-1}$ in 1950 to 19.2 $kg.yr^{-1}$ in 2012, with Asia accounting for two thirds of the total global fish consumption, averaging 21.4 $kg.capita^{-1}.yr^{-1}$ in 2011.[1] The latter figures however, mask significant regional differences within Asia in fish consumption, and also the fact that often fish provide an affordable source of animal protein to the poor, particularly in remote communities. Overall, fish currently account for nearly 30 percent of the animal protein intake in the developing world, but is significantly higher in rural communities in developing countries.[2]

The global population is expected to reach 9.5 billion by 2050. Even if the current rate of fish consumption were to be maintained (though available evidence suggests the per capita consumption among most communities is likely to increase) an extra 30 to 40 million tonnes of food fish will be required to meet the demand.[3] Can this gap between supply and demand for food fish be narrowed?

This question is particularly pertinent when considered in the context of a levelling-off of the traditional supply from marine fisheries, which at best is likely to remain about 90 to 100 million tonnes per year.[4]

Furthermore, approximately 25 percent of the marine catch is reduced to fish meal and fish oil and is not available for direct human consumption. Since the 1970s there has been a significant upsurge in global aquaculture production, averaging a growth rate of about six percent per year in the last three decades, the highest for any primary production sector.[5] The growth of the aquaculture sector has contributed significantly to narrowing the gap between supply and demand for food fish. This has lead to the gradual predominance of farmed supplies in global food fish consumption.[6] This trend is similar to that of other staples reflecting a shift from a hunted to a farmed food fish supply.[7]

Aquaculture production reached 76.3 million tonnes in 2011 with the Asia-Pacific region contributing over 80 percent,[8] and PR China being the leading nation accounting for 65.7 percent of the total global production.[9]

The food fish production from aquaculture, until now, is primarily from intensive monoculture and polyculture practices, conducted in ponds, cages, pens, recirculation systems, as well as rope and raft culture of molluscs among others, in a range of aquatic environments. Intensification of aquaculture practices has led to the use of artificial feeds, prophylactics for disease prevention, drugs of varying sorts for disease control, growth promoters and other ways and means of increasing yields, essentially reflecting comparable developments in land-based agriculture and animal husbandry.

The growth surge in aquaculture in recent times has also been subjected to a higher degree of "policing" by the public, particularly in the wake of the establishment of the Convention on Biological

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[1] Committee on World Food Security (2014)
[2] FAO (2011)
[3] Aquaculture Service, Network of Aquaculture Centres in Asia-Pacific (2011)
[4] Froese *et al.* (2012)
[5] FAO (2011)
[6] Subasinghe *et al.* (2009 and 2012); FAO (2011)
[7] De Silva (2012)
[8] FAO (2014)
[9] Wang *et al.* (2014)

Diversity[10] and the generally accepted notion that all major developments should be sustainable.[11] Overall, sustainability of intensive aquaculture is often questioned on many grounds and it has been pointed out the growth of the sector has to be considered in the context of food security and nutrition.[12]

Intensification not only leads to environmental degradation but an increased demand on resources – physical and biological – and also raises ethical issues on the very high proportion of use of certain biological resources such as fish meal and fish oil in aquaculture.[13] When challenges of feeding nine billion people are considered, the issues raised are competition for land, water and energy.[14] The general consensus is that these issues are likely to be exacerbated further by impending climate change impacts, including those on fisheries and aquaculture.[15]

There have been various major reviews on fisheries stock enhancements, both globally[16] and with specific reference to Asia.[17] As such no attempt will be made to dwell on stock enhancement practices *per se,* in detail, in this synthesis.

Culture-based fisheries is a form of stock enhancement widely practiced in Asia. It is being increasingly adopted as a development strategy particularly in developing countries in Asia to augment the food fish supplies among rural communities. In the light of the above, this synthesis attempts to discuss the importance and status of culture-based fisheries in Asia in greater detail. To this end examples are drawn from developing countries in Asia that have successfully adopted culture-based fisheries, as well as other stock enhancement practices, that have resulted in significant increases in food fish production mostly benefitting rural communities.

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[10] CBD (1994)
[11] De Silva and Davy (2010)
[12] Committee on World Food Security (2014)
[13] Tacon *et al.* (2010)
[14] Hanjra and Qureshi (2010); Godfray *et al.* (2010)
[15] Cochrane *et al.* (2009); De Silva and Soto (2009); Leung and Bates (2013); Nguyen *et al.* (2014)
[16] Cowx (1998); Petr (1998); Welcomme and Bartley (1998); Lorenzen (2008); Lorenzen *et al.* (2001); Molony *et al.* (2003); Bell *et al.* (2006); Bartley (2007)
[17] Petr (1998); Li (1999); Welcomme and Vidthayanon (2003); De Silva and Funge-Smith (2005); Miao *et al.* (2010)

2 STOCK ENHANCEMENT PRACTICES: GENERAL OVERVIEW

2.1 Stock enhancement

Stock enhancement (SE) practices are manifold. They are primarily aimed at improving, directly and or indirectly, the stock size/yield above that obtained in an existing fishery resource, and/or aimed at conservation of a species and or a stock.

FAO defined fisheries enhancements[18] as technical interventions in existing aquatic resource systems, which can substantially alter the environmental, institutional and economic attributes of the system. This is the process by which qualitative and quantitative improvements are achieved from waterbodies through exercising specific management options.

The most common enhancement of fish populations is through stocking, either using hatchery produced seed or wild collected seed (e.g. freshwater eels), for varying purposes. Accordingly, such interventions require direct and indirect management enhancements (e.g. introduction of closed seasons and habitat improvements) in order to result in enhanced fish production through capture fisheries. Enhancements may also lead to biodiversity conservation through the establishment of conservation units, sanctuaries and other managerial measures.[19] In general, most stock enhancements in inland waters are achieved through the release of hatchery reared seed stock of selected finfish species.

More recently, high valued crustacean species, such as the giant freshwater prawn, *Macrobrachium rosenbergii*[20] and Chinese mitten crab *Eriocheir sinensis*[21] are being used increasingly in stock enhancement in Thailand, Bangladesh and China, respectively.

Stock enhancement may also be conducted to augment recreational fisheries, generally in developed countries, and also in biomanipulation. The latter is carried out particularly in relation to improving potable water supplies, and tends to utilize filter feeding molluscs in conjunction with piscivorous finfish species.[22] In certain countries in Asia, e.g. Cambodia, Lao PDR and Thailand, hatchery reared seed stock of a number of species are released to natural waters to commemorate "national fish day" each year, a tradition that has been ongoing for nearly four decades.[23] This practice has both religious and a socio-political purposes, and because they are not evaluated, the outcomes are rarely documented.

2.2 Purpose and benefits of stocking

The purposes of stocking are wide ranging and are summarized in Table 1. The benefits gained from stocking are equally variable. A global review of inland fisheries enhancements undertaken by FAO[24] indicated that stockings in Asia and Oceania are undertaken for increasing yields, production of food and generation of income (Figure 1). This data is now somewhat dated, but still reflects the global interest in stock enhancement as a means to contribute significantly to narrowing the gap between the supply and demand for food fish.[25]

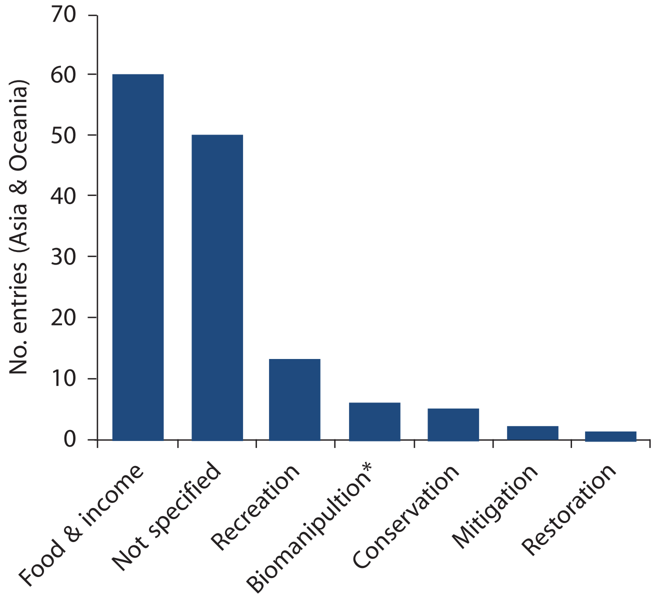
[18] FAO (1997)
[19] Park (2010)
[20] Sripatrprasite and Lin (2003); Ahmed and Garnett (2010); Jutagate and Rattanachai (2010)
[21] Cheng *et al.* (2008); Wang *et al.* (2015)
[22] Reeders and de Vaate (1990); Jeppesen *et al.* (2007 and 2012)
[23] Anonymous (2014); Phounsavath (2014)
[24] FAO (1999)
[25] Beard *et al.* (2011); Youn *et al.* (2014)

Table 1 Purposes of stocking in inland waters

Stocking type	Rationale	Key assumptions	Comments and 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, 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	Production from current species naturally constrained Performance of stocked species 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 – Alien (exotic) species main species used here, e.g. tilapia in Sri Lanka
Create new fisheries	Fill a vacant niche	Artificial water body does not have natural "fauna" Habitat is below carrying capacity and resource base will not change substantially Species performance in new environment acceptable	– Developing countries – Newly created artificial reservoirs – Transfer fish into new waterbodies or where new species are introduced into existing fisheries
Environmental change	Control environmental conditions and aquatic pests	Species stocked will achieve desired outcome	– Developing and developed countries – Examples: Biomanipulation; control of algal blooms in eutrophic ecosystems by enhancing herbivores through a reduction of planktonivorous fish and introduction of piscivorous fish; stocking of selected fish species to control 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

Note: Adapted from Ingram and De Silva, 2015.

Stock enhancement practices are generally poorly monitored and the socio-economic benefits and/or losses are rarely documented. As the relevance of stock enhancement practices become increasingly important as development strategies to enhance food fish production, the introduction of accompanying monitoring mechanisms becomes an imperative. Such initiatives will provide the basic information to planners and developers to bring about improvements that will be beneficial to the communities. The need to improve inland fishery databases and the monitoring programmes has also been emphasized by others.[26]



Data source: FAO Inland Water Resources and Aquaculture Service (1999) Adapted from Ingram and De Silva (2015)

Figure 1 Reasons for stocking in Asia and Oceania regions

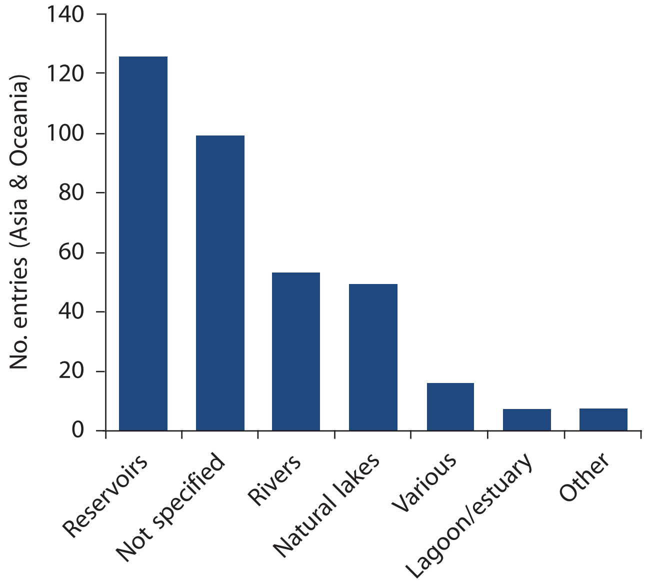
2.3 Types of waterbodies stocked

In Asia, almost all types of inland waters are stocked such as reservoirs and lakes, floodplain depressions, oxbow lakes, rivers, lagoons (Figure 2). However, almost always the primary purpose of stocking these waterbodies in developing countries in Asia is to increase the food fish supplies. This is in contrast to developed countries where it is more often than not to enhance recreational fisheries and for conservation purposes.[27]

Stock enhancement of riverine systems for fisheries development in Asia is relatively rare compared with developed countries.[28] Increasingly, there is a realization of the need to restore "river health", particularly that of major rivers in Asia,[29] and in certain instances stocking of finfish is being used as a tool for this purpose.[30]

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 waterbodies the recapture rate may be low and repeated enhancement is not always necessary to maintain the fishery if natural recruitment occurs.[31]

[26] See also Bartley *et al.* (2015)
[27] Welcomme and Bartley (1998)
[28] De Silva and Funge-Smith (2005)
[29] Dudgeon (2005); Trivedi (2010); Zeng and Wu (2013)
[30] Qiao and Guo (2012); Zeng and Wu (2013)
[31] Welcomme and Bartley (1998)



Source: FAO Inland Water Resources and Aquaculture Service (1999)
Adapted from Ingram and De Silva (2015)

Figure 2 Types of waterbodies being stocked

2.4 Assessing stocking success

In general, and in inland waters in Asia in particular, the success of stocking is measured in terms of the overall increase in yield. In certain instances success is measured in terms of the monetary gains to the fishers. A good example of the latter is the stocking of giant freshwater prawn, which commands a high market price, in spite of the fact that the net return of the numbers stocked often are less than one percent.[32] The outcomes from stocking of a species in a particular waterbody in one year would not guarantee that comparable results will be obtained in another year, emphasizing the uncertainty associated with stocking success.[33] In view of the fact that it is often difficult to assess the direct benefits from stocking on fish yields and distribution of socio-economic gains the overall impacts of stocking are difficult to assess explicitly.[34]

Nevertheless, it is becoming increasingly important that specific indicators to determine stocking successes have to be evolved and used as a regular tool for management. This is primarily so as success and sustainability are often linked to economic viability and governments are playing a decreasing role in conducting regular stocking programmes to prop up dwindling returns.

Measures of success of stocking could take one or a combination of many forms, depending on the objectives of the stocking programme. Among possible criteria for measuring success are:

- gains in yield in relation to numbers stocked (in terms of weight or monetary value);
- comparison between stocked and non-stocked waters;
- returns from tagging (physical and or genetic markers); and
- improvements in income to fishers/stakeholders.

The results from stocking are known to be variable, with documented cases where stocking programmes have failed,[35] made no discernible impact,[36] or have been highly successful.[37]

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[32] Jutagate and Rattanachai (2010)
[33] Lorenzen *et al.* (2001)
[34] Lorenzen (2005); Garaway *et al.* (2006)
[35] For example: Moran *et al.* (1991); Amarasinghe (2010)
[36] For example: Saltveit (2006)
[37] For example: Lorenzen (2008); Amarasinghe (2010)

Instances where repeated stocking of an endemic species (e.g. bilih, *Mystus padangensis*) from one waterbody (Singkarak Lake) to another (Toba Lake) have succeeded are also known.[38] Conversely, the repeated stocking and translocation of icefish (Salangidae) into lakes and reservoirs in China has had "boom and bust" cycles, and the underlying reasons for this are not well understood.[39] In Victoria, Australia, the evaluation of stocking programmes conducted for recreational purposes is an ongoing process, and the returns from stocking ranged from 11 to 99 percent.[40]

The success of stocking programmes are impacted by many factors:[41]

- stocking density and ecological carrying capacity of the receiving environment;
- age and size of fish at stocking;
- condition and health of stocked seed;
- genetic factors;
- presence and amount of suitable habitat, food, competitors and predators at release sites;
- timing of stocking relative to above factors; and
- release methods.

Stocking success could be impacted by one or more of the above factors, and also the influence of each factor could differ among species, habitats and as well as in time and space.

2.5 Risks associated with stocking

Stocking, and indeed all stock enhancement practices, essentially involve a direct and/or indirect manipulation of the environment. As such there will be consequences, favourable and or unfavourable. In order to make the outcome as favourable as possible and to attain the desired impacts, risks associated with stocking have to be considered.

A review of the risks associated with stocking, recognized the following:[42]

- genetic impacts;
- ecological and environmental impacts, including displacement of species;
- infectious disease or pathogen transmission; and
- chemical release.

The nature and extent of each of the above risks will differ from stocking practice to practice, and the original objectives thereof. Each can be mitigated by good risk management, e.g. genetic resources management, proper choice of species and habitats to stock, fish health inspection and quarantine, and good husbandry practices.

[38] Maskur *et al.* (2010)
[39] Kang *et al.* (2015)
[40] Ingram *et al.* (2015)
[41] Wahl *et al.* (1995), Li (1999); Brown and Day (2002)
[42] Ingram and De Silva (2015)

3 CULTURE-BASED FISHERIES

In the foregoing sections general considerations on stock enhancements were dealt with. From here on, aspects of culture-based fisheries, a form of stock enhancement that has become a part of governmental strategies for some developing countries in Asia, are dealt with in detail. Accordingly, in these countries culture-based fisheries have become a component of the national fishery and aquaculture development plans[43] and in some instances existing legislation has been amended to accommodate/facilitate adoption of culture-based fisheries (e.g. Sri Lanka).[44]

3.1 What are culture-based fisheries?

FAO[45] defines culture-based fisheries as:

"A fishery in which the use of aquaculture facilities is involved in the production of at least a part of the life cycle of a conventionally fished resource: aquaculture is usually the initial hatchery phase that produces larvae or juveniles for release into natural or modified waters."

As such, culture-based fisheries falls within the realm of stock enhancement practices, discussed earlier. However, culture-based fisheries as practiced in most of Asia will consist of two phases:

- a farmed phase for the provision of stocking material, where the seed or juveniles are produced in an aquaculture hatchery; and
- a wild phase or quasi-wild phase where the culture stock are placed into a waterbody. This phase may also involve the care of stocked seed to varying extents.

Caring activities undertaken after stocking-out to the waterbody include:

- preparing the waterbody by removing macrophytes, if any;
- keeping watch of the stock thereby permitting the stocked fish to reach harvestable size;
- removing dead fish, if any; and
- taking steps to minimize the escape of stocked fish by maintaining sluices and weirs in good condition.

Culture-based fisheries are often carried out by communities living in the vicinity of waterbodies through a co-management process[46] to provide ownership of the stock to the respective communities.

As there is intervention in the life cycle and ownership of the seeded stock, culture-based fisheries often fall within the realm of aquaculture.[47] Thus, culture-based fisheries differ greatly from the wide array of other enhancement practices.[48]

Overall the main characteristics of culture-based fisheries can be summarized as:

- culture-based fisheries are secondary users of existing water resources that can be combined with other uses;

[43] For example: Government of Cambodia (2010); Ministry of Agriculture and Forestry (2010), Fisheries Administration (FiA), (2012)
[44] De Silva (2011)
[45] FAO (2011)
[46] Lorenzen *et al.* (2001); De Silva *et al.* (2006); Wijeynayake *et al.* (2007)
[47] De Silva (2003)
[48] Welcomme and Bartley (1998); Lorenzen *et al.* (2001); De Silva and Funge-Smith (2005); De Silva (2010); Miao *et al.* (2010)

- culture-based fisheries are often practised in communal waterbodies and or those that are auctioned and/or leased to groups and or individuals by authorities;[49]
- often the waterbodies used for culture-based fisheries are not capable of sustaining a fishery through natural recruitment;[50]
- in culture-based fisheries, suitable seed are stocked enabling them to feed on the naturally produced food organisms in the waterbody, and attain a marketable size in six to eight months (note exceptions such as in the case of culture-based fisheries involving eels in Australia;[51]
- the choice of stocked species should be based on their feeding niches and local preferences, ensuring that naturally produced food organisms are utilized, mirror imaging pond polyculture systems;
- the stocked seed are often cared for (e.g. preparing the waterbody such as for example removing weed cover, if any; keeping watch; ensuring minimal escape) by the community or their representatives who will have ownership of the final harvest;
- the sharing of benefits, food fish and monetary gains from the sale of fish may differ between communities, even within a country/region; and
- culture-based fisheries practise calls for continued vigilance of the stock and planning related to harvesting and therefore it generates a high degree of synergy in the community that brings about better harmony and common societal gains.[52]

In Asia in general, culture-based fisheries are commonly practised in small waterbodies, natural (e.g. lakes, beels, oxbow lakes) and or quasi natural (reservoirs and rice paddies).[53]

A summary of the principle forms of culture-based fisheries practices[54] indicates that they are generally benign and can be considered an environmentally friendly practice in which the only external input is seed stock. There may still be socio-economic issues, including access and tenure. Table 2 provides a summary of types of inland waterbodies that are used for culture-based fisheries in Asia.

Table 2 Summary of types of inland waterbodies that are used for culture-based fisheries in selected countries in Asia and the mode of management adopted

Country	Type of waterbody	Management type	Authority
Bangladesh	Ox bow lakes Beels	Auctioned to individuals and or groups	Middendorp and Balarin (1999); Valbo-Jørgensen and Thompon (2007)
Cambodia	Small reservoirs	Village committee	Lim Song *et al.* (2013)
China	Lakes, reservoirs	Respective fisheries bureaus	Wang *et al.* (2015)
Lao PDR	Small reservoirs	Committee elected by the downstream village community	Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
Myanmar	Flood plains depressions	Leases (the culture-based fisheries akin activity is referred to as lease fisheries)	Anonymous (2003)
Sri Lanka	Non-perennial reservoirs	Village fisheries committee selected from agricultural committee	Wijenayake *et al.* (2005)
	Perennial reservoirs	Fisheries society of each reservoir	Pushpalatha and Chandrasoma (2010)
Viet Nam	Small reservoirs	Individual and/or group lessees	Nguyen *et al.* (2001)

[49] Nguyen *et al.* (2001); De Silva *et al.* (2006); Phomsouvanh *et al.* (2015)
[50] Mendis (1977); Thayaparan (1982); Quiros (1998); De Silva *et al.* (2006)
[51] See Skehan and De Silva (2008) for details
[52] Kularatne *et al.* (2009); Saphakdy, *et al.* (2009)
[53] Middendorp and Balarin, (1999); Nguyen *et al.* (2001); De Silva *et al.* (2006); Saphakdy *et al.* (2009); Ahmed and Garnett (2010); Phomsouvanh *et al.* (2015)
[54] De Silva *et al.* (2006)

3.2 Development trends in culture-based fisheries

There is a long history of traditional stocking of different types of waterbodies, but these practices were not on a scale or as organized and methodical as at present. Sri Lanka did not have an inland fishery of any magnitude prior to 1962,[55] but had considerable potential with its cascading system of small reservoirs in each river catchment.[56] Culture-based fisheries were an important development strategy proposed for utilization of small waterbodies for food fish production.

This strategy to utilize these multitude of small, preferably non- perennial reservoirs that retain water for a minimum period of eight months to enhance food fish production through a stock and recapture strategy was proposed by Mendis in 1977, [57] but the emphasis at the time was on increasing fish food supply through intensive aquaculture development.

This was also the era when artificial propagation techniques were developed, perfected and extended to regional centres and it was logical that seed was used efficiently in aquaculture (because of higher survival rates) rather than subjected to the risks of open water stocking (where survival might be far lower and recapture quite uncertain). There were other reasons for the failure of culture-based fisheries, among which were lack of adequate planning and mobilization of village communities, who were primarily agriculturists, for a fisheries related activity[58] and in certain instances because of the existing social hierarchies.[59]

As intensive aquaculture began to make an impact on the global food fish supply (Figure 3), there was a gradual development of culture-based fisheries in countries where lacustrine waters were readily available. This development was also facilitated by the wide dissemination and successes in the artificial propagation of commonly favoured aquaculture species resulting in minimizing a common bottleneck of seed stock availability. Culture-based fisheries were also attractive as they

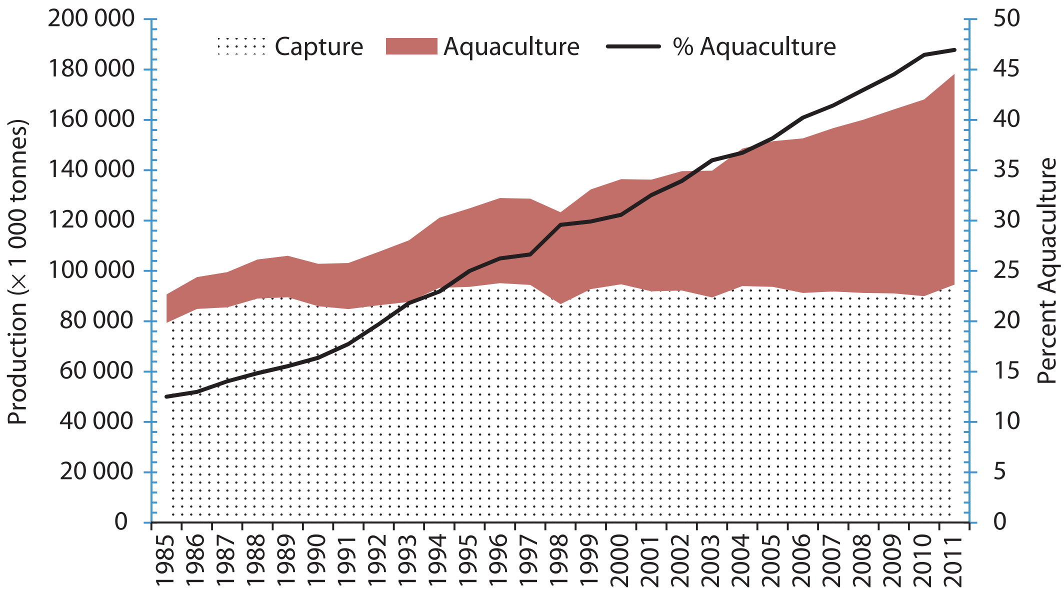


Figure 3 Trends in capture fisheries and aquaculture over the last 30 years and the percentage contribution of aquaculture to global fish production. Based on data from FAO (2014)

55 Fernando and Indrasena (1969)
56 Brohier (1934, 1935 and 1936)
57 Mendis (1977)
58 Middendorp and Balarin (1999); Kularatne *et al.* (2009)
59 Valbo-Jørgensen and Thompson (2007)

are a low cost development and do not depend on external feed inputs. This development initiation occurred in many countries, e..g. Bangladesh,[60] Cuba,[61] China[62] and Sri Lanka.[63]

3.3 Current practices in culture-based fisheries

Significant interest and increase in the extent of culture-based fisheries have occurred over the last two decades, and increasing needs to explore fresh avenues of food fish production and mitigate declining wild catches in waterbodies, without resorting to intensive aquaculture, have become imperative. With the now widespread expertise on artificial propagation of commonly cultured finfish species and the associated facilities, both governmental and private, in most Asian countries one key bottleneck in this regard has been minimized.

Culture-based fisheries practices are wide ranging and as such no attempt will be made to deal with each and every practice in Asia. Moreover, the culture-based fisheries practices or some crucial aspect of them could be different from practice to practice in a country. The best example of this is seen in Lao PDR where the harvesting strategies (Table 3) and the benefit sharing protocols (Table 4) take three forms that are linked.

Table 3 Three basic forms of management (based on the harvesting patterns) of the waterbodies that are adopted through a consensus of each of the communities

Category 1	
Harvesting Permit the village households to fish for their daily needs using scoop nets and hook and line, five months after stocking. The community embarks on harvesting the remaining stock via a ticket system where the public can purchase the right to catch fish for sale, when the water level recedes approximately 8 to 9 months after stocking The ticket price varies according to the gear to be used (for example, use of a lift net, often operated by women folk, 20 000 Kip; cast net, 40 000 Kip; where 8 000 Kip = USD1) The harvesting associated with ticket sales could go on for two to three days, but generally there is about 10% reduction in the ticket price after the first day	Gains to community households Households able to meet daily fish needs in this manner, Households are not permitted to catch for sale Gear limited to small dragnet and traditional traps only
Category 2	
Similar approach to Category 1	Able to meet daily fish needs but households are not permitted to catch for sale Gear limited to small dragnet and traditional traps only A portion of the ticket sales are provided to each household
Category 3	
Harvested only as the water level recedes, generally 8 to 9 months post stocking with engagement of the whole community Harvesting is publicized widely and the harvest auctioned on site	Fish for communal social occasions/ festivities Monetary gains based on net gains after harvest

Note: Adopted from Phomsouvanh *et al.,* 2015.

[60] Middendorp and Balarin (1999;) Valbo-Jørgensen and Thompson (2007)
[61] Quiros (1998)
[62] Li (1992); Wang *et al.* (2014 and 2015)
[63] Chakrabartly and Samaranayake (1982); Thayaparan (1982); Chandrasoma (1986); Chandrasoma and Kumarasiri (1986)

Table 4 The disbursement protocols of each of the categories of management (these are coupled to the harvesting strategies given in Table 1

Category 1
Restricted to ticket sales; 10 to 20% of the proceeds reserved for purchase of seed stock for the next culture-based fisheries cycle.
The rest of the monetary gains invested in community amenities. These include improvements/developments such as improvement to the local school (providing electricity), improving the temple community hall, investing on improving another waterbody in the village for culture-based fisheries activity by improving the dam structure/sluice gates etc.
Category 2
Of the ticket sales 10 to 20% is retained for the purchase of seed stock for the next cycle.
Of the remainder, 50% is divided among the households; every household in the community is entitled to this benefit.
The rest is utilized as follows: 6% advisers and committee members; 6% accountant and cashier; 10% labour (keeping watch etc.); 20% improving public amenities; 38% other social welfare, religious activities and associated hospitality.
Category 3
The total revenue is disbursed as follows:
50% sharing amongst households of the community.
The remainder is disbursed as follows: 20% purchase of fry and fingerlings; 6% advisers and committee members; 6% accountant and cashier; 10% labour (keeping watch etc.); 20% improving public amenities; 38% other social welfare, religious activities and associated hospitality.

Note: Adapted from Phomsouvanh *et al.*, 2015.

One of the major deviations from the more accepted form of culture-based fisheries is that introduced in Sri Lanka, through a co-management principle, in medium sized reservoirs (100 to 700 ha at full supply level), where conventional capture fisheries existed. In this instance the access to the waterbody is strictly regulated through membership of a fishery society, instituted among fishers under government supervision, and the society regulates the stocking programme financed through a levy on the catches of the members. The type and the quantity of gear used is regulated through a consensus of the society membership, and so is the stocking strategy.[64]

In Australia (State of Victoria) there is a culture-based fisheries practice in operation in waterbodies such as farm dams, wetlands and lakes and reservoirs, leased to individuals where freshwater eels are stocked (primarily glass eels and elvers of the short finned eel, *Anguilla rostrata,* caught in estuarine waters during the inland migration) by licensees and harvested at marketable size (approximate weight 600 to 1 500 g). In addition, the practice may also involve transfer of stunted juvenile eels, popularly known as "restock" between waterbodies.[65] This culture-based fisheries practice is perhaps exceptional in that it is based on a single species and the produce is almost entirely exported.

3.3.1 The culture-based fishery cycle(s)

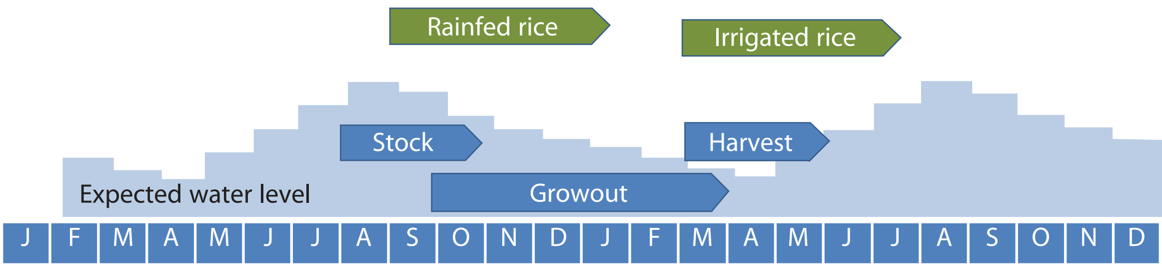
Culture-based fisheries are largely practiced in small waterbodies for the purpose of producing food fish. The culture-based fishery activities have to revolve around the primary use(s) of these waterbodies, which more often than not is for downstream agriculture complemented with

[64] Pushpalatha and Chandrasoma (2010); Chandrasoma *et al.* (2015)
[65] Skehan and De Silva (1998); Landline (2015)

household gardening. Consequently, culture-based fisheries cycles have to be complementary with the use of the primary resource for other purposes.

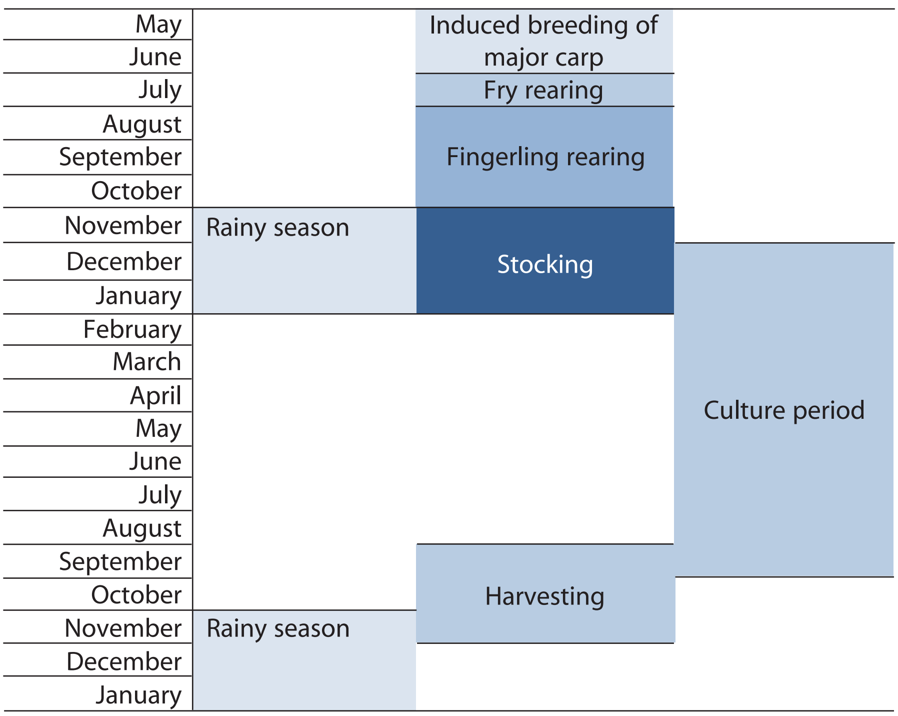
For example, in Sri Lanka the water usage in small waterbodies (driven by agrarian laws) is primarily determined by the paddy cultivation needs downstream. As such, the use of these waters for culture-based fisheries will have to comply with paddy cultivation needs; it may be that the waterbody was stocked for culture-based fisheries, but the ensuing needs for paddy cultivation could demand more than the usual supply of water and meeting this requirement will have priority.

The match of culture-based fisheries cycles to the other needs of the water resources have been schematically depicted in various forms and examples are given in Figures 4 and 5 for Lao PDR and Sri Lanka, respectively. What is evident is that the events of the culture-based fisheries cycle are dictated by the elements and therefore careful consideration needs to be given in adopting culture-based fisheries in an area.



Note: Adapted from Phomsouvanh *et al.* (2015)

Figure 4 A schematic representation of the culture-based fisheries cycle in small waterbodies in Lao PDR



Note: Adapted from Amarasinghe and Weerakoon (2009)

Figure 5 A schematic representation of the culture-based fisheries cycle in non-perennial reservoirs in Sri Lanka

3.3.2 Species used

A range of species is used in culture-based fisheries (Table 5). Among the most common species groups used across most countries in the region are the Chinese and or Indian major carps. These are known to have fast growth rates and also occupy different food niches that are complementary with each other and are readily available in waters suitable for culture-based fisheries. Moreover, these are the primary species for which artificial propagation techniques were developed and extended across hatcheries throughout Asia,[66] and in most Asian countries seed stock supplies of these species are not limited.

Consequently, initial aquaculture developments in Asia were based on these species for which one driver was the availability of seed stock. The above attributes together with consumer acceptance influence culture-based fisheries developments in most of Asia even to date. Cambodia is perhaps exceptional in that omnivorous species are preferred.[67]

In recent years there has been a tendency to use high valued species such as mandarin fish (*Siniperca chuasti*), Mongolian coulter (*Culter mongolicus*) and mitten carb (*Eriocheir sinensis*) in China,[68] and giant freshwater prawn for example in Bangladesh,[69] Thailand[70] and in Sri Lanka.[71]

More recently, in China the use of high valued species in culture-based fisheries is often chosen at the expense of a reduction in the overall yield, in order to mitigate deterioration of water quality brought about by excessive fertilization that favoured the production of the major carps.[72]

More often than not issues related to the use of alien species in stock enhancement practices, including culture-based fisheries developments, have become a general concern, especially following the Convention on Biological Diversity[73] and the FAO Code of Conduct for Responsible Fisheries and accompanying technical guidelines for responsible fisheries.[74]

Alien species play a significant role in aquaculture and related practices in most countries.[75] For example, the introduction of tilapias into Sri Lanka is considered to have triggered the development of the inland fishery sector.[76] However, alien species are often targeted for causing loss of aquatic biodiversity, even though explicit evidence to this effect is not often readily available.

These issues have been previously reviewed and the important contribution of alien species to Asian aquaculture production cannot be ignored.[77]

Unlike intensive aquaculture, there is much greater probability of stocked seed species in culture-based fisheries impacting wild populations (Table 5). However, most of these alien species have been established throughout Asian countries, and are among major aquaculture species in most countries. An assessment of the impacts of introduced Nile tilapia and major carps in Southeast Asian freshwaters on native fish communities[78] in relation to culture-based fisheries practices concluded

[66] Jhingran and Pullin (1985); Lin and Peter (1991)
[67] Limsong *et al.* (2013)
[68] Cheng *et al.* (2008); Lin *et al.* (2015); Wang *et al.* (2015)
[69] Ahmed and Garnett (2010)
[70] Jutagate and Rattanachai (2010)
[71] Chandrasoma *et al.* (2015)
[72] Lin *et al.* (2015); Wang *et al.* (2015)
[73] CBD (1994); DIAS (2004)
[74] FAO (1996); FAO (2008)
[75] http://www.fao.org/fishery/dias/en
[76] Fernando (1977); Amarasinghe and De Silva (1999)
[77] Bartley (1996); Bartley and Minchin (1996); Bartley and Casal (1998); De Silva *et al.* (2004, 2006 and 2009); Diana (2009)
[78] Arthur *et al.* (2010)

Table 5 Commonly used species in culture-based fisheries practices in five countries

Cambodia	China	Lao PDR	Sri Lanka	Viet Nam
Pangasianodon hypophthalmus	*Aristychthys nobilis*$^{+}$	*Catla catla*$^{@*}$	*C. catla**	*C. mrigal*$^{@*}$
Channa striata	*Hypophthalmichthys molitrix*$^{+}$	*A. nobilis**	*A. nobilis**	*A. nobilis**
Clarias batrachus	*Ctenopharyngodon idellus*$^{+}$	*H. molitrix**	*H. molitrix**	*H. molitrix**
Clarias macrocephalus	*Mylopharyngodon piceus*$^{+}$		*O. niloticus**	
Anabas testudineus	*Neosalanx spp.*	*Oreochromis niloticus**	*Macrobrachium rosenbergii*	*C. idellus**
Barbonymus gonionotus	*Siniperca chuasti*	*Cyprinus carpio*		*C. carpio*
	Culter mongolicus	*B. gonionotus*		
	Eriocheir japonica sinensis	*Labeo chrysophekadion*		
		Cirrhinus molitorella		

Notes: Compiled from varying sources and modified after De Silva, 2015; * alien to the country; + Chinese major carp species; @ Indian major carp species.

that that the former have not negatively impacted biodiversity nor the biomass of the native species. The possible negative impacts of the tilapias, which are widely introduced into Asia for aquaculture related purposes, has been reviewed,[79] including culture-based fisheries, and the conclusion was that there is no explicit evidence of its adverse impact on biodiversity.

There does appear to be a misconception that use of indigenous species in culture-based fisheries and/or other stock enhancement practices will impact minimally on biodiversity. Our knowledge and understanding of biodiversity issues are now driven by modern genetics, and molecular genetics in particular. There is significant evidence that the unplanned release of hatchery reared stocks of indigenous species have negatively impacted on wild counterparts, in some instances resulting in loss of strains and sub-species.[80] As such, the issue is not indigenous versus alien, but the absence of a prudent genetic management plan supported by a proper broodstock management strategy.[81] It is also important to point out that genetically improved strains of a species for intensive aquaculture may not necessarily be suitable for culture-based fisheries. A case in point was when a genetically improved farmed tilapia strain of Nile tilapia, *Oreochromis niloticus,* was used in culture-based fisheries trials in small reservoirs in Sri Lanka it proved to be unsuccessful, resulting in a very low survival rate and yield.[82]

3.4 Benefits of culture-based fisheries

The benefits arising from culture-based fisheries can be broadly considered as direct and indirect. Admittedly not all benefits from culture-based fisheries are very visible, quantifiable and/or documented previously. The situation is further exacerbated by the general lack and/or dearth of monitoring programmes and/or evaluations of culture-based fisheries resulting in the lack of appreciation of the benefits or impacts of culture-based fisheries.

The general lack of monitoring and evaluation, considered to be common in inland fisheries related sectors,[83] has constrained the recognition of the benefits arising from culture-based fisheries to communities as well their contribution to national inland fisheries development.

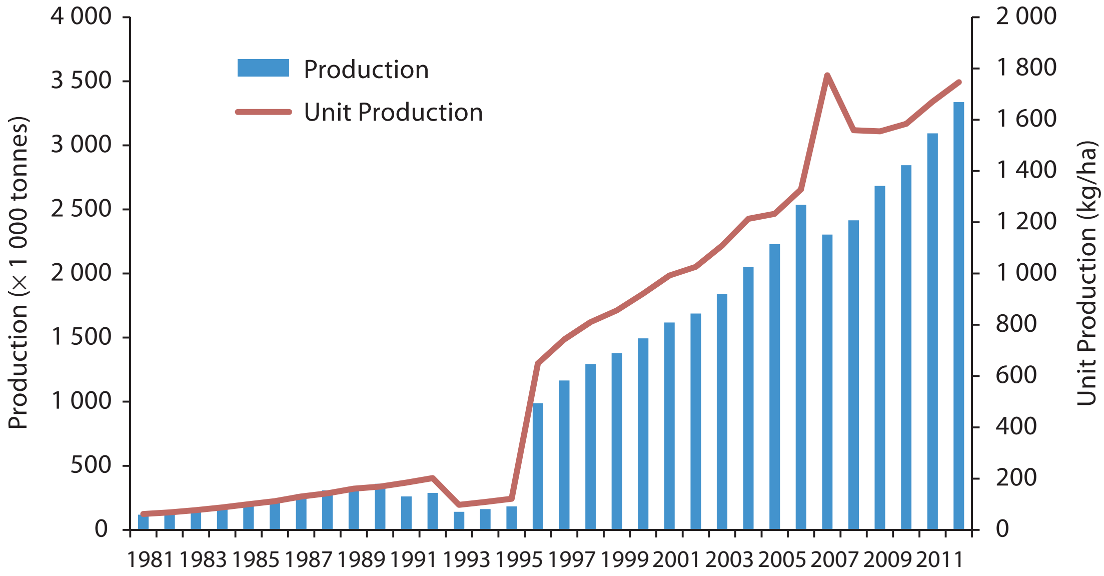
The availability of detailed data on contributions from culture-based fisheries would undoubtedly come in useful in national planning to step up culture-based fisheries development. There are indications that some nations are beginning to improve the databases on culture-based fisheries activities.[84] Renewed requests from organizations such as the FAO to member countries to impress on the importance and relevance of instituting monitoring and evaluation programmes could lead to a much needed improvement in this regard.

3.4.1 Direct benefits – Food fish production

The most obvious and measurable and well documented benefits of culture-based fisheries are the increase in food fish production and related monetary benefits to the community, as well as the overall socio-economic gains. It was indicated previously that country statistics on culture-based fisheries production, apart from China, are not available. It was also pointed out that in the long run maintaining culture-based fisheries statistics *per se* will be advantageous to fine tuning and furthering this development.

[79] De Silva *et al.* (2004)
[80] For example : Waples (1991); Kamonrat (1996); Hamasaki *et al.* (2010); Ingram *et al.* (2011)
[81] FAO (2008); Bartley *et al.* (2009); Nguyen and Sunnucks (2012); Nguyen (2015)
[82] Wijeynayake *et al.* (2007)
[83] Bartley *et al.* (2015)
[84] Sripatrprasite and Lin (2003); Jutagate and Rattanachai (2010); Chandrasoma *et al.* 2015)

In China culture-based fisheries production has increased steadily over the years (Figure 6), and currently accounts for an average production of nearly 1 800 kg.ha^{-1}.yr^{-1}, a significantly high level of production for an extensive aquaculture practice with limited external input, in the form of fertilizer. A summary of mean fish production (over a five year period) in a group of reservoirs in Sri Lanka that practiced culture-based fisheries is given in Table 6.[85] It is evident that there is a very wide variation in the mean yield per ha (468 kg.ha^{-1}; SE ±97).



Source: Wang *et al.*, 2014

Figure 6 Trends in food fish production, total and unit area, from culture-based fisheries practices in China.

Table 6 Mean fish yield from culture-based fisheries practices in a group of reservoirs in Sri Lanka*

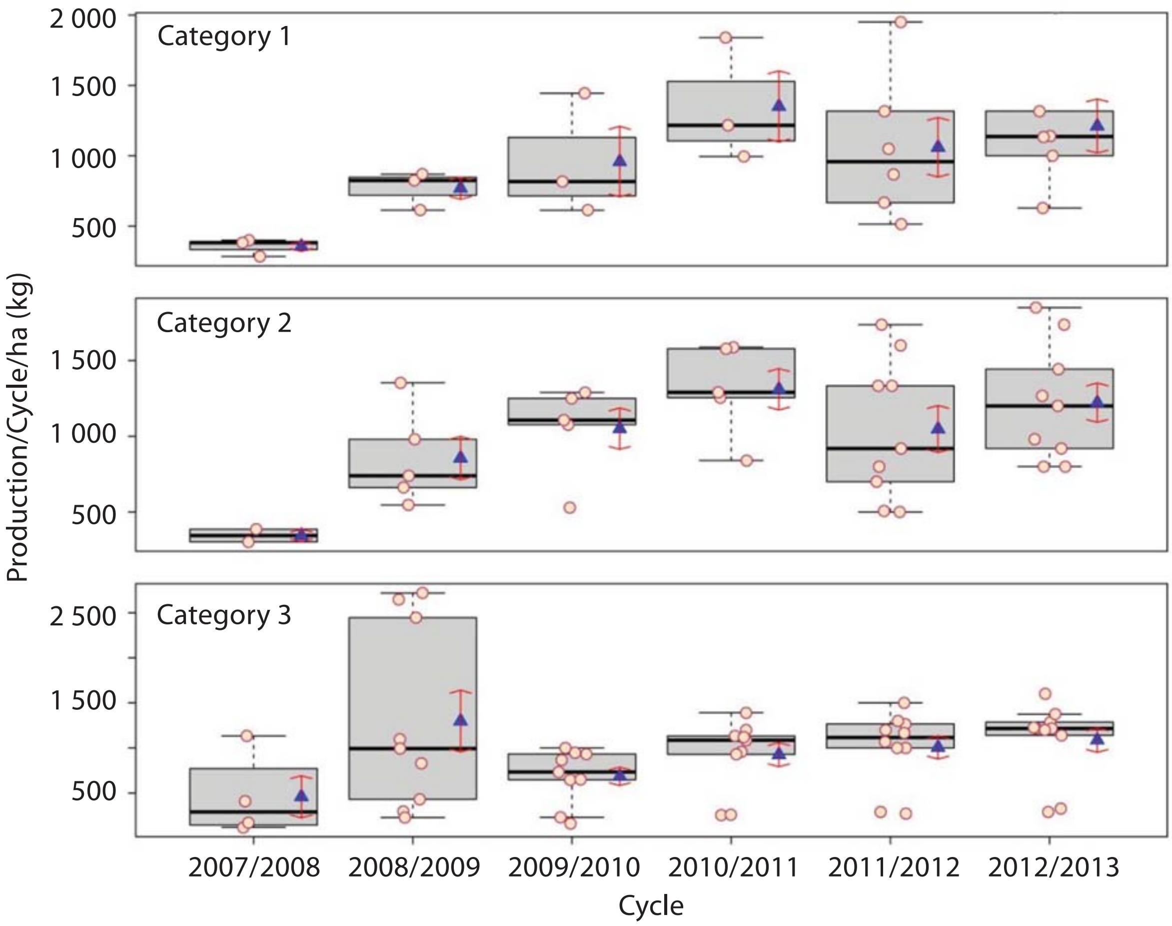
Reservoir	Yield (kg.ha^{-1})	Reservoir	Yield (kg.ha^{-1})
Bulankulama wewa	352.5	Lunuweraniya wewa	710.5
Gambirigas wewa	127.1	Madagamkadawara wewa	72.4
Karmbegama wewa	53.3	Palujandura wewa	275.9
Katugampalagama wewa	242.8	Swodagama wewa	1 800.8
Pahala Sandanankulama wewa	194.5	Weli wewa	372.7
Kumbalporuwa wewa	205.3	Wawegama wewa	181.9
Kekunawa wewa	642.6	Doser wewa	1 514.0
Pahala wewa	526.6	Bodhagama wewa	623.9
Wawullewa wewa	120.4	Galwale wewa	248.0
Mataluwawa wewa	56.7	Meegas wewa	715.6
Gonnoruwa wewa	54.6	Mahagalara wewa	877.1
Kudaindi wewa	377.1		

Notes: Table modified after Wijenayake *et al.* (2005); *the overall average production was 437 kg^{-1}.ha^{-1}.cycle

[85] Wijenayake *et al.* (2005)

A mean yield of 468 $kg.ha^{-1}$ from culture-based fisheries is significantly higher than that recorded from conventional capture fisheries in lakes and reservoirs in the region.[86] Sri Lanka has over 10 000 non-perennial reservoirs totalling 39 270 ha in extent at full supply level.[87] If 25 percent of these were to be utilized for culture-based fisheries with an average production of 468 $kg.ha^{-1}$, an additional fish production of approximately 4 595 $tonnes.year^{-1}$ would be achieved.

Comparable observations were reported from culture-based fisheries conducted in small waterbodies in Lao PDR (Figure 7). Furthermore, it is evident that there is an improvement in production with experience, and that the overall fish yields are impacted by the type of management adopted. However, in Lao PDR the type of management for each waterbody is decided through a consensus of the community. The impacts on fish yields in medium sized reservoirs that have been achieved through the introduction of culture-based fisheries, co-managed through a committee consisting of stakeholders constituted for this purpose in the last five years has been remarkable. Most of all these also provide an explicit example of increase in food fish production from a conventional capture fishery versus culture-based fisheries.[88]



Notes: Bold horizontal bars are the medians, circles represent data points for each waterbody and triangles represent the means with ±SE among waterbodies. Adapted from Phomsouvanh *et al.* (2015). Please see Tables 3 and 4 for an explanation on the three categories depicted here. The three categories are: (a) community households are permitted to fish for daily needs four to five months after stocking and the proceeds from the ticket sales at the final harvesting are used for community development activities and procuring seed stock for the next cycle; (b) similar to (a) except that the 50 percent of the proceeds from the ticket sales is distributed within the community households; and (c) not permitted to fish until the final harvest and the proceeds divided among households in an agreed manner.

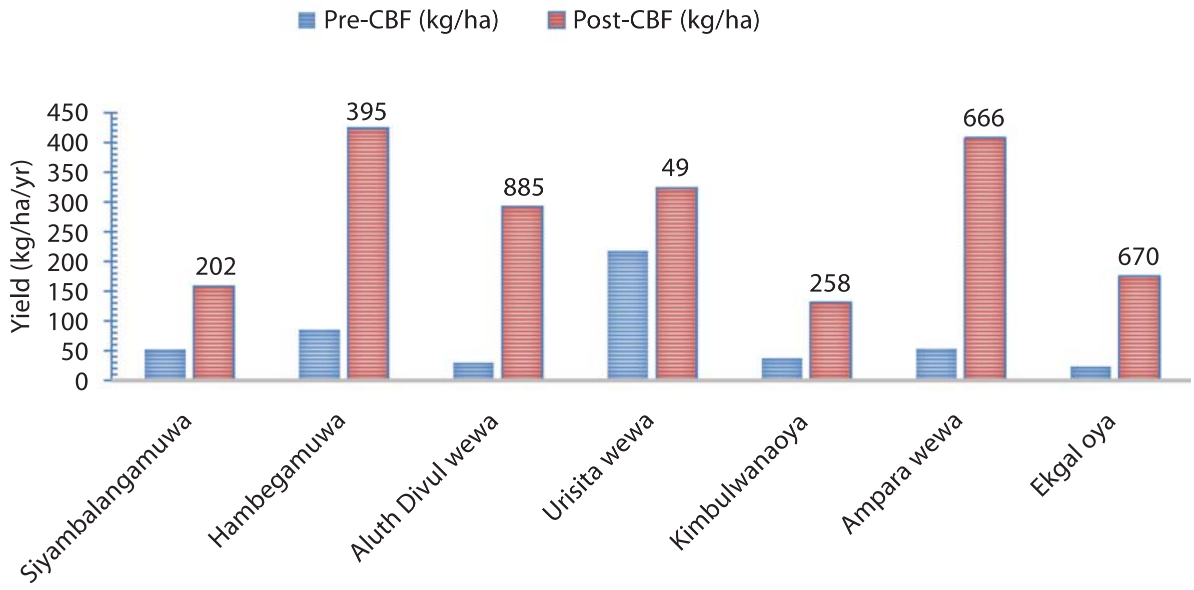
Figure 7 Boxplots presenting the distribution of production per cycle per ha (kg) in the three categories of culture-based fisheries practices, for the period from 2007 to 2013

[86] De Silva *et al.* (1991); Moreau and De Silva (1991)

[87] Jayasinghe and Amarasinghe (Forthcoming)

[88] Pushpalatha and Chandrasoma (2010); Chandrasoma *et al.* (2015)

The introduction of culture-based fisheries in medium size reservoirs (100 to 700 ha at fsl) in Sri Lanka resulted in increases in yields ranging from 49 to 885 percent (Figure 8). This is a very unusual example where traditional artisanal capture fisheries have been transformed to culture-based fisheries with encouraging results. It is possible that the limited indigenous fish fauna of the island that could support profitable fisheries through natural recruitment enables this effective transformation to a profitable culture-based fisheries strategy.



Notes: The numbers indicated against each bar denotes the percent increase in production after the adoption of culture-based fisheries. Modified after Chandrasoma *et al.* (2015)

Figure 8 Average annual fish production of medium perennial reservoirs in Sri Lanka during pre-culture-based fisheries period and after the introduction of culture-based fisheries.

Overall, adoption of culture-based fisheries in medium size reservoirs has resulted in an increase from 71 $kg.ha^{-1}.yr^{-1}$ (SE ± 26) to 273 $kg.ha^{-1}.yr^{-1}$ (SE ±46) with an average increase of 262 $kg.ha^{-1}.yr^{-1}$. It is estimated that there are 17 100 ha of medium sized reservoirs in Sri Lanka.[89]

There are conventional capture fisheries in all these reservoirs at present, targeting mostly the exotic Nile tilapia using gillnets. If culture-based fisheries were to be adopted in these reservoirs, based on the above data, it is estimated that fish production could be increased by 3 454 $tonnes.yr^{-1}$.

Adoption of culture-based fisheries in 25 percent of non-perennial reservoirs and in medium sized reservoirs could provide an increased fish yield of up to 8 060 $tonnes.yr^{-1}$. The current (2012) total inland and aquaculture in the island is estimated at 68 950 tonnes[90] and the estimated increase in production by adoption of culture-based fisheries represents an increase of nearly 12 percent. It is believed this is a conservative estimate of the potential impacts of culture-based fisheries on food fish production in Sri Lanka, where a larger degree of mobilization (say up to 50 percent of the acreage) coupled with improved management of non-perennial reservoirs will enable even further significant increases to national food fish production.

In general, in culture-based fisheries there are wide variations in yields, within a country and between countries, and reasons for this variation are not immediately apparent. Among the plausible reasons for this variation could be the natural productivity of the waters, which in turn is dependent on the

[89] Jayasinghe and Amarasinghe (Forthcoming)
[90] http://www.naqda.gov.lk/fish_production.php

catchment features[91] and allochthonous nutrient inputs through the production cycle.[92] In addition, it is most likely the management measures also play an important role, particularly in terms of minimization of escapees, effective harvesting and such.

It should also be noted that the average yields obtained in China (cf. 1 800 $kg.ha^{-1}.yr^{-1}$) are unlikely to be achieved elsewhere. The high yields obtained in China were driven by use of large quantities of inorganic fertilizer that over time brought about heavy eutrophication, and general environmental deterioration including the frequent occurrence of blue-green algal blooms, even being a health hazard to communities living in the vicinity.[93]

Triggered by some recent events of eutrophication and blue green algal blooms of some major lakes receiving aquaculture effluent,[94] there has been increasing regulation by authorities on some of these practices.[95] This will undoubtedly result in a reduction in the overall yields in the foreseeable future.[96] Despite this, these authors still consider that the overall economic viability of culture-based fisheries practices will be maintained, with a shift to using higher valued species such as mandarin fish and mitten crab. A similar trend was previously observed in species shifts in Chinese rice-fish culture.[97]

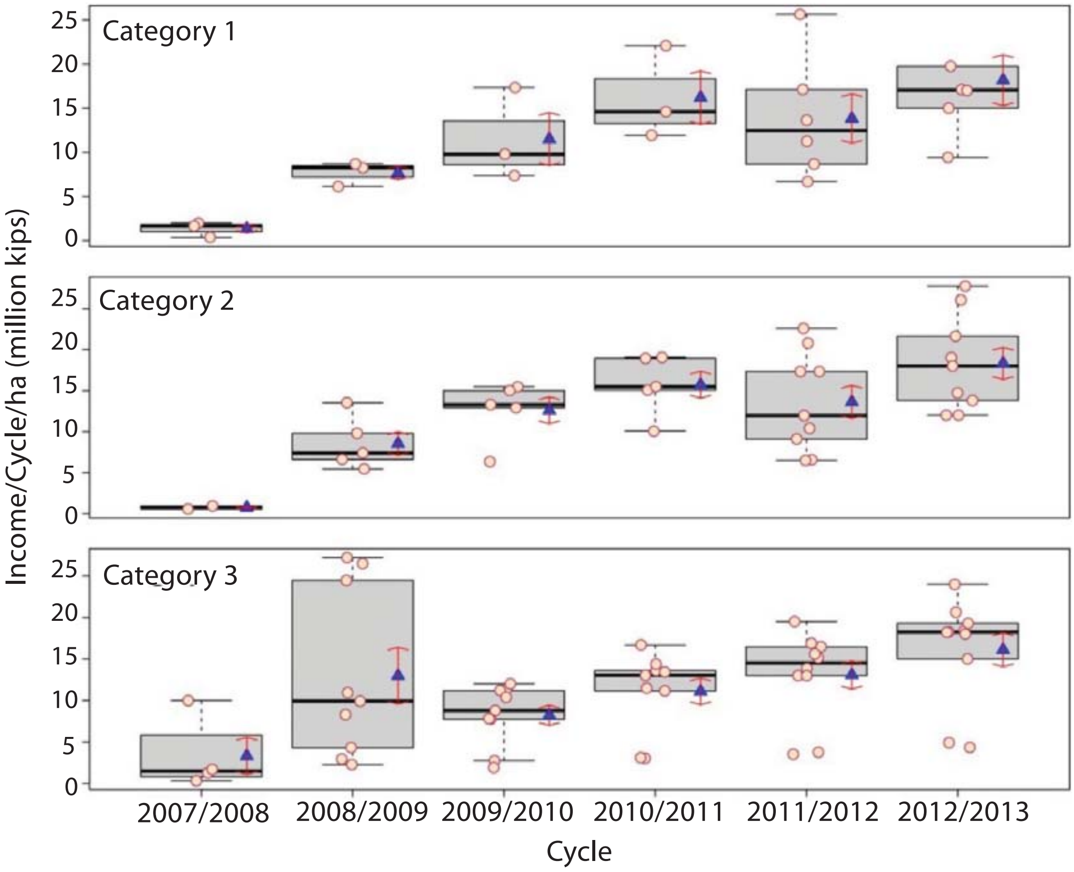
3.4.2 Direct benefits – Economic impact

The arrangements that are put in place for the utilization of inland waterbodies for food fish production are wide ranging and differ between countries and within a country on the prevailing administrative set ups, as well as on the size of the waterbody. For example, in China most inland waterbodies used for culture-based fisheries are auctioned or leased out to cooperatives formed of fishers whereas in Viet Nam they are leased to individuals and/or groups of individuals.[98] In Cambodia, Lao PDR and Sri Lanka in most instances, the communities that are engaged in downstream cultivation utilizing the water resource have the purview to develop and/or adopt culture-based fisheries and for this purpose management units are set up from persons drawn from the village.

Although it is often taken for granted that the household incomes of communities that are engaged in culture-based fisheries are significantly improved, there is very limited information documented in this regard; once again highlighting the need to put in place regular monitoring programmes.

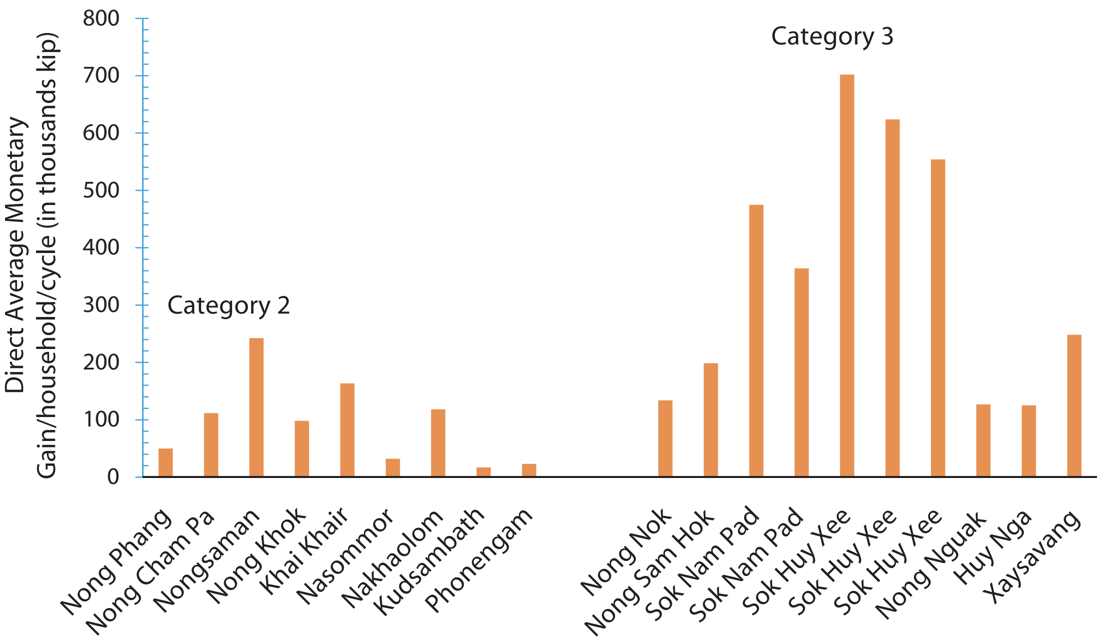
For purposes of this synthesis a recent example from Lao PDR (Figures 9 and 10), which clearly indicates the monetary gains to households is presented. In addition to the household gains there are other community gains from culture-based fisheries. These differ from country to country and/or from practice to practice. These gains take the form of investments on improving community amenities such as the school playground, the village temple/community hall, among others. In Lao PDR all communities allocate a pre-determined proportion of the monetary gains (see Tables 3 and 4) for these purposes. The allocation of funds from each cycle is arrived at by consensus.[99] In Sri Lanka a proportion of the monetary gain is retained as a bank deposit that is often used to provide assistance to community members to meet funeral expenses and as insurance in the case of major ailments of family members.[100]

[91] Wijenayake *et al.* (2005); Jayasinghe *et al.* (2006)
[92] See, for example, Jayasinghe and Amarasinghe (2007)
[93] Cai *et al.* (2012); Zhang *et al.* (2015)
[94] See, for example, Guo Longgen *et al.* (2009); Cai *et al.* (2012)
[95] Lin *et al.* (2015)
[96] Lin *et al.* (2015); Wang *et al.* (2015)
[97] Miao (2010)
[98] Nguyen *et al.* (2001)
[99] Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
[100] Kularatne *et al.* (2009)



Notes: Bold horizontal bars are the medians, circles represent data points for each waterbody and triangles represent the means with ±SE among waterbodies. Please see Figure 7 legend and Tables 3 and 4 for an explanation on the three categories depicted here. Adapted from Phomsouvanh *et al.* (2015)

Figure 9 Boxplots representing the distribution of income per cycle per ha (million kip; USD1 = 8 000 kip) in three categories of culture-based fisheries practices, for the period from 2007 to 2013.



Note: Waterbodies under category 1 do not gain any direct monetary benefits

Figure 10 The average monetary gain per cycle per household for waterbodies of categories 2 and 3

3.4.3 Direct benefits – Employment and facilitation of entrepreneurship

As culture-based fisheries practices become popular and an increasing number of waterbodies are utilized for this purpose there will be a concurrent increase in the number of people who become engaged in the activities, albeit mostly on a part-time basis. The great bulk of these people are farmers who will opt to be involved in the fishery related activity.[101] Some of them will opt or be elected to take responsibility in the co-management structure as officials of the committee,[102] for which they will be remunerated (see Tables 3 and 4).

Increased culture-based fisheries activities require a reliable supply of appropriate seed stock. Also, the majority of the species used in culture-based fisheries in Asian countries are highly fecund cyprinids (see Table 5). Artificial propagation techniques for most of these cyprinids are well developed. In this context, production of larvae and fry in sufficient quantities is not a constraint. The constraint for most countries is fry to fingerling rearing facilities as fingerlings (approximately 4 cm to 6 cm in TL; 2 g to 5 g) are preferred for stocking.

Table 7 The numbers of fin fish seed stocked in millions in culture-based fisheries practices in Sri Lanka over the years

Year	2006	2007	2008	2009	2010	2011	2012	2013
Finfish fingerlings	12.75	12.18	17.48	27.07	34.34	44.72	36.98	48.79

Note: Based on data extracted from http://www.naqda.gov.lk/fish_production.php

The number of fingerlings, primarily Indian major carps, stocked in culture-based fisheries in Sri Lanka over the last five years is given in Table 7. It increased from 12.75 million to 48.79 million in the space of eight years. This increasing fingerling requirement was met essentially from small-scale entrepreneurs who entered into partnership with government hatcheries, constructing their own simple facilities for the purpose. These initiatives not only generate wealth (see Table 8), but also create employment opportunities in rural areas and most of all brings about confidence in inland fishery activities.[103]

Table 8 Sequence of events that depict the involvement and the progress of one individual in developing a fry to fingerling rearing facility in Sri Lanka

Activity	Result
4 earthen ponds 500 m^2; begins carp fry rearing	Economic loss
Encouragement by an aquaculturist, Mr R.H. Pothuwila who donated Rs. 6 000; access to bank loans; sold 75 000 fingerlings at the rate of Rs. 1.50/fingerling	Net profit Rs. 35 000
Training under NAQDA	Enthusiasm raised; conviction fortified
8 earthen ponds stocked; 175 fry; 175 000 fry in his ponds with an expected harvest of 150 000 fingerlings and a monetary return of Rs. 225 000	Floods destroyed the harvest
Takes up job in garment factory in Colombo	Despondent; returns to the village after 2 months
Regional Aquaculture Extension Officer of NAQDA loans 100 000 rohu fry; harvests 75 000 fingerlings	Earns enough to settle all loans
Continues rearing fish fingerlings in ponds; prepares feeds using locally available ingredients	Savings of Rs. 2 million banked

101 Kularatne *et al.* (2009); Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
102 Phomsouvanh *et al.* (2015)
103 Anonymous (2011)

Table 8 *(continued)*

Activity	Result
Presently owns a pond facility consisting of 4 earthen ponds of each of 1 100 m^2 in size. In addition, he has constructed a pond of 800 m^2 size for tilapia fry rearing His pond facility is capable of rearing up to 550 000 fry, with the expected harvest of 400 000 fingerlings per culture cycle	Built new house; provides fish fry (brought from NAQDA fish breeding centres) to an out-grower; provides the out-grower with fish feed required for fingerling rearing; buys back these fingerlings at the rate of Rs. 1.50 per fingerling and keeping a profit of 50 cents per fingerling, he sells them to NAQDA. In 2010, he sold 1.6 million fingerlings to NAQDA and other governmental organizations
Target is to produce 2 million fingerlings in 2011	

Note: This also shows the private-public partnership in culture-based fisheries in Sri Lanka
Source: Anonymous, Aquaculture Asia January 2011

3.4.4 Direct benefits – Nutritional benefits

Fish has been a major component of the diet for millennia and it is thought that consumption of fish (in a generic sense) contributed to the development of the human brain and made us what we are today.[104] In the modern era the nutritional advantages of fish consumption and positive impacts of it on human health are well documented.[105] Perhaps the health benefits that fish consumption offers is one of the main drivers for the trend in increasing food fish consumption in developing countries, though yet to be backed by quantitative data. In the developing world fish provide an affordable source of animal protein to poor rural communities.[106]

By virtue of the fact that culture-based fisheries are practiced in rural areas they are most likely to improve the health of adopting communities. For example, in Lao PDR in one category of prevailing culture-based fisheries management the community households are permitted to fish for their daily household needs commencing approximately four months after stocking (Tables 3 and 4).[107] This is most likely to improve the nutrition and health of the households providing food fish for a prolonged time period not only improving household nutrition directly but making available funds that would have been used for the purchase of fish for other purposes. Once again these are aspects that need further study and attempts need to be made to quantify these benefits.

3.4.5 Indirect benefits

In culture-based fisheries usually only the direct benefits, primarily in the form of increased food fish production and associated monetary gains, if any, are taken into consideration. However, in addition to these there are many less obvious but important benefits that are difficult to quantify such as community development and capacity building.

Although nutritional gains can be attributed directly to increases in fish consumption in rural communities that practice and are engaged in culture-based fisheries, the consequent, indirect health benefits remain largely unknown. This is also an area of study that needs to be addressed and if proven to be true can act as an important tool to encourage further developments and adoption of culture-based fisheries.

[104] Crawford *et al.* (1999); Cunnnane and Stewart (2010)
[105] For example: Sastry (1985); Simopoulos (1991); Horrocks and Yeo (1999); Young and Conquer (2005); Dawczynski *et al.* (2010); Siriwardhana *et al.* (2012; Kim *et al.* (2013)
[106] See Hortle (2007); Lymer *et al.* (2008); So-Jung *et al.* (2014)
[107] Saphakdy *et al.* (2009); Phomsouvanh, *et al.* (2015)

It has been pointed out previously that the great bulk of culture-based fisheries are practised in small waterbodies that are incapable of supporting any form of a fishery, except perhaps very sporadic angling.[108] When culture-based fisheries are practised it is common to harvest "weed fish", indigenous species that are "naturally recruited" (e.g. *Rasbora* spp., *Barbus* spp. that do not attain a large size) but would not have been harvested if not for culture-based fisheries.[109] The quantities of weed fish harvested during the culture-based fisheries harvesting can be quite substantial, and are often relished by rural communities.[110] These fish species are eaten whole and indeed are known to provide additional nutritional benefits, particularly to children of poor communities.[111]

Culture-based fisheries is an activity that takes place within a broader community, and which often uses common property resources (e.g. a waterbody). The primary purpose of the waterbody may not be for fish culture, although fish production can be a valuable secondary use of the water resources. This can lead to issues about how the water is managed and can even lead to conflicts when there are differing priorities (e.g. use of water for supplemental irrigation versus retaining enough water to grow fish). Whether these issues are resolved effectively or not depends to a large extent on how the community or group is able to balance or agree on priorities. The latter is a key to choosing water bodies for culture-based fisheries adoption.[112] Culture-based fisheries are essentially a communal activity, where in most instances the downstream farming communities are engaged to make effective secondary use of the water resources for food fish production and with the ancillary result of providing subsidiary income. Such an activity is most effective when synergies are generated among the different farming groups bringing about socio-economic gains for the whole community.

Culture-based fisheries are often initiated by authorities providing training to selected representatives from communities. This capacity building is extended to others in the community, and indeed to adjacent communities that may be interested in adopting culture-based fisheries, literally generating a snowballing effect, rarely seen in other fishery related activities.[113] Furthermore, community leaders have been selected by authorities to represent leadership in fishery related activities, and the overall indirect benefits of this form of human capital development in rural communities to the socio- economic gains of whole communities cannot be undervalued.

3.5 Constraints on culture-based fisheries developments

Culture-based fisheries practices and the benefits thereof are not well monitored making it hard to evaluate overall contributions. It is somewhat unfortunate that statistics pertaining to culture-based fisheries *per se* are not collated and or maintained as a separate entity by most countries, with the exception of China. This lapse could impact on further developments and adoption of culture-based fisheries, as its contribution to the food fish supply could be masked and consequently may not attract the attention of planners and developers, or entrepreneurs. In general, the need to improve data collation on inland fisheries has been highlighted recently,[114] and collation of data on different aspects of inland fisheries will be an important addendum to this process.

Ideally, seed stocked in culture-based fisheries should be fingerlings of the chosen species, especially because the waterbodies are often not eradicated of wild fish completely, including predatory fish. In most countries fry production of desired species is not limiting, however as stated earlier, there

[108] For example : Nguyen *et al.* (2001); Wijenayake *et al.* (2005); Jayasinghe *et al.* (2006); Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
[109] See Nguyen *et al.* (2001; 2005); Wijenayake *et al.* (2005)
[110] Nguyen *et al.* (2001; 2005); Wijenayake *et al.* (2005); Limsong *et al.* (2014)
[111] Roos *et al.* (2003 and 2007); Thilsted (2012)
[112] De Silva *et al.* (2006); Kularatne *et al.* (2009); Saphakdy *et al.* (2009); Phomsouvanh, *et al.* (2015)
[113] Kularatne *et al.* (2009); Saphakdy *et al.* (2009); Limsong *et al.* (2013)
[114] Bartley *et al.* (2015)

are constraints on fry to fingerling (nursing) rearing facilities. This limitation will drive communities to stock fry resulting in low returns. Development of culture-based fisheries can encourage the emergence of parallel developments of fry to fingerling rearing facilities, through public-private partnership, thereby mitigating this constraint.

In certain instances, communities have improvised methods to grow fry to fingerling in the waterbody itself using hapas (net systems) for example. Such improvisation brings benefits that are twofold: first, the overall cost of the seed stock is reduced (including transportation costs), and second, the process ensures higher returns at harvesting.

Seed stock used in culture-based fisheries should be in good condition as after release the opportunities to manage disease occurrence become relatively difficult, if not impossible. It is in this context that regular watch should be kept of any signs of disease occurrence and mortalities, which should be removed immediately.

A major constraint to culture-based fisheries development is the lack of organizational capability and/or commitment among communities to undertake culture-based fisheries[115] and/or lack of harmony among stakeholders.[116] Agreement on *inter alia* a fishery management plan, fishing season, size limits, species to be stocked and access to the culture-based fisheries will be essential. It is therefore, very important that prior to embarking on culture-based fisheries that a community organization structure is set up and a clear consensus obtained from all the stakeholders.

In most instances culture-based fisheries activities in Asia were and often are government initiated. In the very early days, governmental initiatives to encourage culture-based fisheries among rural communities were short lived, as for example in Sri Lanka.[117] These failures in culture-based fisheries adoption were mostly attributed to lack of appreciation of the process and the potential benefits as well as lack of organization of communities gearing them to ownership of the activities.

In most countries there are no provisions for insurance of culture-based fisheries practices. One possible reason for the lack of interest in culture-based fisheries by the insurance sector may be the lack of suitable legislation permitting/recognizing culture-based fiheries as a community activity utilizing a public water resource. Therefore, countries need to ensure that the legal background is provided in order to facilitate bank borrowing and insurance for culture-based fisheries as has happened in Sri Lanka where previously the law (Sri Lanka Agrarian Act of 1947) stated that culture-based fisheries could not be conducted in non-perennial waterbodies.

Marketing and price fluctuations can be a disincentive in seasonal waterbodies using culture-based fisheries. In a given geographical location/region the harvesting in culture-based fisheries will usually be in compliance with the prevalent hydrological cycle (see Figures 4 and 5). Also harvesting in most instances is accomplished during a three to four day period e.g. Lao PDR,[118] Sri Lanka[119] and Viet Nam.[120] Consequently, there could be a glut of food fish (in most instances Chinese and Indian major carps) and the respective communities may not get the best returns for the produce. Apart from improving the prevalent market channels catering to culture-based fisheries it is appropriate that adjacent communities work out suitable time frames to harvest so that possibilities of a glut of fish within a very narrow time frame in a small geographic area is minimized, thereby ensuring fair farm gate prices.

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[115] Kularatne *et al.* (2009)
[116] Valbo-Jørgensen and Thompson (2007)
[117] Thayaparan (1982); Chandrasoma (1986)
[118] Garaway *et al.* (2006); Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
[119] Jayasinghe *et al.* (2005); Kularatne *et al.* (2009); Pushpalatha and Chandrasoma (2010)
[120] Nguyen *et al.* (2001 and 2005)

3.6 Risks associated with culture-based fisheries developments

Culture-based fisheries in Asia are often conducted in small waterbodies as a secondary activity, mostly through community engagement. The guarding of stocked seed is crucial to obtaining significant yields. Most communities engaged in culture-based fisheries introduce a roster system to keep watch of the stock and the cost of this labour is accounted for.[121]

Where small waterbodies are leased out for varying time periods to individuals and/or groups of individuals, e.g. Viet Nam,[122] lessees have to invest in minor repairs of the waterbodies, otherwise risk losing stocked seed.

As in all primary production activities, culture-based fisheries cycles are subjected to the elements, primarily the rainfall patterns, resulting in certain degree of unpredictability of the water levels. This is a facet that is beyond human control. The available mitigating measures will involve careful planning to comply with the hydrological cycle of waterbodies, such as for example to adjust stocking and harvesting accordingly.

Ever increasing risks are associated with the higher frequency of occurrence of flash floods, change in monsoonal rain patterns and longer periods of dry weather all of which are attributed to climate change.[123] Flash floods could result in the loss of all or a significant proportion of the stock and also could bring about damage to sluice gates or other infrastructure resulting in loss of revenue and most of all impacting on the enthusiasm and the commitment of rural communities. There is evidence from the past that such mishaps resulted in communities abandoning culture-based fisheries.[124]

3.7 Impact of research and development efforts on culture-based fisheries and future needs

Research and development efforts on culture-based fisheries development over the years have been relatively limited when compared to those on conventional aquaculture. Perhaps one of the early efforts was initiated by the United Kingdom's Department for International Development (DFID) in Bangladesh in respect of inland fisheries development. This also included culture-based fisheries related activities such as stock enhancement in oxbow lakes.[125] As a result of these research and development efforts for example the stocking densities were adjusted to suit the water transparency[126] and two management systems were put in place for fisheries enhancement and participatory resource management in oxbow lakes,[127] and a fresh stocking strategy was developed to utilize the spring and autumn algal blooms by the seed stock.[128] All these lead to the consolidation of culture-based fisheries practices in oxbow lakes in particular. These efforts were followed by work on the socio-economic sustainability of culture-based fisheries in oxbow lakes and beels.[129] It was pointed out that a key to sustainability and equitable distribution of benefits from culture-based fisheries was harmony among stakeholders.

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[121] Saphakdy *et al.* (2009); Phomsouvanh *et al.* (2015)
[122] Nguyen *et al.* (2001)
[123] IPCC (2007 and 2013)
[124] Thyaparan (1982)
[125] Petr (1998); Middendorp *et al.* (1999)
[126] (Hasan and Middendorp (1998)
[127] Middendorp and Balarin (1999)
[128] Hasan *et al.* (1999)
[129] Valbo-Jørgensen and Thompson (2007)

Importantly, the contribution of culture-based fisheries to the health and well-being of rural communities needs to be addressed. This is an area that would require a team of researchers with a very wide range of expertise, such as social scientists working in conjunction with medical specialists and nutritionists. Quantification of extent of improvement to nutrition and health of rural communities from culture-based fisheries will provide a boost to furthering these practices and contribute to food security at large.

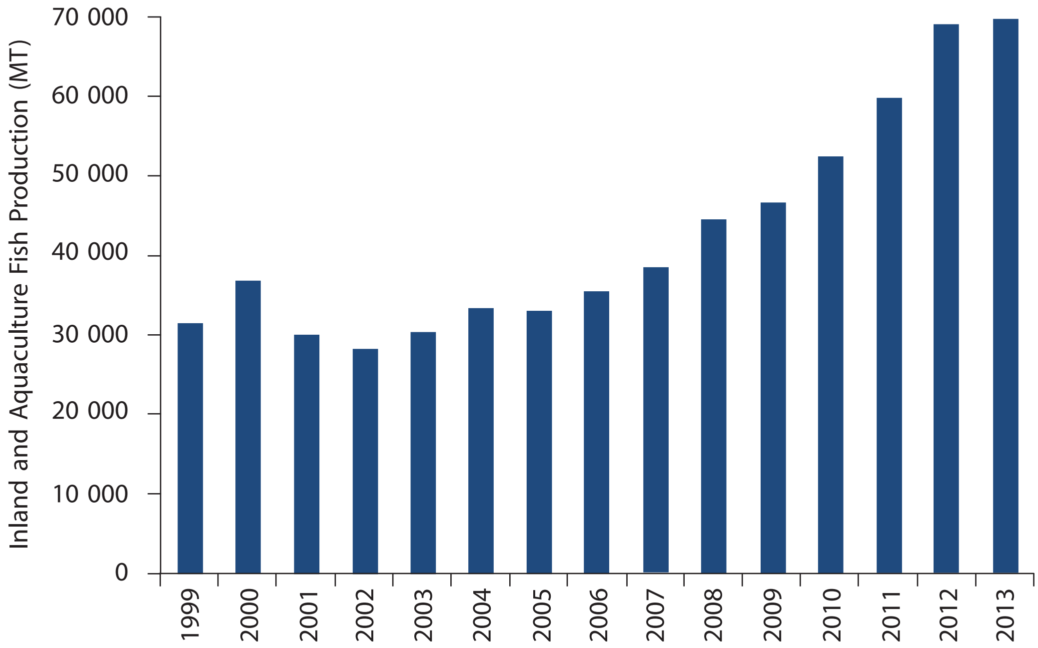
The Australian Centre for International Agricultural Research (ACIAR) has supported a geographically and technically diverse research and development programme on culture-based fisheries from 1995 to the present. This has covered a number of Asian countries, viz. Cambodia, Lao PDR, Sri Lanka and Viet Nam.

Sri Lanka offers a good example of the application of research and development efforts on culture-based fisheries, arising from this initiative, over the last decade or more. The major results of these efforts are summarized as follows:[130]

- The establishment of a science-based objective method for selecting non-perennial and perennial waterbodies for culture-based fisheries practices,[131] thereby avoiding waste of resources, in particular seed, and effort; these science based methods, with suitable modifications could be adopted for other tropical countries that wish to embark on culture-based fisheries;
- implementation of culture-based fisheries systematically on a large scale in village reservoirs in early 2000s, and associated research and development work on species combinations, proportions and stocking densities have enabled significant increases in fish production from about 28 000 MT in 2002 to about 69 800 MT in 2013 (Figure 11);
- the expansion of culture-based fisheries development is evident from the significant increase of number of fingerlings stocked (see Table 7);
- the development of models based on catchment features used indirectly to determine the stocking densities in small waterbodies for culture-based fisheries (general applicability for water bodies in most countries);
- the gradual success of culture-based fisheries based on the application of science and improved community organization sparked off an ancillary sector of fry to fingerling rearing bringing about employment opportunities and economic gains to rural households, and virtually eliminating the bottleneck on fingerling supplies; and
- in recent times, culture-based fisheries have been successfully extended to medium and major perennial reservoirs that have resulted in large increases in fish yield (Figure 8) and consequent gains in the socio-economic status of fishers and related communities.[132]

Some of the future research needs to develop and consolidate culture-based fisheries practices in Asia have been highlighted in the two previous sections. It is reiterated that improvements in data collation are a necessity, coupled with work on application of culture-based fisheries in countries where there is open access to waterbodies such as in Cambodia (Limsong *et al.*, 2014).

[130] Modified after Amarasinghe and Wijenayake (2015)
[131] Nissanka *et al.* (2000); De Silva *et al.* (2004)
[132] Chandrasoma *et al.* (2015)



Note: Drawn from the data reported at http://www.naqda.gov.lk/inland_Aquaculture.php.

Figure 11 Annual inland fisheries and aquaculture production in Sri Lanka (1999–2013)

3.8 Culture-based fisheries and food security

The role of culture-based fisheries in food security and/or fish food security should not be considered in isolation but in the context of all food needs for a growing population. The projected food needs for a growing population by year 2050 will require an estimated 70 percent increase from the current level. This increase entails an addition of 1×10^9 tonnes of cereal, 200×10^6 tonnes of meat,[133] and 30 to 40×10^6 tonnes of fish to the current levels to feed 9.5 billion people. These increases in the volumes of food commodities have to be produced within the limitations of certain primary resources (land, water, physical and biological) available on this planet, and in a way that maintains environmental integrity. Only when these requirements are met can production be truly sustainable. However, this will need major paradigm shifts,[134] including shifts pertaining to food fish production.

When the challenges of feeding nine billion people are considered the primary issues raised are competition for land, water and energy.[135] In addition to these, particularly with respect to food fish, are the over exploitation of fishery resources and use of wild caught fish for conversion into fish meal and fish oil.[136] The impending climate change impacts, particularly on aquaculture, are thought to exacerbate these problems.[137]

As pointed out in the Introduction (Chapter 1) the gap between food fish supply and demand has been mostly accounted for by the growth in the aquaculture sector. But the question arises: can one expect aquaculture to grow indefinitely in the ensuing years? This is particularly so in the wake of competition for some of the key primary resources, as well as growing concerns that intensification is detrimental to maintaining environmental integrity, and hence overall sustainability in respect of all food production sectors.[138] Intensification of aquaculture practices and the consequent negative

[133] FAO (2009)
[134] Charles *et al.* (2015); Chartres and Noble (2015); Poppy *et al.* (2015)
[135] Hanjra and Qureshi (2010); Godfray *et al.* (2010); Chartres and Noble (2015)
[136] Tacon *et al.* (2010)
[137] De Silva and Soto (2009); Leung and Bates (2013); Nguyen *et al.* (2014)
[138] Charles *et al.* (2015); Chartres and Noble (2015); Poppy *et al.* (2015)

environmental impacts on watersheds are becoming an increasing concern as exemplified in the case of China,[139] the global leader in aquaculture production.

It is in the above contexts that culture-based fisheries become important; the only external input in culture-based fisheries is seed stock that feed on the naturally produced food organisms in a waterbody. It is low cost and utilizes existing waterbodies and is often community based. Culture-based fisheries focused on food production does not make additional demands on feed inputs, land or water, but is an effective secondary user of existing resources. Culture-based fisheries are a low cost strategy, requiring minimal technical expertise, and impacting mostly rural communities that tend to be poorer than their urban counterparts.[140]

There is a school of thought that the vast marine resource could be used for future aquaculture developments.[141] But this proposition will have to take into account the limitations imposed by basic ingredients needed for feeds, viz. fishmeal and fish oil, as well as the ethical question of converting a human protein source to a protein source for animals when there is a considerable degree of malnutrition prevailing on our planet. Added to this will be the monetary costs involved in this development, perhaps a development that is beyond the capabilities of developing nations, which in turn are the backbone of aquaculture production.

In the early phases of culture-based fisheries developments it was considered that small waterbodies (cf. <40 ha) that retained water for a minimum period of eight to ten months of the year were the most suitable. Based on the above notion, and the fact there is an estimated 66 710 052 ha of such waterbodies in Asia[142] with the potential for developing culture-based fisheries, it has been proposed that if 5 percent of these waters were used for culture-based fisheries with an expected yield of 700 $kg.ha^{-1}.yr^{-1}$ it would result in a total yield of 2.5×10^6 of food fish per year.[143]

It is evident that a number of Asian countries have embraced culture-based fisheries as a strategy for improving food security. To this end relevant changes in policies and legislative needs have been put in place. Added to this political will, is the fact that concerted research and development efforts on culture-based fisheries over the last decade or more have provided the technical knowledge to improve yields from culture-based fisheries. Templates are available on species combinations and proportions[144] and models are available that could be used for determining the most desirable stocking rates.[145] Accordingly, countries that embark on culture-based fisheries as a fresh strategy will find it easy to adopt and implement.

It has been shown in the foregoing sections that some countries in Asia have been capable of improving fish production (and incomes) significantly. It has also been demonstrated that in certain instances e.g. Sri Lanka, culture-based fisheries could replace conventional capture fisheries in medium-sized reservoirs bringing about substantial increases in fish production. Often these reservoirs are shallow and subjected to heavy draw down making them unsuitable for cage culture for example, a relatively intensive aquaculture practice that results in high yields.

In the above context it would not be unrealistic to assume that in Asia 20 percent of the water area of 66 710 052 ha could be mobilized for culture-based fisheries within the next decade, if not earlier. This together with the improved know-how could result in an average yield of 800 $kg.ha^{-1}.yr^{-1}$ being achieved, resulting in a total fish yield of approximately 10.72×10^6 $tonnes.yr^{-1}$; a considerable addition to food security for Asia through a low-cost, easily adoptable and an environmentally friendly practice.

[139] Guo *et al.* (2009); Cai *et al.* (2012); Lin *et al.* (2015); Zhang *et al.* (2015)
[140] Yunus (2007)
[141] Duarte *et al*. (2009)
[142] *FAO (1999)*
[143] *De Silva (2003)*
[144] *Nguyen et al. (2001); Wijenayake et al. (2005); Jayasinghe et al. (2006); Wang et al. (2015)*
[145] *Wijenayake et al. (2005); Jayasinghe et al. (2006);* Phomsouvanh, *et al*. (2015)

4 RECOMMENDATIONS AND CONCLUSIONS

In the foregoing sections it has been demonstrated that culture-based fisheries practices are being embraced by a number of developing countries in Asia as a plausible strategy for enhancing food fish production, particularly among rural communities. It has also been shown that culture-based fisheries are often practised in small waterbodies that tend to serve many purposes, especially the irrigation of downstream paddy cultivation. Food fish production is a secondary activity adopted by the communities, on community-based management principles, with benefit sharing arrangements being arrived at through a consensus.

The secondary use of water resources for food fish production through adoption of culture-based fisheries generally involves only one external input, i.e. seed stock. Exceptions exist such as in China where fertilizer is used to enhance productivity of the waterbody, a practice that is, gradually declining.

The examples cited earlier demonstrate that in all instances significant increases in food fish production and monetary benefits have been achieved. In view of the limited external inputs, culture-based fisheries are considered to be a relatively low cost, environmentally friendly practice increasingly embraced by governments in the region. To the latter end governments have incorporated culture-based fisheries developments in strategies to increase food fish production and, where relevant, suitable legislative changes have been made to facilitate the adoption of culture-based fisheries.

Culture-based fisheries are, however, a relatively new practice that is being adopted by most countries. In order to ensure sustainability of culture-based fisheries and to reap the full benefits in development planning processes there is a need to collate and monitor culture-based fisheries activities. Such regular monitoring should include food fish production, monetary and nutritional gains (direct and indirect) to communities, and employment opportunities, and others.

Regular monitoring could also lead to a deeper understanding of the issues involved and further strengthening of culture-based fisheries practices. It could also encourage associated infrastructure development from local governments. Successes in culture-based fisheries have been shown to trigger small-scale entrepreneurship benefitting small communities, and public-private partnerships. Both of these are features of development that will promote the long term sustainability of culture-based fisheries.

To facilitate adoption of culture-based fisheries by rural communities it will be useful to have suitably developed manuals made available. Such manuals can be of two forms: one dealing with the technical aspects and the other showing, through ample graphic or pictorial illustration, the step-wise processes involved in culture-based fisheries.

As culture-based fisheries become increasingly popular it will be relevant to develop criteria that act as indicators of success, and also enable cross comparisons between management styles, intra- and inter-country practices as well as regional practices.

Such criteria will enable guidelines to be readily available to policy-makers and investors. Among such criteria may include standardization of food fish yield estimations (e.g. $kg^{-1}.ha^{-1}$.cycle), returns from stocking on a weight basis, extent of employment created, arrangements that are used for sharing monetary benefits and synergetic impacts on communities practising culture-based fisheries. Importantly, management guidelines also should consider the development of better management practices relevant to each country and consider plausible mitigation measures in the wake of climate change impacts. Some of the predicted impacts such as increasing frequency of unusual weather events in the tropics of Asia are likely to have a direct bearing on culture-based fisheries practices.

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