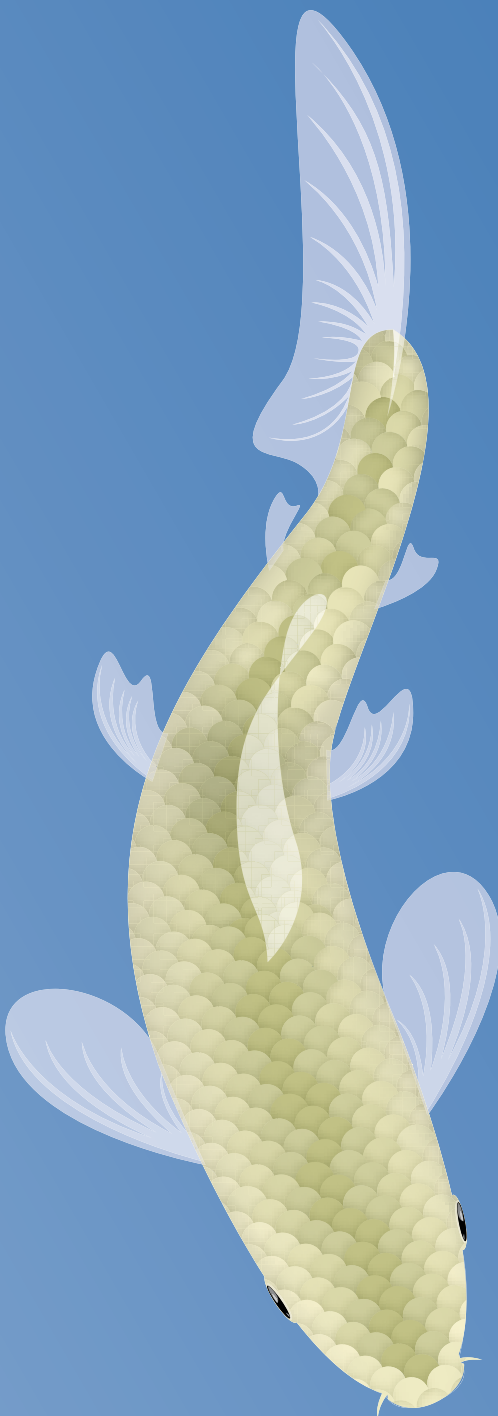


Perspectives on culture-based fisheries developments in Asia



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Edited by Sena S. De Silva, Brett A. Ingram and Simon Wilkinson



Australian Government
**Australian Centre for
International Agricultural Research**



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Foreword

Food and nutritional security remains problematic in many developing countries. There are many initiatives underway which are designed to increase food supply, employment and income opportunities, most of which require considerable capital inputs (for instance cropping, livestock production and aquaculture). Often overlooked, are the opportunities to produce more food from the natural productive ecology of lakes and forests. Culture-based fisheries are one example of a relatively simple and low cost technology which can deliver nutritional and economic benefits to communities which often have few livelihood options.

Culture-based fisheries are based in lakes and reservoirs, where fish populations are supplemented by hatchery-produced fingerlings. The stocked fish may breed naturally in the lakes, or they may be species which are desirable but which do not breed in the still-water environments. Fish growth is driven by the natural productivity of the water bodies. Generally, local communities have ownership of the fish, with the benefits shared or used for communal purposes. However, there are other options for management and ownership depending on local needs, cultural arrangements and other uses of the water.

Research and development of culture-based fisheries has been a major endeavour for NACA and ACIAR since the mid-1990s. This has involved projects in Sri Lanka, Indonesia, Vietnam, Lao PDR and Cambodia^{1,2}, the results of which have been reported in previous publications, as noted below. In this volume, we bring together an update from research conducted in those countries and others. We trust the information will foster further development and spread of culture-based fisheries in Asia and beyond, and in doing so, bring livelihood and nutritional benefits to otherwise resource-poor communities.

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1. De Silva S. (ed.), 2001. *Reservoir and culture-based fisheries: biology and management*. Proceedings of an International Workshop held in Bangkok, Thailand from 15-18 February 2000. ACIAR Proceedings No. 98. 384 pp.

2. De Silva S. S., Amarasinghe U. S. and Nguyen T. T. (eds.), 2006. *Better-practice approaches for culture-based fisheries development in Asia*. ACIAR Monograph No. 120, 96 pp.

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Preface

It is estimated that the global population will reach 9.5 billion by 2050. Providing the food needs for nine billion people is a major global concern with projections suggesting that the current level of food production needs to be increased by 70 percent. Specific projections for example include an increase in production of 1 billion tonnes of cereals and 200 million tonnes of meat.

Since 1950 the per capita fish consumption has increased from 6 kg/year to 19.2 kg/year in 2012, with Asia accounting for two thirds of the global fish consumption, averaging 21.4 kg/caput/year in 2011. It is estimated that even at the current rate of fish consumption the world will require an additional 30-40 million tonnes of food fish by 2050 to account for the expected population increase. Global food fish supplies, until recently, were predominantly of a hunted origin - based on wild capture fisheries, but in the last few decades this predominance changed to a farmed origin, like all our other staples, resulting from the sustained development of aquaculture, approximately at 6 percent per year over the last three decades or so. Aquaculture production reached 76,321,310 tonnes in 2011, with the Asia-Pacific region contributing over 80 percent, and PR China being the leading nation accounting for 65.7 percent of the total global production.

The question arises whether this growth impetus in intensive aquaculture can be maintained as in the last three decades, especially in the wake of increasing competition for primary resources, physical and biological, and the need to maintain environmental integrity. It is in this context that use of existing water bodies for the secondary purpose of food fish production, particularly in rural areas in developing countries, becomes important. Culture-based fisheries is an environmentally friendly practice being an effective secondary use of existing water resources for food fish production in which the only external input is seed stock.

This book is a result of the “Regional Consultation on Culture-Based Fisheries Development in Asia”, held in Siem Reap, Cambodia, 21-23rd of October 2014, under the auspices of the Australian Centre for International Agricultural Research (ACIAR), the Mekong River Commission (MRC) and the Network of Aquaculture Centres in Asia-Pacific (NACA). The consultation was jointly organised by NACA and the Fisheries Administration of the Royal Government of Cambodia.

The primary objectives of the consultation were threefold:

- To showcase the achievements of the ACIAR funded project, “Culture-based fisheries development in Lao PDR and Cambodia”, coordinated by NACA.
- To evaluate important and relevant principles pertaining to sustained developments in culture-based practices, mostly emanating from research and development projects on the subject area conducted under the auspices of the ACIAR since 1995.
- To bring to the public domain specific examples of gains from adoption of culture-based fisheries as an effective means of increasing food fish supplies, benefitting rural communities in particular.

Accordingly, this book, for clarity and convenience, is divided into five sections.

- **Part 1:** A summary of the discussions of selected important issues pertaining to culture-based fisheries at the regional consultation.
- **Part 2:** Key aspects that have to be considered in culture-based fisheries developments.
- **Part 3:** Selected case studies on culture-based fisheries developments in the region.
- **Part 4:** R&D projects on culture-based fisheries supported by ACIAR over the years and publications that have resulted from these.
- **Part 5:** Other abstracts from the regional consultation.

It is hoped that this book will be useful to all stakeholders who are engaged, or likely to be engaged, in culture-based fisheries development.

The Editors

February 2015.

PART 1.

A summary of the discussions of selected important issues pertaining to culture-based fisheries at the regional consultation

CBF definition related

- CBF are stock enhancement practices in water bodies that are generally incapable of supporting sustainable fisheries through self-recruiting fish populations, and where the stock is managed and owned either individually and or collectively.
- Often the water bodies in which CBF is practised are communally managed by village organisations that are operational for managing the water regime, such as for downstream cultivation. However, in some countries water bodies may be auctioned for CBF purposes by the authorities to an individual and or groups of individuals.
- In CBF the natural productivity is utilised by the stocked seed, and rarely are external nutrients added to the system and or provided in the way of food for the stocked fish species. An exception may be when grass carp is stocked.
- CBF is often conducted in small water bodies, perennial and or seasonal, that retain water for at least six to eight months of the year.
- Increasingly, however, CBF are being practised in larger water bodies and through a strict co-management regime, with restricted access to the fish resources¹. Although there have been fisheries based on natural recruitment in these water bodies, adoption of planned stocking programs, together with the strict enforcement of a regime of co-management where only members of the relevant management unit are permitted to access the resource, essentially makes these a form of widening CBF practices.
- It should also be noted that addition of seed stock to a water body with a view to enhancing fish production is only one facet of stock enhancement (SE). SE² may also include other practices, such as introduction of close seasons, gear restrictions, establishment of conservation zones, improving and or establishing spawning grounds, removing impediments to spawning and other migratory pathways.

1. Chandrasoma, J., et al. (current volume) Impact of introduction of culture-based fisheries on fish production in perennial reservoirs of Sri Lanka.

2. Weimin, M., De Silva, Sena S., Davy, F.B. (Eds.), 2010. Inland Fishery Resource Enhancement and Conservation in Asia. *RAP Publication* 2010/22, Regional Office for Asia and the Pacific, FAO, Bangkok.

Socio-economic aspects of CBF

- In general CBF are practised in rural areas, often where water bodies suitable for such activities are located. Hence, the primary beneficiaries of CBF are rural communities, who often tend to be impoverished.
- As CBF is a relatively low cost activity, with the main external input being seed stock, most developing country governments regard CBF to be relevant to and an integrated part of rural development.
- Accordingly, a number of developing country governments in Asia have recognised CBF as a major strategy for improving nutrition and rural household incomes, and have introduced legislation, where relevant, to facilitate such developments.
- The nature and the manner of sharing of the socio-economic gains of CBF may differ between the management regimes of water bodies, within a region and country, and could be relatively unique to some regimes. In most regimes there is an emphasis on utilising a proportion of the gains on improving social amenities, a trait that is prevalent among rural communities in developing countries.

Indigenous versus alien species in CBF practices

- The spectrum of species used in CBF practices differ between regions within a country and between countries, often being dictated by the indigenous fish fauna of the country, the availability of suitable indigenous fish species for CBF practices (e.g. fast growing), fry and fingerling availability, consumer acceptance, among others.
- On the other hand, in some countries alien species that have been established and have been used for aquaculture (intensive) purposes for a significant length of time, and which have not shown any explicit evidence of impacting biodiversity, continue to be used for CBF.
- In all instances the choice of alien species for CBF practices have to be within the realm of the fishery/ biodiversity laws and regulations of the country.

- Irrespective of whether indigenous or alien species are used in CBF practices, these practices offer a greater potential that stocked fish mingle with wild populations and so care should be taken to ensure/ minimise loss of genetic diversity of the respective wild counterparts through a well-planned broodstock management strategy.
- › Certain CBF practitioners have already become alert to the fact that the most desired seed stock size is fingerlings and have utilised the water body to rear hatchery purchased fry to advanced fry and or fingerlings in improvised hapas, thereby reducing the purchase price of seed stock and also reducing the overall mortality to grow out.

Potential challenges and constraints to expansion of CBF practices in the region

- CBF practices are almost entirely dependent on the prevailing weather patterns, particularly those conducted in non-perennial, small water bodies, which also happens to be the where the bulk of current practices are conducted. As such, the potential impacts of climate change in relation to onset of the rainy periods and increased frequencies of prolonged dry and or rainy periods could impact on the production cycle³.
- Careful planning will be needed to ensure fry/ fingerling availability in accordance with changing weather patterns, where relevant, and also continued vigilance to ensure the safety of the stocked seed.
- Since the CBF cycle follows the prevailing weather pattern within a given region/locality, the harvesting tends to occur within a narrow time frame. As CBF practices become more prevalent this could lead to an oversupply of fish within this narrow time frame resulting in poor returns to the practitioners/ community management units.
 - › To overcome the above the management groups within a region/locality have to liaise with each other and spread the harvesting as much as possible to avoid an oversupply.
 - › In addition, the CBF practicing communities need to explore the possibilities of adopting simple, least energy costing, processing techniques for selected species in order to maintain reasonable farm gate prices.
- As CBF practices become increasingly popular, there will be a corresponding increase in the demand on seed stock, particularly advanced fry and or fingerling of desired species.

- › Such practices should be encouraged to reduce constraints on fingerling supplies.
- › In addition, as had happened in certain countries (e.g. Sri Lanka), fry to fingerling rearing as an auxiliary sector should be encouraged when constraints on fingerling supplies are minimised and also provides additional livelihood opportunities to rural communities.

Scope of CBF as a strategy for increased food fish production

- All evidence indicates that, over the last one and a half decades, CBF practices have become popular in many developing countries in Asia for augmenting food fish production and providing subsidiary income to rural communities.
- Consequently, some governments have recognised CBF developments to be a major strategy for food fish production in rural communities, and in certain instances have introduced and or amended existing legislation to facilitate CBF adoption by community groups.
- In the early phases of CBF developments it was considered that small water bodies (cf < 40 ha) that retained water for a minimum period of 8-10 months of the year were the most suited.
 - › Based on the above notion, it was reported that there are 66,710,052 ha (FAO)⁴ in Asia with the potential for developing CBF.
 - › Assuming a production of 700 kg/ha/yr⁵, based on Chinese practices and if only 5 % of the water bodies were used, it was estimated that fish production would be increased by 2.5 million t/yr; a substantial increase at that.
- Much water has flown under the bridge since the above prediction was made; notably:

3. De Silva, S.S., 2012. *Better Management Practices for Culture-Based Fisheries, Lao PDR*. 46 pp.; <http://enaca.org/publications/inland-aquaculture/better-management-practices-culture-based-fisheries-lao.pdf>

4. FAO, 1999. *Irrigation in Asia in figures*. FAO, Rome, Italy.

5. De Silva, S.S., 2003. Culture-based fisheries: an underutilised opportunity in aquaculture. *Aquaculture* 221, 221-243.

- › Many other countries have embarked on CBF.
 - › As a result of R&D the overall return from CBF has increased substantially. For example, in China it is reported to be 1,746 kg/ha/yr⁶.
 - › Similarly, larger perennial water bodies are being used for CBF (e.g. Sri Lanka and Thailand), which has boosted fish production further.
 - › As such, if only the small water bodies are taken into consideration and in view of the fact many governments have embraced CBF as a strategy for increasing food fish production in rural areas, one could assume that by the end of the present decade at least 10 % of 66,710,052 ha could be utilised for CBF. Assuming a production level of 1,000 kg/ha, this will result in a yield of nearly 6.7 million t/yr, a very significant addition to the global food fish needs.
- Returns from CBF are very country and area specific. In order to optimise the returns the practices also require a very well organised and a cooperative community. Often these communities have had little previous experiences in fishery related activities. Hence, adequate planning, training and other relevant research needs must be fulfilled to optimise yields from CBF - perhaps the most environmental friendly and sustainable form of aquaculture.
 - The notion that CBF will revolve around producing relatively low-valued fish, feeding low in the trophic chain, will change in some countries where high-valued species will be cultured to meet market demands, as is happening in China , and increasing use of species such as the giant freshwater prawn, *Macrobrachium rosenbergii*.

6. Wang, Q, Cheng L., Liu, J., Li, Z., Xie, S. and De Silva, S.S., 2014. Freshwater Aquaculture in PR China: Trends and Prospects. *Reviews in Aquaculture*, 20 pp.

PART 2.

General aspects of culture-based fisheries

Culture-based fisheries: Why, what, where, how and for whom?

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Abstract: In the wake of increasing population and rising average per caput consumption of food fish and a plateauing off of the traditional food fish supplies there is an urgent need to close the increasing gap between supply and demand. It is generally acknowledged that aquaculture would increasingly contribute to closing this gap. Aquaculture production is still and likely to continue to be dominated by freshwater finfish production well into the foreseeable future, concentrated in developing countries.

However, increasing intensification of inland aquaculture is confronted with resource limitations such as land and water, and biological inputs such as feeds and consequently other plausible alternatives have to be explored. One such alternative is to utilise small and medium sized water bodies, which are estimated to be found in great abundance in developing countries of the tropics (e.g. estimated around 67×10^6 ha in Asia alone). These are mostly incapable of supporting even subsistence fisheries through natural recruitment, but could be utilised, secondarily, for culture-based fisheries development (CBF).

CBF is essentially a stock and recapture strategy, where the stocked fish feed and grow on naturally produced food resources, and which are most effective when communally managed. The returns from CBF could be very significant in terms of nutritional as well as monetary benefits to the communities.

In this presentation the relevant background information on food fish needs and the ways and means of introducing CBF practices in inland waters are dealt with. The importance of this environmentally “friendly” practice to enhance food fish production in rural communities are emphasised and the way such practices need to be conducted for optimal benefits are discussed.

Key words: *Culture-based fisheries, small water bodies, rural communities, food fish needs.*

Introduction

There is a general consensus that the current world population of 7.1 billion will increase to 9.5 billion by 2050, with the bulk of the increases occurring in the developing world. The commonly asked question in many a forum is ‘can the world provide sufficient food or is our planet capable of producing sufficient food to cater to the increasing population?’ The projected food demand will require a substantial increase in food production, nearly a 70% increase from the present level. This entails, for example, an increase of nearly 1×10^9 tonnes of cereals and 200×10^6 tonnes of meat (FAO 2009). The subject of meeting the food needs in 2050 for a projected population of 9.5 billion has received much attention from numerous sources, and from various viewpoints (e.g. FAO 2009; Hanjra and Qureshi 2010; Godfray et al. 2010). Clay (2011) identified eight steps that, taken together, could enable farming to feed 10 billion people and keep Earth habitable. WFC (2011) addressed the issue on aquaculture, fisheries poverty and food security.

Fish is a significant component of the diet of many around the world, particularly in developing countries, and most significantly in Asia. This is depicted by the fact that the average per caput consumption in Asia is 27–29 kg/yr as opposed to 17–19 kg/yr in the world (FAO 2011).

Moreover in certain Asian countries, such as Cambodia, with a per caput consumption of 52.4 kg/year, fish account for nearly 80% of the animal protein intake.

Fish consumption has been rising in the world. However, it is acknowledged that the traditional food fish supplies, primarily the marine capture fisheries have at best plateaued, around 100 million t/yr. Forecasts for marine capture fisheries remain rather grim with over 58% of the stocks collapsed and overfished, and another 33% fully exploited (Froese et al. 2012) resulting in a widening gap between demand and supply of food fish. It is reckoned that this gap can be narrowed through aquaculture development.

Aquaculture has come to the forefront of food fish production in the last three decades and has enabled food fish supplies to be of farmed dominance like our other staples (De Silva 2012). The aquaculture sector, with a marked developing country dominance, in particular in the Asia-Pacific region and China, has continued to grow at a steady rate of around 6% per annum, the highest rate of growth recorded for any

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primary production sector (Subasinghe et al. 2009). The great bulk of this growth surge in aquaculture has been through a gradual increase in the land area used for aquaculture, expansion of cage culture in existing inland water bodies and in the sea together with an increasing degree of intensification of the culture practices; the latter achieved through improved water management, improved feeds, disease control, genetic improvement and the like. Overall, however, aquaculture production occurs predominantly in fresh- and brackish waters (FAO 2011).

Although growth of the aquaculture sector has been relatively consistent over the last two decades or so, there are many challenges that confront it. Intensification of aquaculture leads to environmental degradation, increased demand on resources- physical and biological, and also raises ethical issues regarding the very high proportion of use of certain biological resources such as fish meal and fish oil (Tacon et al. 2010). More often than not, when considering the challenges of feeding 9.5 billion people the issues of competition for land, water and energy and the over exploitation of capture fishery resources are often raised (Hanjra and Qureshi 2010; Godfray et al. 2010; Cao et al. 2015). The general consensus is that these issues are further exacerbated by impending climate change impacts on aquaculture, particularly in respect of specific, productive farming systems (De Silva and Soto 2009; Leung and Bates 2013; Nguyen et al. 2014). In the above context one has to accept that aquaculture intensification cannot go unabated, and the sector has to explore other potential and plausible means of increasing food fish production.

Why CBF

It is thought that the dilemma that confronts strategists in determining ways of narrowing the gap between supply and demand for food fish needs for a growing population is far from straight forward. Further, intensification and opening up new areas (land) for aquaculture development, particularly in tropical Asia, the mainstay of modern aquaculture are unlikely to be the primary thrust in to the foreseeable future, but other alternatives, including expansion in mariculture, are needed and possible (Klinger and Naylor 2012). On the other hand, utilisation of the vast acreages of small water bodies may also be an acceptable CBF development strategy for most nations and governments for a number of reasons. These water bodies, estimated at nearly 66.7 million ha in Asia alone (FAO 1999), may be natural and quasi natural, manmade, perennial and or seasonal, retaining water for six to eight month in a calendar year. The potential of CBF as an opportunity to increase food fish availability and nutrition among rural communities have been highlighted previously (De Silva 1993).

Historically, the potential of CBF for increasing food fish production among rural communities was first recognised by Mendis and Indrasena (1965) when they proposed CBF as a strategy for utilisation of the vast numbers of biologically productive small, non-perennial water bodies in Sri Lanka. CBF trials were also conducted by Fernando and Ellepola (1969) in two Sri Lankan reservoirs using *Oreochromis mossambicus* as stocking material. Based on these studies, Mendis (1977) recommended developing CBF in minor irrigation reservoirs of the country. A concerted attempt was made to revive this strategy in the 1980s (Chakrabarty and Samaranyake 1983; Chandrasoma and Kumarasiri 1986) but was not pursued with sufficient vigour and associated planning, and the program fell into disrepute and was abandoned. It is also relevant to note that in that era the promising strategy, pursued in most of Asia and elsewhere, perhaps very appropriately, was to develop and intensify the traditional forms of aquaculture, such as pond, cage and pen culture.

What is CBF

CBF are stock enhancement practices in water bodies that are generally incapable of supporting sustainable fisheries through self-recruiting fish populations, and where the stock is managed and owned either individually and or collectively. Accordingly, CBF practices fall within the realm of aquaculture (FAO 1994). CBF is often conducted in small water bodies, perennial and or seasonal, that retain water at least for six to eight months of the year. Often the water bodies in which CBF is practised are communally managed by village organisations that manage the water regime for other purposes, most commonly for downstream cultivation. However, in some countries (e.g. Vietnam) water bodies may be auctioned for CBF purposes by the authorities to an individual and or groups of individuals for fishery development purposes (Nguyen et al. 2001).

In CBF the natural productivity of the water body is utilised by the stocked seed, and rarely are external nutrients added to the system and or provided in the way of food for the stocked fish species. An exception may be when grass carp is stocked. In Vietnam for example, CBF yield in farmer-managed reservoirs are enhanced through feeding mainly using grass, tender cassava leaves and locally available agricultural by-products such as rice bran and cassava flour (De Silva 2003). On the other hand, encouragement of the use of small water bodies for caring for village livestock, such as cattle and water buffalo is known to improve the productivity and known to have a positive impact on fish yields (Jayasinghe and Amarasinghe 2007).

CBF have a strong social component that is pivotal to their success (Lidzba et al. 2008; Kularatne et al. 2009). In general, CBF are practised in rural areas where the great bulk of water bodies suitable for such activities are located. Hence the primary beneficiaries of CBF are rural communities that often tend to be impoverished. In CBF practices community organisations, and or their representatives that are involved in the management of the water resource, are also engaged in the management of the fishery activities.

As CBF are relatively low cost activities, with the main external input being seed stock, most developing country governments regard CBF to be relevant to and an integrated part of rural development. It is an environmentally acceptable practice with minimal external inputs (De Silva 2003), and is also a very effective and a non-consumptive secondary use of a water resource for food fish production.

Where CBF

The stock enhancement practice of CBF falls within the realm of aquaculture (FAO 1994) as the stocked seed are cared for by a management committee, an individual and or a group of individuals that will own the resource at harvest. In general, CBF are practised in small water bodies (< 40 ha), perennial and or seasonal that retain water for a minimal period of six to eight months, for easiness and facilitation of effective management, as well as optimising fish production (Chakrabarty and Samaranayake 1983; Chandrasoma and Kumarasiri 1986; Nguyen et al. 2001; De Silva et al. 2006; Wijenayake et al. 2005; Jayasinghe et al. 2006; Pushpalatha and Chandrasoma 2010). High biological productivity in these water bodies, which is generally unexploited in terms of fisheries production, is also a driving factor for utilising them for CBF development (Mendis 1977).

Small water bodies confer a number of advantages for practicing CBF. These tend to be more productive and there is minimal loss of stocked seed as they are easy to manage and keep watch. Furthermore, these often enable complete harvest at the end of the growth cycle and facilitate community involvement.

The water bodies used for CBF come under different regimes of management. In countries such as India, Lao PDR and Sri Lanka for example, these come under the jurisdiction of different authorities associated with downstream cultivation. These authorities work in conjunction with the relevant rural community who live in the vicinity of the water body, and the former are engaged in the day to day management of the water resource and, as a result, they do not fall under the common pool (open access) property

regime. Accordingly, when CBF are practiced by such communities a separate entity is organised/constituted among those engaged in the water management to take care of the fishery related activities. However, almost always, the whole community would benefit from the fishery activities/CBF practices even though not directly engaged in the activity.

On the other hand, increasingly CBF are being practised in larger water bodies through a strict co-management regime, with restricted access to the fish resources (Kulatilake et al. 2010; also see Amarasinghe and Wijenayake and Chandrasoma et al., this volume). Although in these water bodies there have been fisheries based on natural recruitment, adoption of planned stocking programs together with the strict enforcement of a regime of co-management where only members of the relevant management unit are permitted to access the resource, essentially makes these a form of broadened CBF practices.

Geographically, CBF by any means are not restricted to Asia. De Silva (2003) reviewed CBF practices elsewhere, such as in Cuba and Brazil. However, in the last decade or so there has been very little information coming forth on CBF practices in other continents. It may be said that CBF will be a suitable alternative in continents where intensive aquaculture has not taken a foot hold and where the capital and technical inputs are not easily available. In the geographical regions where per capita water availability is low, such as Asia and Africa (Nguyen and De Silva 2006), CBF being a non-consumptive user of standing water, is an ideal option for fisheries enhancement.

How CBF

CBF are essentially direct stock and recapture strategies that result in significantly higher fish yields than otherwise would have been possible through natural recruitment. The fish used in CBF are typically fast growing species that feed lower in the food chain along with other determining factors including the availability of suitably sized, good quality seed stock and prevailing consumer preferences. Species that utilise the naturally produced food organisms in the water bodies are preferred, as external feed inputs are not used in CBF, apart from grass when grass carp (*Ctenopharyngodon idellus*) is stocked (De Silva et al. 2006). Use of organic fertiliser, in the form of cow dung for example, is encouraged when available, and so are other indirect approaches that increase nutrient input, such as permitting the use of the water body for livestock grazing (Jayasinghe and Amarasinghe 2007).

The species combinations in CBF and the proportion of each species used differ from region to region and country to country. These are determined through R&D (e.g. Nguyen et al. 2005; Wijenayake et al. 2005; Jayasinghe et al. 2006). The species used may be a combination of indigenous and alien species and or the latter only (Table 1). In countries such as Cambodia indigenous fish species are used mostly as the prevailing regulations discourage the use of alien species. On the other hand, in Sri Lanka where there is a relatively poor freshwater foodfish fauna, CBF is almost entirely dependent on alien species that have been used for all forms of aquaculture activities in the country for over six decades.

CBF are practices that are managed by communities living beside the water bodies. Often the primary function of water bodies used for CBF is downstream cultivation (e.g. rice), and more often than not communities are organised to manage the water resource for this purpose. For purposes of CBF, representatives from such organised bodies are drawn in. The management processes involve the planning of seed stocking (and procurement), maintaining vigilance to minimise poaching, taking care of the stock in general, conducting and selling the harvest. Figure 1 depicts schematically the CBF better management practices that are in operation in Lao PDR, and the general principle is applicable to most CBF practices, with minor regional /country variations.

As evident from Figure 1, CBF in perennial water bodies is totally dependent on the prevailing weather pattern(s) as the key stages of stocking and harvesting are dictated by the water level. Essentially, this is also the case in CBF development in non-perennial reservoirs of Sri Lanka (De Silva 1988; Amarasinghe 2006). Accordingly, the harvesting in CBF often occurs within a narrow time frame, which in a given area, can result in an oversupply of fish at that time that can also affect the farm gate price. It is imperative therefore, as CBF develops and intensifies, that adjacent CBF communities communicate with each other and arrive at appropriate harvesting and related market strategies to minimise negative impacts

on farm gate price(s). On the other hand, as CBF popularise it may be that communities develop appropriate, low energy cost processing techniques as an alternative strategy.

CBF - for whom?

It has been pointed out in the previous sections the importance of community involvement in CBF. These community organisations are pivotal to the success of CBF, irrespective of the country. As CBF are mostly carried out in small water bodies, which tend to be rurally located, the primary beneficiaries are those communities that live in the vicinity of the water bodies, and who have traditionally enjoyed the use of the water resource(s) for their wellbeing. Even though the whole community (all households) may not be directly involved in CBF, the water body used is a communal property and as such all households benefit, albeit to different degrees depending on the extent of involvement in the CBF practice per se. For example, those households that contribute to keeping watch of the stock, transportation of seed stock and or taking an active role in the management committee will be entitled to a higher share of the benefits.

In Lao PDR communities that practice CBF have evolved three types (Table 2) of benefit sharing schemes that are interrelated with the harvesting protocols employed by each (Saphakdy 2009; Phomsouvanh et al. 2015). It is evident from Table 2 that every household of the village community benefits and, importantly, a certain proportion of the CBF returns are almost always utilised for improving social amenities in the community. Admittedly, such well organised and structured benefit sharing protocols do not operate in every country. With the broadening of CBF into large perennial water bodies, such as in Sri Lanka, the common community gains are administered by the “fisher societies” through a consensual approach.

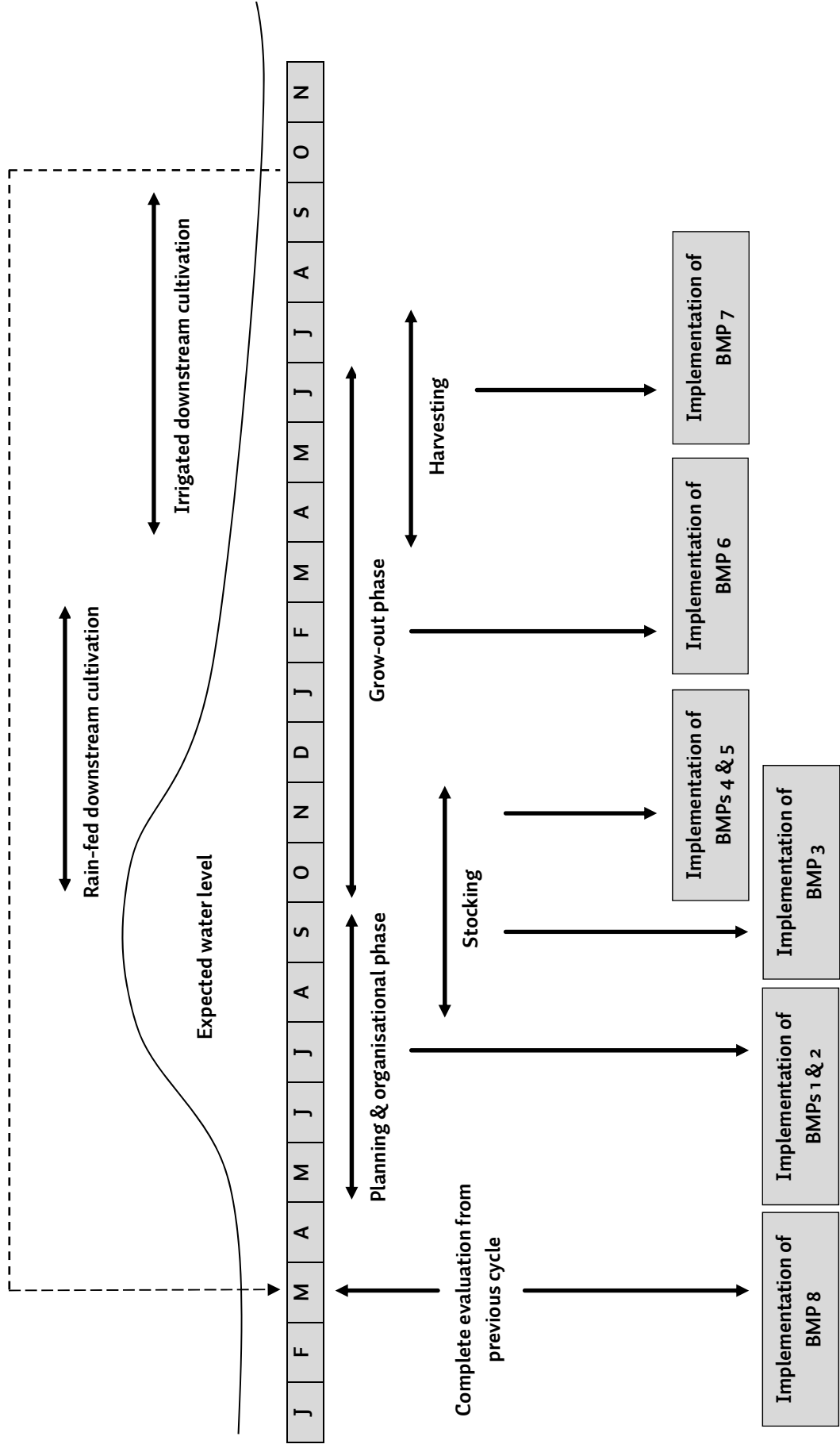
Table 1. Commonly used species in CBF practices in four different countries (compiled from varying sources; * alien to the country).

Cambodia	Lao PDR	Sri Lanka	Vietnam
<i>Pangasianodon hypophthalmus</i>	<i>Catla catla</i> *	<i>Catla catla</i> *	<i>Cirrhinus mrigal</i> *
<i>Channa striata</i>	<i>Aristichthys nobilis</i> *	<i>A. nobilis</i> *	<i>A. nobilis</i> *
<i>Clarias batrachus</i>	<i>Hypophthalmichthys molitrix</i> *	<i>H. molitrix</i> *	<i>H. molitrix</i> *
<i>C. macrocephalus</i>	<i>Oreochromis niloticus</i> *	<i>O. niloticus</i> *	<i>Ctenopharyngodon idellus</i> *
<i>Anabas testudineus</i>	<i>Cyprinus carpio</i>		<i>Cyprinus carpio</i>
<i>Barbonymus gonionotus</i>	<i>B. gonionotus</i>		
	<i>Labeo chrysophekadion</i>		
	<i>Cirrhinus molitorella</i>		

Table 2. The three basic forms of management (based on the harvesting patterns) of the water bodies that are adopted through a consensus of each of the communities in Lao PDR. Modified after Phomsouvanh et al. (2015).

Harvesting	Gains to community households	Distribution of monetary gains
Category 1		
<p>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= 1 US \$). 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.</p>	<p>Daily fish needs in this manner and households are not permitted to catch for sale; gear limited to small drag net and traditional traps only.</p>	<p>Restricted to ticket sales; 10-20 % of the proceeds reserved for purchase of seed stock for the next CBF cycle.</p> <p>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 water body in the village for CBF activity by improving the dam structure/sluice gates etc.</p>
Category 2		
<p>Similar approach to Category 1.</p>	<p>Daily fish needs and households are not permitted to catch for sale; gear limited to small drag net and traditional traps only; a portion of the ticket sales are provided to each household.</p>	<p>Of the ticket sales 10- 20 % is retained for the purchase of seed stock for the next cycle.</p> <p>50 % of the remainder is divided among the households; every household in the community is entitled for this benefit. The rest is utilised as follows: 6% advisors 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.</p>
Category 3		
<p>Harvested only as the water level recedes, generally 8-9 months post stocking with engagement of the whole community; harvesting is publicised widely and the harvest auctioned on site.</p>	<p>Fish for communal social occasions/ festivities; monetary gains based on net gains after harvest.</p>	<p>50% of the total revenue is shared amongst households of the community. The remainder is disbursed as follows: 20% purchase of fry and fingerlings; 6% advisors 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.</p>

Figure 1. A schematic representation of elements of better management practices for CBF in Lao PDR. (Descriptions of BMPs 1-8 are provided in De Silva 2012_a).



Conclusions

CBF have come a long way since the initial recognition of its potential with regard to utilising small, non-perennial water bodies (Mendis 1977). These practices have become the backbone of inland food fish supplies in some countries, such as Sri Lanka. Based on the utilisation of small water bodies in Asia, that is reputed to cover nearly 67 million ha, De Silva (2003) previously predicted that using only 50% of this acreage for CBF could increase food fish supplies by 2 million t/yr. Since this prediction was made, many related developments that would further facilitate the returns from CBF have occurred. Primarily, CBF management methods have improved considerably and, in China for example, the mean yield from CBF has reached 1,746 kg/ha/yr (Wang et al. 2014). As such, it will be pertinent to revisit old projections and adjust the needs and recognise the constraints that will enable more realistic and higher food fish targets to be achieved through CBF. Most importantly, this increased food fish production will be forthcoming from essentially environmentally friendly practices that could be sustained in the long term.

Another important development facilitating adoption of CBF is the recognition by governments of many developing nations in Asia that CBF is a low cost strategy that will enhance food fish production and augment rural incomes. Consequently, governments have, where appropriate, amended and or enacted regulations that facilitate CBF developments (e.g. *Agrarian Services Act 47 of 2000* of Sri Lanka; Government of Cambodia 2010, The Strategic Planning Framework for Fisheries 2010–2019). Changes to governmental policies and Acts affecting CBF will be crucial to their further development in the next decade, particularly in harnessing the large extent of suitable water bodies for CBF.

CBF may also be an appropriate strategy to be tested and adopted in regions where concerted attempts at popularising intensive aquaculture have not yielded the desired outcomes. Equally, it could be a suitable strategy to be implemented where there is a dearth of suitably trained human capital for practicing intensive aquaculture. It should, however, be noted that CBF success will be optimised only if the practices are geared to existing micro-climatic and geographic conditions; this will entail conducting appropriately planned preliminary trials to ascertain the most suitable species, the species combinations, harvesting regimes and strategies, among other needs.

It is also important to point out that future CBF activities will have to take into account potential climate change impacts. Practice and success of CBF are dependent on the prevailing weather patterns and relevant adjustments to climate change impacts will be critical to maintaining optimal returns.

References

- Amarasinghe, U.S., 2006. Culture-based fisheries development in Sri Lanka: a case study. In: De Silva, S.S., Amarasinghe, U.S., Nguyen, T.T.T. (Eds.), *Better-practice approaches to culture-based fisheries development in Asia*. pp. 50-72. ACIAR Monograph 120.
- Cao, L., Naylor, R., Henriksson, P., Leadbitter, D., Metian, M., Troell, M. and Zhang, W., 2015. China's aquaculture and world's wild fisheries. Curbing demand for wild fish in aquafeeds is critical. *Science*, 347, issue 6238; 133-135.
- Chakrabarty, R.D. and Samaranyake, R.A.D.B., 1983. Fish culture in seasonal tanks in Sri Lanka. *Journal of Inland Fisheries*, Sri Lanka, 2; 125-140.
- Clay, J., 2011. Freeze the footprint of food. *Nature*, 475; July 21, 2011.
- Chandrasoma, J. and Kumarasiri, W.S.A.A.L., 1986. Observations on polyculture of fish in seasonal tanks in Sri Lanka. *Journal of Inland Fisheries*, Sri Lanka, 3; 49-55.
- De Silva, S.S., 1988. Reservoirs of Sri Lanka and their fisheries. *FAO Fisheries Technical Paper*, 298; 128 pp.
- De Silva, S.S., 2003. Culture-based fisheries: an underutilized opportunity in aquaculture. *Aquaculture*, 221; 221-243.
- De Silva, S.S., 2012. Aquaculture - a newly emergent food production sector- and perspectives of its impacts on biodiversity and conservation. *Biodiversity and Conservation*, 21 (12); 3187-3220.
- De Silva, S.S., 2012a. *Better Management Practices for Culture-Based Fisheries*, Lao PDR. 46 pp.; <http://enaca.org/publications/inland-aquaculture/better-management-practices-culture-based-fisheries-lao.pdf>.
- De Silva, S. S. and Soto, D., 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *FAO Fisheries Technical Paper*, 530; 137-215.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T. (Eds.), 2006. *Better-practice approaches to culture-based fisheries development in Asia*. ACIAR Monograph 120, 96 pages (translated into Laotian, Sinhalese, Tamil and Vietnamese).
- FAO (Food and Agriculture Organization of the United Nations), 1994. Aquaculture production 1986-1992. *FAO Fisheries Circular*, Vol. 815, Revision 6. Rome, Italy, 214 pp.
- FAO, 1999. Irrigation in Asia in figures. FAO, Rome, Italy.
- FAO 2009. *How to feed the world in 2050*. FAO, Rome, 36 pp.

- FAO, 2011. World aquaculture 2010. *FAO Fisheries and Aquaculture Technical Paper 500/1* Rome, Italy, 120 pp.
- Fernando, C.H. and Ellepola, W.B., 1969. A preliminary study of two village tanks (reservoirs) in the Polonnaruwa area with biological notes on these reservoirs in Ceylon. *Bulletin of Fisheries Research Station, Ceylon*, 20; 3-13.
- Froese, R., Zellert, D., Kleisner, K. and Pauly, D., 2012. What catch data can tell us about the status of global fisheries? *Marine Biology*, 159; 1283-1292.
- Godfray, H.C.J., Beddington, J.R., Crute, I. R., Haddard, L., Lawrence, D., et al., 2011. Food security: the challenge of feeding 9 billion people. *Science*, 327 (February 2011); 812-818.
- Hanjra, M.A. and Qureshi, M.E., 2010. Global water crisis and future food security in an era of climate change. *Food Policy*, 35; 365-377.
- Indrasena, H.H.A., 1965. Freshwater fishery resources. *Bulletin of Fisheries Research Station, Ceylon*, 18; 1-4.
- Jayasinghe, A. and Amarasinghe, U., 2007. Buffaloes in favour of culture based fisheries in Sri Lanka. *Aquaculture Asia Magazine*, 12 (3); 2-8.
- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2006. Culture-based fisheries in non-perennial reservoirs of Sri Lanka; Influence of reservoir morphometry and stocking density on yield. *Fisheries Management and Ecology*, 13; 157-164.
- Klinger, D. and Naylor, R., 2012. Searching for solutions in aquaculture: charting sustainable course. *Annual review of Environment and Resources*, 37; 247-276.
- Kularatne, M.G., Amarasinghe, U.S., Wattage, P. and De Silva, S.S., 2009. Evaluation of community participation for the development of culture-based fisheries in village reservoirs of Sri Lanka. *Aquaculture Economics & Management*, 13; 22-38.
- Kulatilake, M., Liyanage, H.S.W.A., Fernando, W.M.J.R., Chandrasoma, J. and der Knapp, M.V., 2010. Development of co-management in inland fisheries in Sri Lanka: case studies of Senanayake Samudra and Mahavilachchiya reservoirs. *Aquatic Ecosystem Health & Management*, 13; 281-287.
- Leung, T.L.F. and Bates, A.E., 2013. More rapid and severe disease outbreaks for aquaculture in the tropics: implications for food security. *Journal of Applied Ecology*, 50; 215-222.
- Lidzba, C, Siriwardena, N. and Kumara U., 2008. Fish farming in seasonal reservoirs: Beyond technical feasibility. In: M.J.S. Wijeyaratne and U.S. Amarasinghe (Eds.) *Participatory Approaches to Reservoir Fisheries Management: Issues, Challenges and Policies*. pp. 151-262. Sri Lanka Association for Fisheries and Aquatic Resources, Colombo, Sri Lanka.
- Mendis, A.S., 1965. A preliminary survey of 21 Ceylon lakes: 2. Limnology and fish production potential. *Bulletin of Fisheries Research Station, Ceylon*, 16; 7-16.
- Mendis, A.S., 1977. The role of man-made lakes in the development of fisheries in Sri Lanka. *Proceedings of the Asia-Pacific Fisheries Council*, 17; 247-254.
- Nguyen, T.T.T. and De Silva, S.S., 2006. Freshwater finfish biodiversity and conservation: an Asian perspective. *Biodiversity and Conservation*, 15; 3543-3568.
- Nguyen, Son H., Bui, Anh T., Le, L.T., Nguyen, Thuy T.T. and De Silva, S.S., 2001. Aspects of the culture-based fisheries in small, farmer-managed reservoirs, based on three production cycles, in two provinces of northern Vietnam. *Aquaculture Research*, 32; 975-990.
- Nguyen, H. S., Bui, A. T., Nguyen, D. Q., Truong, D. Q., Le, L. T., Abery, N.W. and De Silva, S.S., 2005. Culture-based fisheries in small reservoirs in northern Vietnam: effect of stocking density and species combinations. *Aquaculture Research*, 36; 1037-1048.
- Nguyen Lam Anh, Vinh Dang Hoa, Bosma Roel, Verreth Johan, Leemans Rik and De Silva Sena S., 2014. Simulated impacts of climate change on current farming locations of striped catfish (*Pangasianodon hypophthalmus*; Sauvage) in the Mekong Delta, Vietnam. *Ambio*, 43; 1059-1068.
- Phomsouvanh Akhane, Saphakdy Bounthong and De Silva Sena S., 2015. Production trends, monetary returns and benefit sharing protocols from the extensive aquaculture practice of culture-based fisheries in rural communities in Lao PDR. *Aquaculture*, 439; 29-38.
- Pushpalatha, K.B.C. and Chandrasoma, J., 2010. Culture-based fisheries in minor perennial reservoirs in Sri Lanka: variability in production, stocked species and yield implication. *Journal of Applied Ichthyology*, 26; 98-103.
- Saphakdy, B., Phomsouvanh, A. Davy, B., Nguyen, T.T.T. and De Silva, S.S., 2009. Contrasting community management and revenue sharing practices of culture-based fisheries in Lao PDR. *Aquaculture Asia Magazine*, 14 (3); 2-6.

Subasinghe, S., Soto, D. and Jia, J., 2009. Global aquaculture and its role in sustainable development. *Reviews in Aquaculture*, 1; 2-9.

Tacon, A.G.J, Metian, M., Turchinni, G. and De Silva, S.S., 2010. Responsible aquaculture and trophic level implications to global fish supply. *Reviews in Fisheries Science*, 18; 94-105.

Wang, Q, Cheng L., Liu, J., Li, Z., Xie, S. and De Silva, S.S., 2014. Freshwater Aquaculture in PR China: Trends and Prospects. *Reviews in Aquaculture*, 20 pp.

Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Athula, J.A., Pushpalatha, K.B.C. and De Silva, S.S., 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. *Fisheries Management and Ecology*, 12; 249-258.

World Fish Centre, 2011. Aquaculture, fisheries, poverty and food security. *WFC Working Paper 2011/65*, Penang, Malaysia, 62 pp.

General aspects of stock enhancement in fisheries developments

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

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

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

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

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

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

Introduction

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

Stocking occurs in freshwater, estuarine and marine environments worldwide to replenish, maintain or enhance populations of aquatic organisms. Many species of fish as well as gastropods and crustaceans

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

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

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

Purpose and benefits of stocking

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

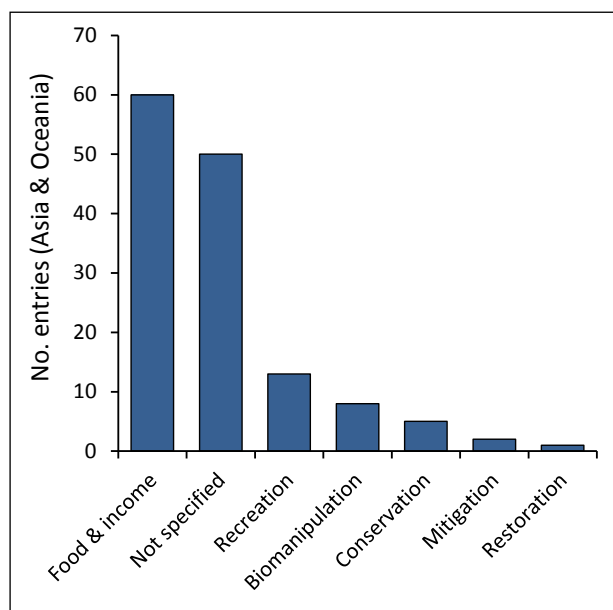
Stocking is the primary source of fish in CBF, in which fish are released into typically small permanent and temporary water bodies (<100 ha) to increase the supply of fish as food in rural areas, as well as providing additional income to rural farmers, thereby contributing to poverty alleviation (Lorenzen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

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

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

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

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



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

The principle benefit of stocking is to produce food and income from fish harvested from stocked waters. Some stock enhancement activities, including CBF, can provide very high returns to cash investment and labour (e.g. Hansson et al. 1997; Lorenzen et al. 1998; De Silva 2008). Stocking activities also provide benefits through ancillary

industries, such as employment in hatcheries, aquaculture feed mills, fishing, processing and marketing, as well as tourism associated with recreational and sport fisheries (De Silva and Funge-Smith 2005).

Species stocked

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

Table 1. Purposes of stocking in inland waters

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

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

Many species have been the subject of stock enhancement, including fish, molluscs and crustaceans. The most commonly used species for stocking inland waters are cyprinids (common carp, Chinese or Asian carps and Indian major carps), salmonids (salmon and trout) and cichlids (tilapias) (Table 2). Thirty-three finfish, two crustacean and one reptile species have been used

directly in stock enhancement practices in Asia and those that are directly and or indirectly impacted through inland fisheries enhancement programs/activities (Miao et al. 2010). Of the fish species, 51% were cyprinids and 12% were salmonids. De Silva (this volume), listed 14 species commonly used in CBF in four Asian countries. While most stock enhancements have focused on finfish, invertebrates have also been released, including giant freshwater prawn (*Macrobrachium rosenbergii*) in Thailand (Jutagate and Kwangkhang, this volume) and Sri Lanka (Amarasinghe and Wijenayake, this volume) and mitten crab (*Eriocheir sinensis*) in China (Wang et al. this volume).

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

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

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

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

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

* Indigenous species.

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

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

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

Waterbodies stocked

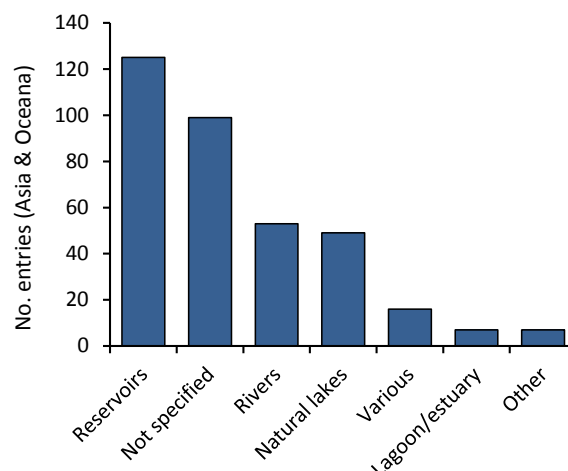
Globally, reservoirs and lakes (manmade impoundments, natural lakes, floodplain depressions, oxbow lakes, lagoons etc.) are most commonly stocked (FAO Inland Water Resources and Aquaculture Service 1999) (Figure 2). The primary purpose of stocking these water bodies in developing countries is to increase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

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

Stakeholders

A wide range of stakeholders are involved in stocking programs, both directly and indirectly, and include decision-makers at all levels from village leaders to country agencies, fisheries, aquaculture, water, environ-

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



mental and conservation managers, water agencies and end users (e.g. commercial and recreational fishers, fish mongers and consumers).

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

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

Assessing stocking success

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

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

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

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

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

Major risks associated with stocking

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

Genetic impacts

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

Ecological and environmental impacts

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

ecological changes brought about an upsurge of bighead carp and silver carp populations and the disappearance of most of the 60 fish species native to the lake (Chen 1989).

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

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

Infectious disease or pathogen transmission

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

Chemical release

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

Exotic species versus native species

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

Management approaches for stocking programs

Management activities that operate on the scale of the ecosystem, rather than arbitrarily defined jurisdictional boundaries, are far more likely to meet their objectives (Scott-Slocombe 1993). Stocking programs are undertaken in complex human–environment systems, involving dynamic interactions between the resources, the technical intervention and users (Bell et al. 2006). Species populations, management units and evolutionary significant units (ESU's¹) therein can extend across jurisdictional and country borders and therefore potentially are governed by, and managed under, several different legislative and regulatory frameworks, posing substantial challenges to ensure that populations structuring is managed consistently. Effective communication, coordination and collaboration are required for governance of such species and populations. Therefore, an ecosystems approach to stocking programs is encouraged. Decision makers should aim to consider environmental, ecological and genetics factors, social needs and jurisdictional differences in planning of stocking programs that will achieve the desired outcomes with minimal impacts on the environment.

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

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

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

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

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

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

Stocking should not be seen as a panacea to recovering failing fisheries. Stocking should always be considered as one management option. Other fisheries enhancement and management options must always be considered, including changes to regulations affecting access

and take (size limits, bag limits, closed seasons), use of reserves and refuges, and habitat protection and improvement.

Risk assessment

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

Better Management Guidelines

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

- Genetic resource management (e.g. broodstock numbers, mating plans, incubation of eggs and stocking of larvae, broodstock turnover) for broodstock management and breeding programs used in conservation, harvest stocking and commercial aquaculture.
- Fish health management (monitoring, diagnosis and treatment to reduce and/or minimise disease occurrence).
- Improved record keeping, reporting and information management.

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

Conclusions

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

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

References

- Allendorf, F.W., 1991. Ecological and genetic effects of fish introductions: synthesis and recommendations. *Canadian Journal of Fisheries and Aquatic Sciences* 48 (Suppl.1); 178-181.
- Amarasinghe, U.S., 2010. Inland fisheries resource enhancement and conservation in Sri Lanka. In: *Inland Fisheries Enhancement and Conservation in Asia* (Miao, W., De Silva, S. and Davy, B. Eds.), pp. 113-132. FAO Regional Office for Asia and the Pacific. RAP Publication 2010/22, Bangkok, Thailand.
- Araki, H. and Schmid, C., 2010. Is hatchery stocking a help or harm? Evidence, limitations and future directions in ecological and genetic surveys. *Aquaculture* 308 (Suppl. 1).
- Arthington, A.H., 1991. Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 48 (Suppl. 1); 33-43.
- Arthur, J.R., Bondad-Reantaso, M.G., Campbell, M.L., Hewitt, C.L., Phillips, M.J. and Subasinghe, R.P., 2010a. Understanding and Applying Risk Analysis in Aquaculture: A Manual for Decision-Makers. *FAO Fisheries and Aquaculture Technical Paper No. 519/1*. 113 pp.
- Arthur, R.I., Lorenzen, K., Homekingkeo, P., Sidavong, K., Sengvilaikham, B. and Garaway, C.J., 2010b. Assessing impacts of introduced aquaculture species on native fish communities: Nile tilapia and major carps in SE Asian freshwaters. *Aquaculture* 299 (1); 81-88.
- Bartley, D.M., 2007. Responsible stock enhancement, restocking and sea ranging: rational and terminology. In *Ecosystem-based Stock Enhancement Workshop*. Bruges, Belgium, 7-8 May 2007.
- Bartley, D.M., Bondad-Reantaso, M.G. and Subasinghe, R.P., 2006. A risk analysis framework for aquatic animal health management in marine stock enhancement programmes. *Fisheries Research*, 80 (1); 28-36.
- Bartley, D.M., Brugère, C., Soto, D., Gerber, P. and Harvey, B. (Eds.), 2007. Comparative assessment of the environmental costs of aquaculture and other food production sectors. Methods for meaningful comparisons, *FAO Fisheries Proceedings* 10. Food and Agriculture Organization of the United Nations, Rome. 241 pp.
- Bell, J.D., Bartley, D.M., Lorenzen, K. and Loneragan, N.R., 2006. Restocking and stock enhancement of coastal fisheries: Potential, problems and progress. *Fisheries Research*, 80 (1); 1-8.
- Bert, T.M., Crawford, C.R., Tringali, M.D., Seyoum, S., Galvin, J.L., Higham, M. and Lund, C., 2007. Genetic management of hatchery-based stock enhancement. In: *Ecological and Genetic Implications of Aquaculture Activities* (Bert, T.M. ed.), pp. 123-174. Springer, Dordrecht, The Netherlands.
- Brown, C. and Day, R.L., 2002. The future of stock enhancements: lessons for hatchery practice from conservation biology. *Fish and Fisheries*, 3 (2); 79-94.
- Chen, H.D., 1989. Impact of aquaculture on the ecosystem of Donghu Lake, Wuhan. *Acta Hydrobiologica Sinica*, 13; 359-368 (in Chinese).
- Cowx, I.G. (Ed.), 1998. *Stocking and Introduction of Fish*. Fishing News Books, Blackwell Science, Oxford. 456 pp.
- Cowx, I.G. and Gerdeaux, D., 2004. The effects of fisheries management practises on freshwater ecosystems. *Fisheries Management and Ecology*, 11 (3-4); 145-151.
- Cunningham, A.A., 1996. Disease Risks of Wildlife Translocations. *Conservation Biology*, 10 (2); 349-353.
- De Silva, S.S., 2008. First culture-based fisheries growth cycle in Lao PDR is overwhelmingly encouraging. *Aquaculture Asia Magazine*, 13 (4); 9-10.

- De Silva, S.S. and Funge-Smith, S.J., 2005. *A review of stock enhancement practices in the inland water fisheries of Asia*. FAO, RAP Publication 2005/12. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok. 93 pp.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T. (Eds.), 2006. *Better-practice approaches for culture-based fisheries development in Asia*, Monograph 120. ACIAR, Canberra. 96 pp.
- De Silva, S.S., Subasinghe, R.P., Bartley, D.M. and Lowther, A., 2004. Tilapias as alien aquatics in Asia and the Pacific: a review. *FAO Fisheries Technical Paper*, 453, 65 pp.
- FAO, 1995. *Code of Conduct for Responsible Fisheries*. Food and Agriculture Organization of the United Nations, Rome. 41 pp.
- FAO, 1996. Precautionary Approach to Capture Fisheries and Species Introductions. *FAO Technical Guidelines for Responsible Fisheries No. 2*. Food and Agriculture Organization of the United Nations, Rome. 54 pp.
- FAO Inland Water Resources and Aquaculture Service, 1999. Global characterization of inland fishery enhancements and associated environmental impacts. *FAO Fisheries Circular No. 945*. FAO, Rome. 89 pp.
- FAO/NACA, 2000. Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy. *FAO Fisheries Technical Paper 402*. Food and Agriculture Organization of the United Nations, Rome.
- Frankham, R., Briscoe, D.A. and Ballou, J.D., 2002. *Introduction to Conservation Genetics*. University of Cambridge Press, Cambridge, UK.
- Garaway, C.J., Arthur, R.I., Chamsingh, B., Homekingkeo, P., Lorenzen, K., Saengvilaikham, B. and Sidavong, K., 2006. A social science perspective on stock enhancement outcomes: Lessons learned from inland fisheries in southern Lao PDR. *Fisheries Research*, 80 (1); 37-45.
- Gozlan, R.E., 2008. Introduction of non-native freshwater fish: Is it all bad? *Fish and Fisheries*, 9 (1); 106-115.
- Hansson, S., Arrhenius, F. and Nellbring, S., 1997. Benefits from fish stocking - experiences from stocking young-of-the-year pikeperch, *Stizostedion lucioperca* L. to a bay in the Baltic Sea. *Fisheries research*, 32; 123-132.
- Hughes, B., 2014. Monitoring: Garbage In Yields Garbage Out. *Fisheries*, 39:6, 243-243 (6); 243 & 287.
- Imsilp, U., Singsee, S., Pin Polchai, Assonjohn, T. and Sukumasavin, N., 2003. Mobile hatchery: a new tool for fisheries extension. In: *Proceedings of the 6th Technical Symposium on Mekong Fisheries*, Pakse, Lao PDR 26-28 November 2003 pp. 79-82.
- Ingram, B.A., 2013. Enhancement programs in Victoria. In: *South Australian Murray Cod Enhancement Workshop Proceedings* (Adelaide, 17-18 July 2013). Fisheries and Aquaculture, PIRSA.
- Ingram, B.A., Barlow, C.G., Burchmore, J.J., Gooley, G.J., Rowland, S.J. and Sanger, A.C., 1990. Threatened native freshwater fishes in Australia - some case histories. *Journal of Fish Biology*, 37 (Supplement A): 175-182.
- Ingram, B.A., Hunt, T.L., Lieschke, J. and Douglas, J., 2015. Monitoring fish stockings in Victoria: 2014 native fish surveys. *Recreation Fishing Grants Program Research Report*. Department of Environment and Primary Industries, Queensland. 50 pp
- Ingram, B.A. and Lasasimma, O., 2008. Production of *Cirrhinus molitorella* and *Labeo chrysophekadion* for culture based fisheries development in Lao PDR. Part 1. Captive spawning. *Aquaculture Asia Magazine*, 13 (2); 24-31.
- Johnsen, B.O. and Jensen, A.J., 1991. The *Gyrodactylus* story in Norway. *Aquaculture*, 98; 289-302.
- Kapuscinski, A.R. and Miller, L.M., 2007. *Genetic Guidelines for Fisheries Management*. University of Minnesota Sea Grant Program, Duluth, MN. 113 pp.
- Koehn, J.D., Lintermans, M., Lyon, J.P., Ingram, B.A., Gilligan, D.M., Todd, C.R. and Douglas, J.W., 2013. Recovery of the endangered trout cod *Maccullochella macquariensis*: What have we achieved in more than 25 years? *Marine and Freshwater Research*, 64; 822-837.
- Leveque, C., 1995. Role and consequences of fish diversity in the functions of African freshwater system - a review. *Aquatic Living Resources*, 8; 59-78.
- Li, J., 1999. An appraisal of factors constraining the success of fish stock enhancement programmes. *Fisheries Management & Ecology*, 6 (2); 161-169.
- Lorenzen, K., 2005. Population dynamics and potential of fisheries stock enhancement: practical theory for assessment and policy analysis. *Philosophical Transactions of the Royal Society B*, 360; 171-189.
- Lorenzen, K., 2008. Understanding and Managing Enhancement Fisheries Systems. *Reviews in Fisheries Science*, 16 (1-3); 10-23.

- Lorenzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., de Silva, S.S., Garaway, C.J., Hartmann, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., Sugunan, V.V. and Swar, D.B., 2001. Strategic review of enhancements and culture-based fisheries. In: *Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium*, Bangkok, Thailand, 20-25 February 2000 (Subasinghe, R.P., Bueno, P., Phillips, M.J., Hough, C. and McGladdery, S.E. eds.), pp. 221-237.
- Lorenzen, K., Juntana, J., Bundit, J. and Tourongruang, D., 1998. Assessing culture fisheries practices in small water bodies: a study of village fisheries in Northeast Thailand. *Aquaculture Research*, 29; 211-224.
- McClelland, E.K. and Naish, K.A., 2007. What is the outcome of crossing unrelated fish populations? A meta-analysis and an evaluation of future research directions. *Conservation Genetics*, 8; 397-416.
- Meffe, G.K., 1992. Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. *Conservation*, 6; 350-354.
- Miao, W., De Silva, S. and Davy, B. (Eds.), 2010. *Inland Fisheries Enhancement and Conservation in Asia*, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. *RAP Publication 2010/22* 189 pp.
- Miller, L.M. and Kapuscinski, A.R., 2003. Genetic guidelines for hatchery supplementation programs. In: *Population Genetics Principles and Applications for Fisheries Scientists* (Hallerman, E.M. ed.), pp. 329-355. American Fisheries Society, Bethesda.
- Molony, B.W., Lenanton, R., Jackson, G. and Norriss, J., 2003. Stock enhancement as a fisheries management tool. *Reviews in Fish Biology and Fisheries*, 13; 409-432.
- Moran, P., Pendas, A., Garcia-Vazquez, E. and Izquierdo, J., 1991. Failure of a stocking policy, of hatchery reared brown trout, *Salmo trutta* L., in Asturias, Spain, detected using LDH-5* as a genetic marker. *Journal of Fish Biology*, 39; 117-121.
- Moritz, C., 1994. Defining Evolutionarily Significant Units' for conservation. *Trends in Ecology & Evolution*, 9; 373-375.
- Naylor, R.L., Williams, S.L. and Strong, D.R., 2001. Aquaculture - A gateway for exotic species. *Science* 294 (5547); 1655-1656.
- Petr, T., 1998. Inland Fishery Enhancement. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April 1997. *FAO Fisheries Technical Paper No. 374*. FAO, Rome. 463 pp.
- Philipp, D.P., Epifanio, J.E. and Jennings, M.J., 1993. Point/counterpoint: conservation genetics and current stocking practices - are they compatible? *Fisheries*, 18 (12); 14-16.
- Ross, L.G., Martinez Palacios, C.A. and Morales, E.J., 2008. Developing native fish species for aquaculture: The interacting demands of biodiversity, sustainable aquaculture and livelihoods. *Aquaculture Research*, 39; 675-683.
- Rowland, S.J., 2001. Record of the banded grunter *Amniataba percoids* (Teraponidae) from the Clarence River, New South Wales. *Australian Zoologist*, 31; 603-607.
- Saltveit, S., 2006. The effects of stocking Atlantic salmon, *Salmo salar*, in a Norwegian regulated river. *Fisheries Management and Ecology*, 13; 197-205.
- Scott-Slocumbe, D., 1993. Implementing ecosystem-based management: Development of theory, practice and research for planning and managing a region. *BioScience*, 4; 612-622.
- Soorae, P.S. (Ed.), 2008. *Global Re-introduction Perspectives. Re-introduction case-studies from around the globe*. IUCN/SSC Re-introduction Specialist Group, Abu Dhabi, UAE. 284 pp.
- Tucker, C.S. and Hargreaves, J.A. (Eds.), 2008. *Environmental Best Management Practices for Aquaculture*. Wiley-Blackwell Publishing, Ames. 592 pp.
- Vitule, J.R.S., Freire, C.A. and Simberloff, D., 2009. Introductions of non-native freshwater fish can certainly be bad. *Fish and Fisheries* 10; 98-108.
- Wahl, D.H., Stein, R.A. and DeVries, D.R., 1995. An ecological framework for evaluating the success and effects of stocked fishes. In: *American Fisheries Society Symposium*, Vol. 15, pp. 176-189.
- Weber, E.D. and Fausch, K.D., 2003. Interactions between hatchery and wild salmonids in streams: Differences in biology and evidence for competition. *Canadian Journal of Fisheries & Aquatic Sciences*, 60; 1018-1028.
- Welcomme, R.L. and Bartley, D.M., 1998. Current approaches to the enhancement of fisheries. *Fisheries Management and Ecology*, 5; 351-382.
- Welcomme, R.L. and Vidthayanon, C., 2003. The impacts of introduction and stocking of exotic species in the Mekong basin and policies for their control. *MRC Technical Paper No. 9*. Mekong River Commission, Cambodia. 38 pp.

Genetic considerations in culture-based fisheries development in Asia

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Abstract: Culture-based fisheries (CBF) is a practice in which, in general, fish are stocked in small water bodies that are unable to sustain an artisanal fisheries through natural recruitment. CBF has gained popularity in recent years, due to its simplicity in terms of inputs and management and cost effectiveness. Traditionally, in the Asian region, exotic species are used, but countries newly embarking on CBF prefer the use of indigenous species. The shift towards the use of indigenous species was believed to counter negative impacts, perceived or otherwise, brought about by use of exotic species. However, it is also true that hatchery-produced fingerlings that escape can also pose a potential threat to genetic diversity and integrity of their wild counterparts.

At the Regional Workshop on “Culture-based fisheries development in Asia” (this volume), it was clear that the debate on the use of exotic versus indigenous species is still an ongoing topic. This paper entails the pros and cons in the use exotic vs. indigenous species in CBF and steps to be followed when decisions are made on species choice for CBF. The ultimate goal is to improve production whilst maintaining genetic diversity and integrity of the surrounding ecosystems.

Key words: Biodiversity, broodstock management, genetic management, captive breeding, alien species, indigenous species.

Introduction

Culture-based fisheries (CBF) is a practice in which fish are stocked in small water bodies which are unable to sustain an artisanal fisheries through natural recruitment. It is often a secondary user of water resources and is seen as an important strategy to improve food security in rural areas of developing countries (De Silva 2003, De Silva et al. 2006a, Amarasinghe and Nguyen 2010). In earlier stages of development, CBF in countries for example Sri Lanka and Vietnam were largely dependent on exotic species such as tilapia, and major Indian and Chinese carps due to availability of fingerlings as well as a lack of suitable fast growing indigenous species (Amarasinghe and Nguyen 2010). The current trend, however, is moving towards including indigenous species for stocking. This change is driven by the need to mitigate the negative impacts of alien species, perceived or otherwise (Sverdrup-Jensen 2002, Mattson 2005, Ingthamjitr 2009), especially in some of the Mekong riparian countries such as Lao PDR and Cambodia.

The preference to use indigenous species in CBF brings about new challenges. CBF, as any other food production sector, needs to be practised in a manner that minimally impacts the environment, including genetic diversity of natural fish populations. Fingerlings used for stocking are often derived from hatcheries that produce seed for aquaculture purposes as there are no hatcheries dedicated to CBF or stock enhancement in the region. Hatchery-produced fish are known to be more adapted to hatchery conditions and therefore less fit in the wild (Araki et al. 2008). Water bodies that are suitable for CBF are often prone to flooding and stocked fish has the

potential and a greater chance to escape and interbreed with their wild counterparts, when compared to intensive aquaculture practices in ponds, cages among others. This will potentially result in reduced fitness and adaptability if wild stocks (Hindar et al. 1991, Waples and Do 1994, Araki et al. 2008).

Consultation with local communities often take place when choosing species for CBF. Species are selected based on local preferences, seed availability and ability to reach a harvest size before the onset of the dry season (De Silva et al. 2006a). Exotic species used for CBF in the Asian region are mainly Indian carps (e.g. rohu, *Labeo rohita*; mrigal, *Cirrhinus cirrhosus*; and catla, *Catla catla*), Chinese major carps (e.g. silver carp, *Hypophthalmichthys molitrix*; bighead carp, *H. nobilis*; and grass carp, *Ctenopharyngodon idellus*), and Nile tilapia (*Oreochromis niloticus*). Of all exotic species used for aquaculture, species that are commonly used in CBF have shown no impacts on local environment (De Silva et al. 2006b), except the African walking catfish (*Clarias gariepinus*) (Na-Nakorn et al. 2004). Species that can interbreed and produce viable off spring with local species, such as the African walking catfish, is therefore discouraged from being used in CBF and not discussed further in this paper.

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The aims of this paper are to discuss issues pertaining to genetic management of species used in CBF. These species can be categorised into two groups: exotic species that do not interbreed with local species and indigenous species. Objectives of genetic management for these two groups of species are different: optimising productivity for the former and mimicking natural level of genetic diversity and minimising adaptation to hatchery conditions in the stocked materials for the latter.

Genetic considerations

Existing exotic species that do not interbreed with local species

Species that fall into this category include tilapia, major Indian and Chinese carps. Artificial propagation of these species has been established for many decades and fingerlings are often readily available. The successes in artificial propagation of these species possibly paved the way for initial expansion of intensive aquaculture in tropical Asia in the early growth phases of the sector, and still continues to make the highest contribution to cultured food fish production globally (FAO 2012). The aim of genetic management for species in this category is to maximise productivity. Water bodies used for CBF are often non-perennial¹, and stocked fish need to reach a marketable size before water levels recede appreciably. Fast growing fish are therefore needed. It is unfortunate that fish selected for fast growth in an aquaculture environment do not always perform as well in CBF due to its reduced adaptability to feed on naturally produced food organisms and competition for resources with other species. For example, Genetically Improved Farmed Tilapia (GIFT) was outperformed by feral tilapia in reservoirs in Sri Lanka (Wijeynayake et al. 2007).

Other technologies could be used to develop fast growing strains included triploidy and monosex. These technologies have proven effective in some species, for example triploid oysters (Stanley et al. 1984) and monosex tilapia (Mair et al. 1997).

Indigenous species

Recently artificial propagation of indigenous fish have been successfully conducted for many species. As a result, more indigenous species have been used for aquaculture and for stocking in natural waters. As mentioned earlier, the use of indigenous species in stocking may relieve the perceived issues brought about by exotic species, but the use of the former also brings to focus

¹ It should be noted that gradually CBF practices are being extended into non-perennial waters in the recent years (see Chandrasoma et al. this volume), and consequently the genetic management in CBF will become even more exacerbated and crucial.

a new set of challenges. Fish, once domesticated and reproduced under hatchery conditions, results in reduced genetic variability (Hamasaki et al. 2010, Nock et al. 2011), changes in behaviour (Jonsson et al. 2003), and reduced fitness within one or two generations of captive rearing (Araki et al. 2008). Hatchery-produced fish once stocked in natural waters could become a major part of the fishery, for example up to 70% of silver barb (*Barbonymus gonionotus*) collected in Thailand waters were of hatchery origin (Kamonrat 1996). Genetic interactions between less fit hatchery-produced fish and wild stocks may result in reduced fitness of wild populations. As such, the aim of genetic management here would be to maintain the hatchery stock as comparable or similar to the wild stock as possible. To achieve this, the broodstock used for fingerling production should be as similar to the local wild fish as possible, and procedures in hatcheries should minimise the difference to wild processes.

Sustainable CBF practices should use fingerlings with a similar level of genetic diversity to wild stock. Choosing an appropriate source of broodstock is an important step. The best option here is to apply supportive breeding, a practice in which mature broodstock from local waters are caught and bred, and their offspring are released into the same area (Ryman and Laikre 1991). This practice prevents exogenous genes being introduced into the local population. There is also evidence suggesting that hatchery stocks that use wild local fish for captive propagation generally perform better than non-local stocks (Araki et al. 2008), another reason justifying the use of local broodstock for breeding. An example of such a breeding program is Murray cod (*Maccullochella peelii*) breeding at the Fisheries Victoria Snobs Creek Hatchery, Australia, a hatchery dedicated to breeding fish for stocking. Mature wild caught males and females are kept in earthen ponds and spawned naturally (mostly monogamous). Larvae are reared to fingerling size (40-60 cm total length) in fertilised ponds before being released into the wild. Such practices have resulted in an increase in effective population size of the wild stocks (Ingram et al. 2011).

When the number of broodstock sourced from one place are inadequate to achieve production targets and there is a need to recruit broodstock from elsewhere, it is important to understand population genetic structure of the species. Introducing new stocks of the same species to local waters may result in changes in population genetic structure (Eldridge and Naish 2007, Marie et al. 2010, Horreo et al. 2011). Genetic DNA markers such as micro-satellites have been extensively used for investigation of population structures and identifying management units. Some studies in the Asian region suggest strong population genetic structure in species that have been candidates for CBF such as mud carp, *Cirrhinus molitorella*

(Nguyen and Sunnucks 2012), or for stock enhancement such as mahseer, *Tor douronensis* (Nguyen 2008), and as such the use of local broodstock is recommended.

It is understood that in the Asian region where CBF is gaining popularity, resources required to undertake population genetic studies are lacking and hence information on population structure of species of interest is often unavailable. Collaboration with better equipped laboratories for such a task is recommended. Otherwise, it is advisable that broodstock should be collected in proximity of the CBF site, or from water bodies with most similar habitats, and fish with similar life history and behaviour (FAO 2008).

When mature wild broodstock are not abundant, domestication is required to maintain a breeding population. In this case, a structured breeding program to maintain genetic diversity and avoid inbreeding of hatchery stock is required. Methods to achieve this are entailed in the FAO Guidelines for Responsible Fisheries (FAO 2008). These include:

- Minimise inbreeding: Inbreeding can be avoided by not mating closely related individuals. This can be achieved by tagging and maintaining a pedigree for all broodstock. When tagging of broodstock cannot be done, increased effective breeding number can be used to minimise inbreeding (below). FAO (2008) recommends for stocking, inbreeding level should be maintained below 0.01. The number of broodstock required depends on the number of generations the hatchery is designed to reach production targets, the sex ratio used and successful spawning rates. For example, in a close breeding population, i.e. no new genetic materials are introduced for 5 generations, assuming pair mating is applied, it requires 250 males and 250 females with 100% spawning rate to achieve an inbreeding level of 0.01. In reality spawning rates are lower than 100% and the number of male and female broodstock required in such a case are much higher.
 - Maximise effective breeding number: This can be achieved by practising the followings:
 - › Ensure many fish are spawned and maintain sex ratio as close to 1:1 as possible – This will improve the chance of all genetic materials to be passed to the next generation. This should be followed by improving technologies to enhance spawning, fertilisation, hatching and nursing rates. It is understood that most hatcheries would like to maintain a minimal number of broodstock and use a skewed sex ratio to reduced production costs, but in the long term this practice would result in an undesirable outcome.
 - › Apply pedigreed mating (keep one daughter from each female and one son from each male to be broodstock for the next generation), or each parent leave the same number of offspring to be broodstock for the next generation.
 - › Equalise the number of offspring from each parent pair to be broodstock for the next generation. This requires each family to be maintained separately until offspring can be selected for broodstock.
 - › Milt among males should not be pooled prior to, or added in a sequential manner, during fertilisation – This is to avoid sperm competition and sperm from one male may fertilising most of the eggs, which reduces effective breeding number.
 - › Stretch generation time – Lengthening the broodstock recruitment interval will slow down the inbreeding process.
 - › Maintain separate breeding lines and then hybridise between these lines – This requires structured facilities and resources.
 - › Apply factorial mating – Instead of breeding full-sib families, a factorial design could be used to improve effective breeding number.
 - › Avoid selection – Selecting larger or better appearance fish will reduce the chance of smaller or less attractive fish passing their genes to the next generation, which reduces genetic diversity.
 - › Influx new genetic material to the broodstock population regularly – It is suggested that if 10-15% new broodstock are introduced each generation, inbreeding can be drastically reduced. An example in this regard is the fish stocking programs in Myanmar, where hatcheries are licensed to recruit new broodstock from the wild periodically, based on the agreement with the government that a proportion of fingerlings produced should be released into public waters as part of the national stock enhancement programs (Aung et al. 2009).
- Apart from ensuring genetic similarity between stock and local wild fish, hatchery procedures from breeding to nursing should mimic wild processes as much as possible (FAO 2008). For example, natural diets should be used rather than artificial feed, ponds are recommended instead of tanks, or stock younger fish which are less adapted to hatchery conditions than larger, older, fish. The latter recommendation however faces the paradox that larger fish survive better in CBF environment.

Conclusions

Given the importance of CBF in providing food security and livelihood of the rural poor, and its popularity as an “environmental friendly” practice due to low input requirements, responsible use of genetic resources should be considered. While improving productivity using better management practices, negative impacts on the environment should be minimised. This can be achieved by careful planning, incorporating conservation aspects in management of CBF together with technology development to improve productivity. A desirable outcome should be better livelihood for the rural poor and their surrounding environment is minimally impacted.

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References

- Amarasinghe, U.S. and Nguyen, T.T.T., 2010. Enhancing rural farmer income through fish production: Secondary use of water resources in Sri Lanka and elsewhere. in: De Silva, S.S., Davy, B.F. (Eds.), *Success Stories in Asian Aquaculture*. Springer, NACA and IDRC, Dordrecht, pp. 103-130.
- Araki, H., Berejikian, B.A., Ford, M.J. and Blouin, M.S., 2008. Fitness of hatchery-reared salmonids in the wild. *Evolutionary Applications* 1; 342-355.
- Aung, O. and Nguyen, T.T.T., Poompuang, S., Kamonrat, W., 2009. Microsatellite DNA markers revealed genetic population structure among captive stocks and wild populations of mrigal, *Cirrhinus cirrhosus* in Myanmar. *Aquaculture* 299; 37-43.
- De Silva, S.S., 2003. Culture-based fisheries: an underutilized opportunity in aquaculture. *Aquaculture* 221; 221-243.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T., 2006a. *Better-practice approaches for culture-based fisheries development in Asia*. ACIAR, Canberra, 96 pp.
- De Silva, S.S., Nguyen, T.T.T., Abery, N.W. and Amarasinghe, U.S., 2006b. An evaluation of the role and impacts of alien finfish in Asian inland aquaculture. *Aquaculture Research* 37; 1-17.
- Eldridge, W.H. and Naish, K.A., 2007. Long-term effects of translocation and release numbers on fine-scale population structure among coho salmon (*Oncorhynchus kisutch*). *Molecular Ecology Notes* 16; 2407-2421.
- FAO, 2008. *Aquaculture Development*. 3. Genetic resource management. FAO, Rome, Italy.
- FAO, 2012. *World aquaculture 2010*. FAO Fisheries and Aquaculture Technical Paper 500/1. 120 pp. FAO, Rome, Italy.
- Hamasaki, K., Toriya, S., Shishidou, H., Sugaya, T. and Kitada, S., 2010. Genetic effects of hatchery fish on wild populations in red sea bream *Pagrus major* (Perciformes, Sparidae) inferred from a partial sequence of mitochondrial DNA. *Journal of Fish Biology* 77; 2123-2136.
- Hindar, J.H., Ryman, N. and Utter, F., 1991. Genetic effects of cultured fish on natural fish population. *Canadian Journal of Fisheries and Aquatic Sciences* 48; 945-957.
- Horreo, J.L., Machado-Schiaffino, G., Ayllon, A.M.G., F., Bright, D., Stevens, J.R. and Garcia-Vazquez, E., 2011. Impact of climate change and human-mediated introgression on South European Atlantic salmon populations. *Global Change Biology* 17; 1778-1787.
- Ingram, B.A., Hayes, B. and Rourke, M.L., 2011. Impacts of stock enhancement strategies on the effective population size of Murray cod, *Maccullochella peelii*, a threatened Australian fish. *Fisheries Management and Ecology* 18; 467-481.
- Ingthamjit, S., 2009. Recent developments in promoting the farming of indigenous species. *Catch and Culture Magazine* 15; 17-19.
- Jonsson, B., Jonsson, N. and Hansen, L.P., 2003. Atlantic salmon straying from the River Imsa. *Journal of Fish Biology* 62; 641-657.
- Kamonrat, W., 1996. *Spatial genetic structure of Thai silver barb Puntius gonionotus (Bleeker) populations in Thailand*. Dalhousie University, pp. 193.
- Mair, G.C., Dahilig, L.R., Morales, E.J., Beardmore, J.A. and Skibinski, D.O.F., 1997. Application of genetic techniques for the production of monosex male tilapia in aquaculture: Early experiences from the Philippines. *Proceedings of the Fourth Central America Symposium on Aquaculture*, Tegucigalpa, Honduras, April 22-24; 225-227.
- Marie, A.D., Bernatchez, L. and Garant, D., 2010. Loss of genetic integrity correlates with stocking intensity in brook charr (*Salvelinus fontinalis*). *Molecular Ecology Notes* 19; 2025-2037.

- Mattson, N.S., 2005. Biodiversity and aquaculture in the Mekong River Basin. *World Aquaculture* 36; 60-62.
- Na-Nakorn, U., Kamonrat, W. and Ngamsiri, T., 2004. Genetic diversity of walking catfish, *Clarias macrocephalus*, in Thailand and evidence of genetic introgression from introduced farmed *C. gariepinus*. *Aquaculture* 240; 145-163.
- Nguyen, T.T.T., 2008. Population structure in the highly fragmented range of *Tor douronensis* (Cyprinidae) in Sarawak, Malaysia revealed by microsatellite DNA markers. *Freshwater Biology* 53; 924-934.
- Nguyen, T.T.T. and Sunnucks, P., 2012. Strong population genetic structure and its management implications in the mud carp, an indigenous freshwater species subject to aquaculture and culture-based fishery. *Journal of Fish Biology* 80; 651-668.
- Nock, C.J., Ovenden, J.R., Butler, G.L., Wooden, Moore I.A., and Baverstock, P.R., 2011. Population structure, effective population size and adverse effects of stocking in the endangered Australian eastern freshwater cod *Maccullochella ikei*. *Journal of Fish Biology* 78; 303-321.
- Ryman, N. and Laikre, L., 1991. Effects of supportive breeding on the genetically effective population size. *Conservation Biology* 5; 325-329.
- Stanley, J.G., Hidu, H. and Allen, S.K.J., 1984. Growth of American oysters increased by polyploidy induced by blocking meiosis I but not meiosis II. *Aquaculture* 37; 147-155.
- Sverdrup-Jensen, S., 2002. Fisheries in the lower Mekong basin: Status and perspectives, *Mekong River Commission Technical Paper*. Mekong River Commission, Phnom Penh, Cambodia, pp. 103.
- Waples, R.S. and Do, C., 1994. Genetic risk associated with supplementation of Pacific salmonids: captive broodstock programs. *Canadian Journal of Fisheries and Aquatic Sciences* 51; 310-329.
- Wijeynayake, W.M.H.K., Amarasinghe, U.S. and De Silva, S.S., 2007. Performance of GIFT strain of *Oreochromis niloticus* in culture-based fisheries in non-perennial reservoirs, Sri Lanka. *Sri Lanka Journal of Aquatic Science* 12; 1-18.

PART 3.

Selected case studies

Summary of culture-based fisheries developments in Lao PDR

This summary is based on the following publications, either in the primary literature, or as manuals and reports posted on the website of the Network of Aquaculture Centres in Asia-Pacific (NACA) that have emanated from projects funded by the Australian Centre for International Agriculture research (ACIAR) since 1997.

- Ingram, B.A. and Lasasimma, O., 2008. Production of *Cirrhinus molitorella* and *Labeo chrysophekadion* for culture based fisheries development in Lao PDR Part I: Captive spawning. *Aquaculture Asia Magazine*, 13; 21-25.
- Lasasimma, O. and Ingram, B. A., 2008. Production of *Cirrhinus molitorella* and *Labeo chrysophekadion* for culture based fisheries development in Lao PDR Part 2: Nursery culture and grow-out. *Aquaculture Asia Magazine*, 13; 23-29.
- Saphakdy, B., Phomsouvanh, A., Davy, B., Nguyen, T.T.T. and De Silva, S.S., 2009. Contrasting community management and revenue sharing practices of culture-based fisheries in Lao PDR. *Aquaculture Asia Magazine*, 14 (3); 2-6.
- Nguyen, T. T. T., 2011. Permanent genetic resources added to molecular ecology resources database 1 August 2010 - 30 September 2010. *Molecular Ecology Resources* 11; 219-222.
- Nguyen, T. T. T. and Sunnucks, P., 2012. Strong population genetic structure and its management implications in the mud carp, an indigenous freshwater species subject to aquaculture and culture-based fishery. *Journal of Fish Biology*, 80; 651-668.
- Anonymous, 2013. Culture based fisheries development in Lao PDR and Cambodia proceeding well. *NACA Newsletter XVIII*, No.4, October-December 2013.
- De Silva, S.S., 2012. *Better Management Practices for Culture-Based Fisheries*, Lao PDR. 46 pp. http://www.enaca.org/modules/library/publication.php?publication_id=709.
- Ingram, B.A., Chanthavong, K., Nanthalth, T. and De Silva, S. (2014). Guidelines for hatchery production of Pa Phia fingerlings in LAO PDR *Fisheries Victoria Internal Report Series No. 17*. 31 pp.
- Phomsouvanh, A., Saphakdy, B. and De Silva Sena S., 2015. Production trends, monetary returns and benefit sharing protocols from the extensive aquaculture practice of culture-based fisheries in rural communities in Lao PDR. *Aquaculture*, 439; 29-38.

Lao PDR, or Laos, is a land-locked nation (18° 00' N; 105° 00' E) with a land area of 236,800 km² and a population of 6.6 million with a per caput GDP of US\$ 3,100 per annum. It is considered as one of the most impoverished nations in Asia. It is also a nation with considerable renewable inland water resources estimated at 333.5 km³ (<https://www.cia.gov/library/publications/the-world-factbook/geos/la.html>). Its economy is mainly agricultural, and the main animal protein in the diet of Laotian people is fish.

Many changes have occurred in the fisheries sector of Laos in the past two decades where the contribution of the aquaculture sector to the food fish supply has bypassed the capture fishery production since 1997 (FAO, 2014). In 2011, aquaculture production in Laos accounted for 73.6 % of the total food fish supply of 116,900 t, reflecting the global trend where aquaculture accounts for over 50 percent of the fish consumed (FAO, 2014). However, the Government of Laos does not reckon intensification of aquaculture as the sole means of meeting the increasing fish food demand by the growing population. It is in the above context that the government recognises the importance of developing CBF in remote, rural areas, utilising the multitude of small water bodies for food fish production (Ministry of Agriculture and Forestry, 2010).

Laos embarked on CBF as a strategy in 1997 to increase food fish production among rural communities, initially under the auspices of the Australian Centre for International Agricultural Research (ACIAR).

R&D activities pertaining to CBF were conducted in Vientiane Province, Bolikhamxay Province and the Vientiane Capital Territory since 2007. Water bodies that under normal circumstances incapable of supporting even a subsistence fishery through natural recruitment were chosen, on agreement with the village organisations for conducting R&D activities, and to act as demonstration practices for adjacent communities. In Laos, as most of Asia, the water management of small water bodies suitable for CBF - the stock and recapture strategy for enhancing food fish production - was often undertaken through village committees constituted with legislative backing for this purpose. For CBF, R&D and further developments of this practice, such

organisations were chosen and personnel were provided with the required training on CBF protocols. Training was provided by the Fisheries Division personnel of the Department of Livestock and Fisheries of the Ministry of Agriculture and Forestry. Personnel of the Fisheries Division were responsible for coordination and providing guidance when and if required by individual communities.

Apart from the main thrust of R&D on CBF in small water bodies in Laos that concentrated on optimisation of food fish production, the nature of community management and related aspects on income/benefit sharing work and development of artificial propagation and broodstock management of indigenous species suitable for CBF (and aquaculture) were also undertaken. The overarching

CBF practices in Laos are a very communal activity with the community engaged from stocking onwards; fry and fingerlings may be cared for a few weeks in hapas to ensure higher survival (top left); harvesting is a communal activity with a multitude of gears used and whole families taking part (bottom); a happy villager with the catch on the final day of a harvest (top right).



objective of this latter component was to encourage the use of indigenous species with suitable consumer preference in CBF developments, and in doing so take steps to ensure impacts on genetic diversity are minimised through the incorporation of relevant broodstock management strategies.

The CBF R&D in Laos has clearly shown its community benefits, and the gains for each household in village communities. The communities that adopted CBF in Laos, unlike elsewhere in Asia, fall into one of three categories, based on the nature of the harvesting and the manner in which the benefits are distributed within the community. The details of these are given in Tables 1.

Table 1. The three basic forms of management (based on the harvesting patterns) of the water bodies that are adopted through a consensus of each of the communities. Adopted from Phomsouvanh et al., 2015).

Harvesting	Gains to community households
Category 1 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= 1US \$). 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.	Daily fish needs in this manner and households are not permitted to catch for sale; gear limited to small drag net and traditional traps only.
Category 2 Similar approach to category 1.	Daily fish needs and households are not permitted to catch for sale; gear limited to small drag net 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 8-9 months post stocking with engagement of the whole community; harvesting is publicised widely and the harvest auctioned on site.	Fish for communal social occasions/festivities; monetary gains based on net gains after harvest.

Table 2. The disbursement protocols of each of the categories of management (these are coupled to the harvesting strategies given in Table 1; adopted from Phomsouvanh et al., 2015)

Category 1 Restricted to ticket sales; 10-20 % of the proceeds reserved for purchase of seed stock for the next CBF 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 water body in the village for CBF activity by improving the dam structure/slucice gates etc.
Category 2 Of the ticket sales 10-20 % 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 for this benefit. The rest is utilised as follows: 6% advisors 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 50% of the total revenue is shared amongst households of the community. The remainder is disbursed as follows: 20% purchase of fry and fingerlings; 6% advisors 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.

Figure 1. Boxplots presenting the distribution of production per cycle per ha (kg) in the three categories of CBF practices, for the period from 2007 to 2013. Bold horizontal bars are the medians, circles represent data points for each water body and triangles represent the means with \pm SE among water bodies (from Phomsouvanh et al., 2015).

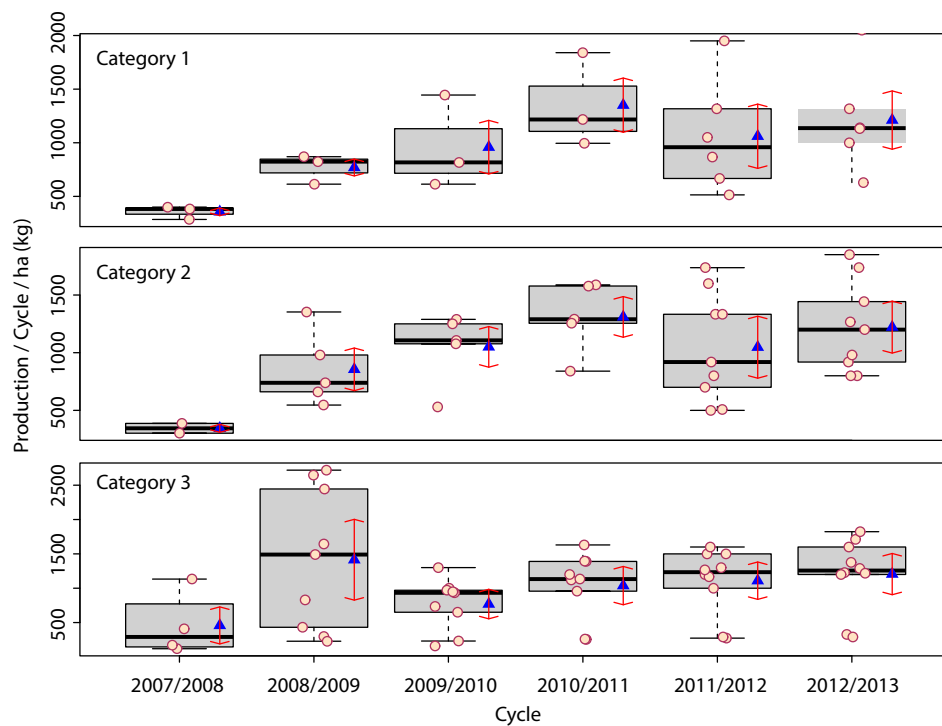
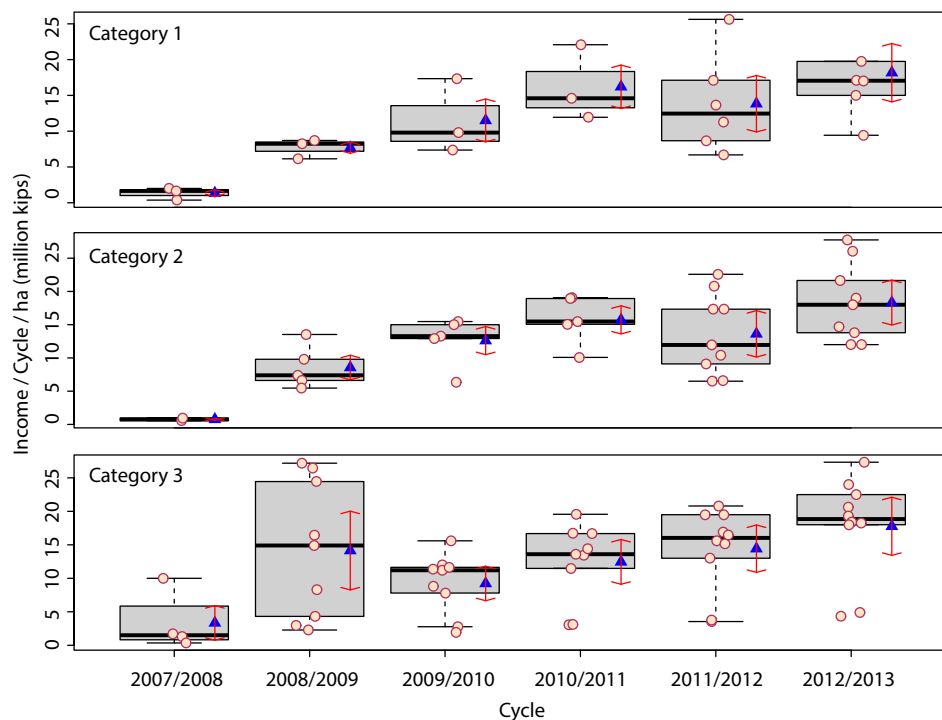


Figure 2. Boxplots representing the distribution of income per cycle per ha (million kip; 1 US \$= 8,000 kip) in three categories of CBF practices, for the period from 2007 to 2013. Bold horizontal bars are the medians, circles represent data points for each water body and triangles represent the means with \pm SE among water bodies (from Phomsouvanh et al., 2015).



and 2., respectively. Overall, it is evident that adoption of CBF, irrespective of the management category practiced, will benefit every household in the village community through the provision of food fish needs and or food fish needs and monetary benefits. An equally important fact is that, irrespective of the management category adopted, the community as a whole gains through the provision and improvement of communal amenities.

The production trends and the monetary benefits from CBF for the three management categories are depicted in Figures 1 and 2. It is evident that for all three categories of CBF management the returns tended to increase initially and then stabilise after three to four cycles of activity. The details on these aspects and the likely reasons for the above observations and other related aspects are dealt with in detail by Phomsouvanh et al. (2015). Overall, it is evident that CBF yielded significant returns to the communities augmenting food fish needs and subsidiary income.

In addition to the above the R&D activities also indicated major trends in relationships between the size of water bodies used for CBF and the corresponding returns. These generalised observations may and or could have applicability in the Asian region and will assist in determining the scope and help in the planning of adopting CBF.

References

FAO, 2014. *FishStatJ - software for fishery statistical time series*: <http://www.fao.org/fishery/statistics/software/fishstatj/en>.

Ministry of Agriculture and Forestry, 2010. *Agriculture Master Plan, 2011-2015*, Vientiane, Lao PDR.

Phomsouvanh, A., Saphakdy, B. and De Silva Sena S., 2015. Production trends, monetary returns and benefit sharing protocols from the extensive aquaculture practice of culture-based fisheries in rural communities in Lao PDR. *Aquaculture*, 439; 29-38.

Challenges and constraints for developing CBF in Cambodia and a possible strategy for success

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Abstract: Fish is the most important source of animal protein in Cambodia. On average it makes up more than 75 % of animal protein and in some areas of the country aquatic resources make up 80 % of the available animal protein. Overall, fish consumption is estimated to be around 63 kg/caput/year (FAO, 2013) (whole fish equivalent) and is many times greater than the global average, reflecting the importance of the fisheries sector to the diet and culture of Cambodian people.

The application of culture-based fisheries in Cambodian waters commenced with the initiation of a project under the auspices of the Australian Centre for International Agricultural Research (ACIAR Project FIS/2011/013), coordinated by NACA. For the initial trial, 16 small reservoirs located in four provinces were selected. These reservoirs differed from each other in surface area, mean depth and the catchment land use features, the latter evaluated using GIS software. In choosing the reservoirs, initial consultations with the village communities responsible for the water regime management were held and their agreement obtained for monitoring and cooperating through the trial period. One common feature in all the reservoirs selected, and for that matter in all water bodies in Cambodia, is the provision of a “conservation zone”, generally in the deeper areas of the water body, where fishing is prohibited.

Culture-based fisheries are a form of aquaculture that utilise small water bodies, both perennial and non-perennial, which cannot support a fishery through natural recruitment processes, for food fish production through a stock-recapture strategy. Culture-based fisheries are environmentally friendly as the only external input is seed stock. It also engages a co-management approach utilising the downstream farming communities in most instances already organised into functional entities for dry land agriculture as the principal beneficiaries (De Silva 2003). Culture-based fisheries are an attractive development strategy as it mobilises dry land farming communities (e.g. rice farmers) to use existing water bodies for the secondary purpose of food fish production. The strategies to optimise benefits from culture-based fisheries, however, vary in detail from country to country and across climatic regimes.

Culture-based fisheries activities were conducted over two growth cycles and in all instances the fish production increased above the levels that were obtained prior to the implementation of culture-based fisheries. In this presentation the stocking strategies and the yields obtained are presented. It is believed, however, the yields could be further enhanced by utilisation of the conservation as nursery areas which will be dealt with in a separate presentation.

Key words: Fish consumption, small water bodies, culture-based fisheries, free access, conservation zone, co-management.

Introduction

Cambodia (13 00°N, 105 00°E) with a total area of 181,035 km² and with relatively short coast line (443 km) and a current population of nearly 15.5 million is blessed with extensive water resources, estimated at 4,520 km². Cambodia with its vast freshwater resources, principally the Mekong river with its two main tributaries (Tonle Sap and Bassac) flowing through it, together with the Tonle Sap Lake or the Great Lake, have been the major source of food fish. Not surprisingly Cambodian people have one of the highest fish consumption levels in the world, estimated at 63 kg/caput/year; considerably higher than the average in Asia (27-29 kg/caput/year) and the world (17-19 kg/caput/year). In some regions of the country, for example in the Tonle Sap region and the associated

plains, it could be as high as 67 – 80 kg/caput/year. This high fish consumption, primarily freshwater fish eaten fresh and or in variety of processed forms, translates into nearly 80 % of the animal protein requirements of Cambodian people (FAO, 2011), which is considerably higher than that in other developing countries (28 - 32 %).

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Fish yields from the Lower Mekong Basin, the primary source of fish for Cambodia (MRC 2010) were estimated to range from low, median and high estimates of 197,572, 395,144 and 790,288 t/yr, respectively, and considerably higher than for other riparian countries (Hortle 2007). The main inland fisheries in Cambodia, until very recently, were the fishing lots in the Great Lake (Tonle Sap) (see for example, Chadwick et al. 2008) and the dai fishery in the mainstream of the Mekong River. The latter is a very seasonal and an intense fishery in which very large quantities of fish, primarily carp species such as *Henicorhynchus* spp., are captured during their migratory phase (Adamson et al. 2009). The latter fisheries provide the raw material for the preparation of the various types of fish sauces and pastes that form a crucial component of the Cambodian cuisine. In the recent past changes in the fishery regulations resulted in the prohibition of the establishment of fishing lots in the Great Lake, and thereby opening vast areas of the lake for fishing by individuals on an open access basis (FiA 2013).

Overall, the fish yield from inland waters in Cambodian waters is at best plateauing (Figure 1). On the other hand, the population of Cambodia is increasing and the most conservative estimate predicts that it would reach 20-22 million by year 2020 (<http://www.indexmundi.com/g/g.aspx?v=21&c=cb&l=en>). Even if the current level of fish consumption is maintained the food fish requirement of Cambodia by year 2020 would be around 1.153 million t/yr, more than double the current supply level..

It is in the above context that the Royal Government of Cambodia has recognised the need to utilise small, inland water bodies for culture-based fisheries development (CBF) as a plausible strategy for increasing food

fish availability in rural communities and to augment their income (Government of Cambodia 2010). As CBF is new to Cambodia and the rural communities thereof, and involves practices that need to be geared to specific locations/regions to obtain optimal returns (De Silva et al. 2006), a R&D program under the auspices of the Australian Centre for International Agricultural Research (ACIAR) (FIS/2011/013) was initiated. During the course of this program it became evident that optimal results (i.e. optimal yields) from CBF cannot be achieved under the existing fishery regulations in Cambodia.

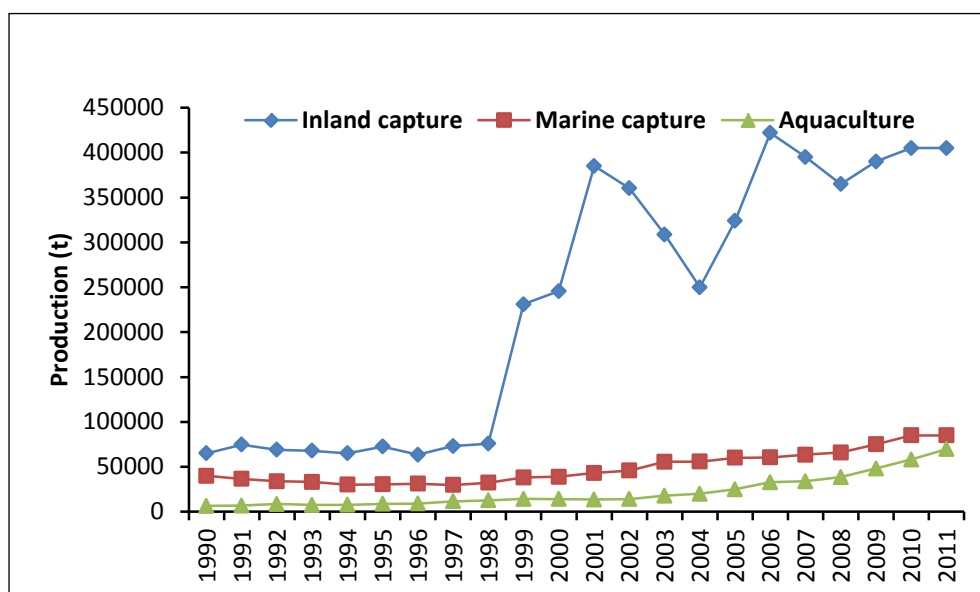
Accordingly, this paper, which is an extension of an earlier treatment of the subject (Limsong et al. 2013) discusses the plausible strategies that could be adopted and the R&D needs to make the returns from CBF practices in Cambodia optimal.

Basics of CBF

CBF is essentially a stock enhancement practice applied to water bodies that are incapable of supporting even a subsistence fishery though natural recruitment, and where the stocked seed is cared for through a community management process, by virtue of this direct and or indirect ownership of the stock it becomes an aquaculture practice, and extensive one at that. Apart from the external input of seed stock there is generally minimal other inputs thereby making it an environmentally friendly process.

In an ideal operation of a CBF practice, once the water body is stocked, the seed is permitted to grow, utilising the naturally produced food resources, for a period of six

Figure 1. Trends in inland, marine and aquaculture production in Cambodia, 1990-2011 (based on FAO, 2014).



to eight months after which, under tropical conditions, the stocked fish will be ready for harvest (see De Silva et al. 2006). Generally, fast growing fish species that are known to have local consumer preferences are chosen. The extent of care rendered to the stock as well as the nature of harvesting and the distribution of profits could vary among the communities/countries.

Cambodian context

Free access

The Cambodian fishery regulations permit free access to any type of water body. Equally, and unlike in most other countries in the region, the communities living besides water bodies suitable for practicing CBF are not organised for water management for downstream cultivation for example. The key here being that when CBF is practised in most countries, the already operational community organisations and or their representatives, are also engaged in CBF management (see Wijenayake et al. 2005; Nguyen et al. 2006; Kularatne et al. 2009; Saphakdy et al. 2009).

Consequently, even though communities living in the vicinity of a water body in Cambodia could be organised into a suitable CBF management unit, as in other countries, under the existing fishery laws this unit does not have the power to stop free access and fishing even immediately after stocking. The situation is further exacerbated by the fact that fishing in relatively easily accessible water bodies to meet the daily food fish needs is a traditional and cultural practice in rural Cambodia. As such a very high proportion of the stocked seed do not reach table/marketable size and the overall yield is considerably reduced.

Conservation zones

The demarcation of a conservation zone in every water body, irrespective of its scientific merits, was introduced in 2010. The conservation zone is indicated very conspicuously with appropriate signage, and overall the community abides by this regulation by refraining from fishing in this zone. The area of the conservation zone in a water body could vary from 10 to 30 % of the area at full supply level, and is often wooded and/or with rooted vegetation such as water lilies, lotus (*Nymphaea* spp.), which are also not harvested. There is a community belief that the conservation zones provide spawning grounds for some native species. However, explicit scientific evidence in this regard is yet to forth come.

Potential/feasible strategy

The objective of any strategy that would enhance CBF production in small water bodies in Cambodia should comply with the existing fishery regulations. Equally, the most direct and logical way of increasing production from CBF practices will be to provide time for the stocked seed to grow to a larger size i.e. reduce the probability of recently stocked fry/advanced fry and or fingerling being captured relatively early in the growth cycle.

Considering all of the above extensive consultations were made with stakeholder communities from four provinces (Kampong Thom, Oddor Meanchey, Preah Vihear and Siem Reap) that are engaged in the ongoing CBF project (FIS/2011/013) with regard to the possibilities of utilising conservation zones as possible nursing areas for an extended periods. The communities were agreeable to such an innovation.

Accordingly, it is proposed that seed stock, whatever stage at the time of purchase (generally advanced fry or early fingerling) be released into the conservation zone which will be appropriately cordoned off either using netting or fencing. Furthermore, brush parks will be introduced into this zone prior to stocking. The netting/fencing will be gradually removed in stages, based on observations on the rate of growth of stocked species. Needless to say there are a host of unknowns that have to be researched in order to adopt this strategy to optimise fish yield from CBF in small water bodies.

Immediate research needs

The immediate research needs are many fold. As the extent of conservation zone in a water body has been based on random observation it will be necessary to determine the optimal ratio of the conservation zone to the water body at full supply level for purposes of nursing the stocked seed. As replication is not possible it will have to be investigated on a random basis where the size of the conservation zone relative to the water body area is increased in a step wise manner (5 % increments) from about 15 to 45 %, taking care that at least three water bodies are included for each increment. It would be desirable to maintain a unified proportion of brush parks in each conservation zone.

The results from the above trial would provide an indication of the range in the extent of the conservation zone that will likely provide the best production. In a subsequent trial, using the same water bodies, a second growth trial should be conducted to ascertain the best length of time the conservation zone be utilised as a nursing area for the stocked seed.

Women folk of village communities play an active role in CBF in Cambodia (left); a selection of fish from CBF in small water bodies (right); monks are often involved during stocking (bottom).



Once armed with the above information, i.e. the ratio of the area of the conservation zone to the total area of the water body and the optimal length of time the former should be utilised for nursing the seed stock, a third trial could be conducted to fine tune these parameters. In all trials, as had been done in other countries, limnological parameters as well as the performance of individual stocked species (the percent recovered, size at harvesting, etc.) should be obtained, and all these data employed to develop a case for better management practices of CBF in Cambodia that could be disseminated to the public/communities for adoption.

References

- Adamson, E.A.S., Hurwood, D.A., Baker, A.M. and Mather, P.B., 2009. Population subdivision in Siamese mud carp *Henicorhynchus siamensis* in the Mekong River: implications for management. *Journal of Fish Biology*, 75; 1371-1392.
- Chadwick, M.T., Juntapas, M. and Sithirith, M. (eds), 2008. *Sustaining Tonle Sap: an assessment of development challenges facing the Great Lake*. Sustainable Mekong Research Network (Sumernet), Bangkok, 144 pp.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T. (eds), 2006. *Better-practice approaches to culture-based fisheries development in Asia*. ACIAR Monograph 120, 96 pp. (translated into Laotian, Sinhalese, Tamil and Vietnamese).
- FAO (Food and Agriculture Organization of the United Nations), 2011. *World aquaculture 2010*. FAO Fisheries and Aquaculture Technical Paper 500/1 Rome, Italy, 120 pp.
- FAO, 2014. *FishStatJ-software for fishery statistical time series*. <http://www.fao.org/fishery/statistics/software/fishstatj/en>.
- Fisheries Administration (FiA), 2012. *Cambodia Fisheries Annual Report 2012*, 16 pp.
- Government of Cambodia, 2010. *The Strategic Planning Framework for Fisheries 2010–2019*, 57 pp.
- Hortle, K.G., 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. *MRC Technical Paper No. 16*, Mekong River Commission, Vientiane, Lao PDR, 87 pp.
- Kularatne, M. G., Amarasinghe, U.S., Wattage, P. and De Silva, S.S., 2009. Evaluation of community participation for the Development of culture-based fisheries in village Reservoirs of Sri Lanka. *Aquaculture Economics & Management*, 13; 22–38.
- MRC, 2010. *State of the Basin report*. Mekong River Commission, Vientiane, Lao, April 2010, 232 pp.
- Limsong Srun, Hort Sita, Sary Ou, Vutha Ouch, Mohan, C.V. and De Silva Sena S., 2013. Introduction of culture based fishery practices in small water bodies in Cambodia: issues and strategies. *Aquaculture Asia Magazine*, 18 (4); 12-17.
- Nguyen, Son H., Bui, Anh T., Le, L.T., Nguyen, Thuy T.T. and De Silva, S.S., 2001. Aspects of the culture-based fisheries in small, farmer-managed reservoirs, based on three production cycles, in two provinces of northern Vietnam. *Aquaculture Research*, 32; 975- 990.
- Saphakdy, B., Phomsouvanh, A. Davy, B., Nguyen, T.T.T. and De Silva, S.S., 2009. Contrasting community management and revenue sharing practices of culture-based fisheries in Lao PDR. *Aquaculture Asia Magazine*, 14 (3); 2-6.
- Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Athula, J.A., Pushpalatha, K.B.C. and De Silva, S.S., 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. *Fisheries Management and Ecology*, 12; 249-258.

Results of a decade of R&D efforts on culture-based fisheries in Sri Lanka

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Abstract: Fisheries enhancement is defined as technical intervention in the life cycles of fish. Culture-based fisheries (CBF) development is one of the major fisheries enhancement strategies practised in inland reservoirs of Sri Lanka. The extensive availability of inland reservoirs in the country, primarily constructed for irrigation of land crops in ancient times, favours CBF development, which is essentially a development since late 1990s. Water retention period in most small village reservoirs in the country is seasonal and lasts for six to nine months in the year. CBF development in these reservoirs therefore requires fast growing fish species such as Chinese and Indian major carps. Hormone induced captive breeding of major carps in government-owned hatcheries and fingerlings rearing in mini-nurseries, maintained by rural agricultural farmers, are the sources of seed for stocking these village reservoirs.

The CBF in village reservoirs of Sri Lanka is a communal activity involving agricultural farmers without prior experience in fisheries. As such, awareness programs conducted for these farmers have facilitated establishment of CBF in small village reservoirs. The biological productivity of water bodies and socio-economic conditions of rural communities were found to vary from reservoir to reservoir. As such, successful R&D efforts were made for selection of village reservoirs suitable for CBF development, based on the biological productivity-related parameters such as reservoir morphometry, allochthonous input of nutrients through livestock farming, and socio-economic characteristics of rural communities that favour CBF. For CBF development in village reservoirs, correct timing is necessary for fingerling production to suit the monsoonal rainy season when the reservoirs get filled. Climate change impacts, which resulted in a shift in peak monsoonal rainy season were therefore identified together with possible resilience capacities of rural communities for sustainability of CBF.

Dissemination of research findings through various means such as production of a documentary film, publication of a monograph which was translated to several regional languages, and holding a series of regional workshops were instrumental for CBF development at the regional level. The Asian Development Bank funded Aquatic Resources Development and Quality Improvement Project, which contained a significant component for CBF development in inland reservoirs of Sri Lanka, has also been facilitated by R&D efforts mentioned above. The recent efforts to develop CBF in Sri Lanka include establishment of profitable CBF with effective co-management in selected minor perennial reservoirs, and the use of *Macrobrachium rosenbergii* post-larvae for CBF in many inland reservoirs.

Key words: Culture-based fisheries, Chinese carps, Indian carps, Inland reservoirs, *Macrobrachium rosenbergii*.

Introduction

In the wide array of fisheries enhancement strategies, the common feature is human intervention in the life cycle of the aquatic organism that is used for fisheries enhancement (Lorenzen et al. 2001), and “culture-based fisheries” and “capture-based aquaculture” are two major terminologies in this context. The term “culture-based fisheries” (FAO 1997; De Silva 2003) is used to define the fisheries enhancement strategies that involve release of hatchery-reared fingerlings to the wild for subsequent recapture after a reasonable growth period. As such, this is essentially “aquaculture-driven.” On the other hand, “capture-based aquaculture” involves capture of cultured organisms from the wild and rearing them in various aquaculture systems such as cages (Ottolenghi et al. 2004) and this enhancement strategy is therefore “fishery-driven.”

As culture-based fisheries (CBF) are aimed at stocking of different species which are able to optimally utilise available food niches, they often share features of polyculture (Bardach et al. 1972). Also CBF comes under the realm of aquaculture because globally in all CBF strategies, ownership is defined (De Silva 2003). The potential for CBF in small, village reservoirs of Sri Lanka was first recognised by Mendis (1965, 1977). Nationally, this is of particular importance due to the fact that Sri Lanka

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has a long tradition of irrigation water management in reservoirs some of which dating back to the first century AD.

Although in general, irrigation systems are recognised as common pool resources, supplying water for agricultural production (Meinzen-Dick and Bakker 1999), in the Sri Lankan context, irrigation water resources do not fall into open access property regime. Irrigation of agricultural lands is essentially based on pre-planned schedules and water is not freely available on demand to the farmers. As such, CBF can be incorporated as a community-based activity during the planning stage of an irrigation schedule for the two cultivation seasons, in a calendar year, in the command areas of each reservoir. These community-based water management strategies and CBF in village reservoirs are facilitated by the Department of Agrarian Development and the National Aquaculture Development Authority of Sri Lanka (NAQDA) respectively, under the legal provisions of *Agrarian Development Act of 2000*.

Due to extensive availability of lentic water bodies in Sri Lanka (Table 1), there is a promising potential for inland fisheries development in the country that favours CBF. Water retention period in most small village reservoirs in the country is seasonal and lasts for six to nine months. CBF development in these reservoirs therefore, requires fast growing fish species such as Chinese and Indian major carps. Hormone induced captive breeding of major carps in government-owned hatcheries and fingerlings rearing in mini-nurseries, maintained by rural agricultural farmers, are the sources of seed material for stocking in the village reservoirs.

In the 1980s, fisheries authorities made efforts to develop CBF in non-perennial reservoirs in the dry zone of Sri Lanka (Thayaparan 1982; Chandrasoma and Kumarasiri 1986). However, in this effort lack of a proper selection method for the identification of suitable reservoirs was a major set-back for developing CBF in non-perennial reservoirs in Sri Lanka. Due to dense distribution of reservoirs in Sri Lanka, it is impossible and impracticable to visit individual reservoirs and observe their suitability

for CBF. Furthermore, politically inspired policy decision to discontinue state patronage to inland fisheries and aquaculture development between 1990-1994, also had a detrimental impact on the inland fishery developments of the country (Amarasinghe 1998). Realising the national need for sustainable development of inland fisheries in Sri Lanka, Deakin University, Victoria, Australia, University of Kelaniya, Sri Lanka and NAQDA developed a collaborative research project under the auspices of Australian Centre for International Agricultural Research (ACIAR) for scientific management of reservoir fisheries of Sri Lanka, a major part of which was sustainable development of CBF. In this chapter, R&D efforts of CBF development in Sri Lanka under the ACIAR-funded project, and subsequent CBF development efforts performed under the Asian Development Bank-funded "Aquatic Resources Development and Quality Improvement Project" (ARDQIP) are reviewed.

Accordingly and primarily, this paper reviews the previous major findings (De Silva et al. 2004; Jayasinghe et al. 2005, 2006; Wijenayake et al. 2005, 2007; Jayasinghe and Amarasinghe 2007; Jarchau et al. 2008; Kularatne et al. 2008, 2009; Amarasinghe and Nguyen 2009; Pushpalatha and Chandrasoma 2010). Furthermore, it is believed that the results of the R&D on CBF in Sri Lanka will have much relevance to developing CBF in other developing countries in the region, thereby contributing to the fish supplies and the socio-economic wellbeing of rural communities in particular.

Influencing strategies for CBF development

After the revival of state patronage for inland fisheries and aquaculture development in the country in 1994, steps were taken to establish NAQDA and to rehabilitate state-owned fish hatcheries which were responsible prior to 1990, for induced breeding and fingerling rearing of Chinese and Indian major carps, and stocking of inland reservoirs. As small village reservoirs are managed by the rural institutions called farmer organisations (FOs),

Table 1. The estimated surface area of lentic water bodies of Sri Lanka. NA - Not available (Source: Jayasinghe and Amarasinghe, in press).

Type	Number	Area (ha)	Percent (%)
Major irrigation reservoirs (ancient)	72	70,850	34.4
Medium-scale reservoirs (ancient)	160	17,001	8.3
Minor irrigation reservoirs (ancient)	> 10,000	39,271	19.1
Floodplain lakes (natural)	NA	40,000	19.4
Upland hydroelectric reservoirs (recent)	7	8,097	3.9
Mahaweli multipurpose system of reservoirs (recent)	6	13,650	6.6
Other (e.g. aesthetic reservoirs, water supplying reservoirs, village ponds)	NA	17,023	8.3
Total		205,892	100.0

which have legal power under the *Agrarian Development Act*, these rural institutions were chosen to implement influencing strategies for CBF development with a view to leading members of FOs across boundaries. Meetings of FOs before the agricultural cultivation period (“Kanna Meeting”), under the supervision of Agrarian Research and Production Assistants (ARPAs) employed by the Department of Agrarian Development. These meetings provided an opportunity to discuss and place before the FOs about the possible nutritional and financial benefits that would be generated from CBF in their reservoir if they were to embark on CBF. This approach was further developed by NAQDA and the aquaculture extension officers of NAQDA, closely worked with the members of FOs to develop an “entrepreneurship plan” for CBF development in each village reservoir.

Efforts for selection of suitable non-perennial reservoirs for CBF development

The general practice adopted for selecting reservoirs for CBF development was ineffective because it was entirely based on the ad-hoc requests made by ARPAs. As such, effective procedures for selection of suitable village reservoirs for CBF development were needed for its sustainability in the country especially due to limitations in terms of manpower and funding for extensive surveys for selecting reservoirs suitable for CBF development. However, ‘human capital’ in the rural institutions (i.e. FOs) has a high potential to be mobilised for CBF development. The efforts to define a better practice model should include both biological aspects related to productivity of water bodies and socioeconomic aspects of rural communities (De Silva et al. 2006).

Limnological aspects

Carlson’s trophic state index (TSI) is a diagnostic approach (Carlson 1977), which in general, is used to monitor status of lentic waters. Carlson’s TSI in non-perennial reservoirs were determined as TSI (SD), TSI (Chl) and TST total phosphorus) according to the following definitions (Jayasinghe et al. 2005).

$$\text{TSI (SD)} = 60 - 14.41 \ln \text{Secchi disk (metres)}$$

$$\text{TSI (Chl)} = 9.81 \ln \text{chlorophyll-a (mg/m}^3\text{)} + 30.6$$

$$\text{TSI (TP)} = 14.42 \ln \text{total phosphorus (mg/m}^3\text{)} + 4.15$$

The relationships between the three definitions of TSI (Table 2; Carlson 1977) can be used to determine the conditions of the non-perennial reservoirs. Jayasinghe et al. (2005) observed that in non-perennial reservoirs of Sri Lanka $\text{TSI (TP)} = \text{TST (SD)} > \text{TSI (SD)}$ showing non-algal particles dominate light attenuation.

Jayasinghe et al. (2005) further showed that CBF yields were positively correlated to chlorophyll-a content. In non-perennial reservoirs with similar trophic characteristics, CBF yield could be predicted from shoreline/reservoir area ratio (Jayasinghe et al. 2006). In rural villages of dry zone of Sri Lanka, buffalo and cattle keeping is one of the economic activities. Nutrient enrichment in village reservoir through cow dung also positively influence CBF yields (Jayasinghe and Amarasinghe 2007).

Biological and technological aspects

In village reservoirs, which do not completely dry up during the dry season, carnivorous fish species such as *Channa striata*, *Glossogobius giuris* are drawn from the associated river basins. Naturally in such reservoirs, stocked fish fingerlings are vulnerable to predatory pressure, resulting in low returns from the CBF efforts (Wijenayake et al. 2005). De Silva (1988) suggested that this could be prevented by stocking large-sized (>10 cm) fingerlings as predator-prey relationship is usually size-dependent. Also, our experience is that when freshwater prawn (*Macrobrachium rosenbergii*) post-larvae are stocked, night stocking (after 19:00 hr) ensures higher survival. This might be due to the reason that prawn post-larvae can move to the bottom of the reservoir so that they can avoid predation by fish species such as *Rasbora daniconius* and *R. cavarii*, which are essentially visual feeders in the water column during twilight periods of the day (De Silva et al. 1996; Weliange et al. 2006).

Table 2. Relationships between three definitions of TSI showing status of reservoir limnology.

Relationship	Condition
$\text{TSI (Chl)} = \text{TSI (TP)} = \text{TSI (SD)}$	Algae dominate light attenuation
$\text{TSI (Chl)} > \text{TSI (SD)}$	Large algae particles dominate
$\text{TSI (TP)} = \text{TST (SD)} > \text{TSI (SD)}$	Non-algal particles dominate light attenuation
$\text{TSI (SD)} = \text{TSI (Chl)} > \text{TSI (TP)}$	Phosphorus limits algal biomass
$\text{TSI (SD)} = \text{TSI (Chl)} < \text{TSI (TP)}$	Factors other than phosphorus limit algal biomass

Species combination of stocked fingerlings is also an important aspect in CBF because optimal utilisation of food resources in the water body is a key to achieve optimal harvests from polyculture systems (Bardach et al. 1972). Although there had not been many scientific studies on this aspect, generally the species combination used was 30% common carp and mrigal, 30% bighead carp/catla; 30% rohu and 10% Nile tilapia/freshwater prawn (Wijenayake et al. 2005, 2007).

In non-perennial reservoirs, the relationship between stocking density (SD) and CBF yield showed a second order curve (Wijenayake et al. 2005), conforming to those that were reported elsewhere (e.g., Bangladesh- Hasan and Middendrop 1998; India- Sugunan and Katiha 2004). Accordingly, the optimal stocking density was determined to be 3,500 fingerlings per ha (Wijenayake et al. 2005). Here, it must be noted that effective area for CBF planning was considered as 50% of the area at full supply level (FSL) because extents of non-perennial reservoirs at FSL during the rainy season gradually shrink to almost zero during the dry season.

Socio-economic aspects

The community meeting of FOs held at the beginning of the cultivation season, the Kanna meeting, is meant for planning agricultural activities through collective decisions. At these meetings, FOs also make decisions whether CBF activities should be incorporated in the agriculture-related economic activities. As these community-based initiatives are backed by the legal provisions of *Agrarian Development Act of 2000*, in most instances, FOs establish Aquaculture Management Committees (AqMCs), which are responsible for stocking fish fingerlings, guarding the stocked fish, harvesting and marketing. The members of AqMCs arrive at agreements with FOs on sharing of CBF profit between the AqMC and FO. In many instances, a levy of about 5% of the net profit is paid to FOs. The group size of AqMC generally varied between 5 and 20. There are rare instances where the entire FO acts as the AqMC because all members of FO take part in the CBF activities. After payment of the levy to the FO, the profit is equally shared by the members of AqMC.

Kularatne et al. (2009) have shown that communities with small group size in AqMCs with satisfactory participation in group activities and those belong to same caste expressed high 'willingness to pay' for CBF activities. Also socioeconomic homogeneity with regard to kinship and political ideology of the farming communities as well as education level and good leadership qualities of group members in AqMCs are found to have a positive influence on the attitudes towards adoption of CBF in village reservoirs (Kularatne et al. 2008). As such, socioeconomic characteristics in rural agricultural

communities are needed to be considered for selecting suitable reservoirs for CBF development. At a national workshop on participatory approaches to reservoir fisheries management, Jarchau et al. (2008) presented a scheme of decision making to select suitable reservoirs for CBF development taking into account both technical feasibility assessment (Figure 1) and social feasibility assessment (Figure 2).

Multi-criteria decision making

For selection of suitable reservoirs for CBF development, several criteria should be considered such as water quality parameters, catchment land-use characteristics, socioeconomic factors and marketing aspects, under which there are several sub-criteria with varying relative importance. As such, a multi-criteria decision making

Figure 1. Decision flow for the technical feasibility assessment of non-perennial reservoirs (Jarchau et al. 2008).

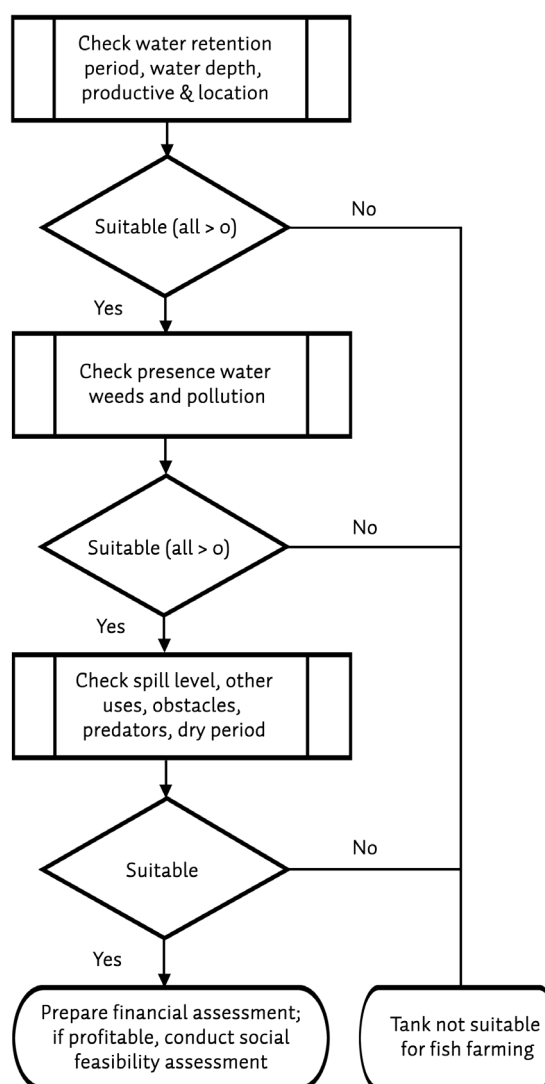
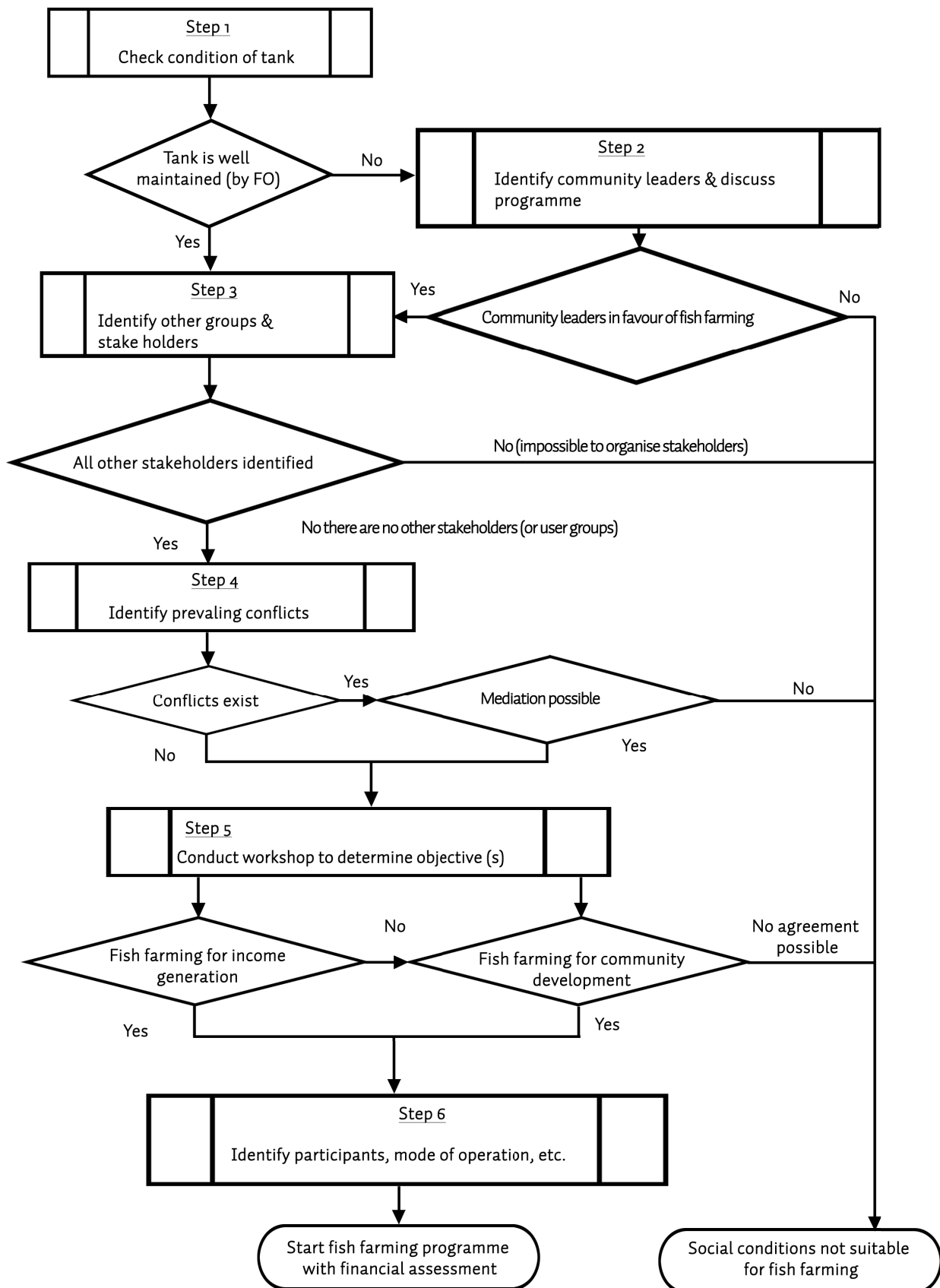


Figure 2. Decision flow for the social feasibility assessment of non-perennial reservoirs (Jarchau et al. 2008).



procedure known as Analytic Hierarchical Process (AHP; Satty 1977) was employed (De Silva et al. 2004). This approach equates sets of heterogeneous criteria into a common denominator, and as such, it is a powerful decision making tool for selection of reservoirs for CBF based on their ranking through relative weighting of multiple criteria.

Other initiatives for CBF development

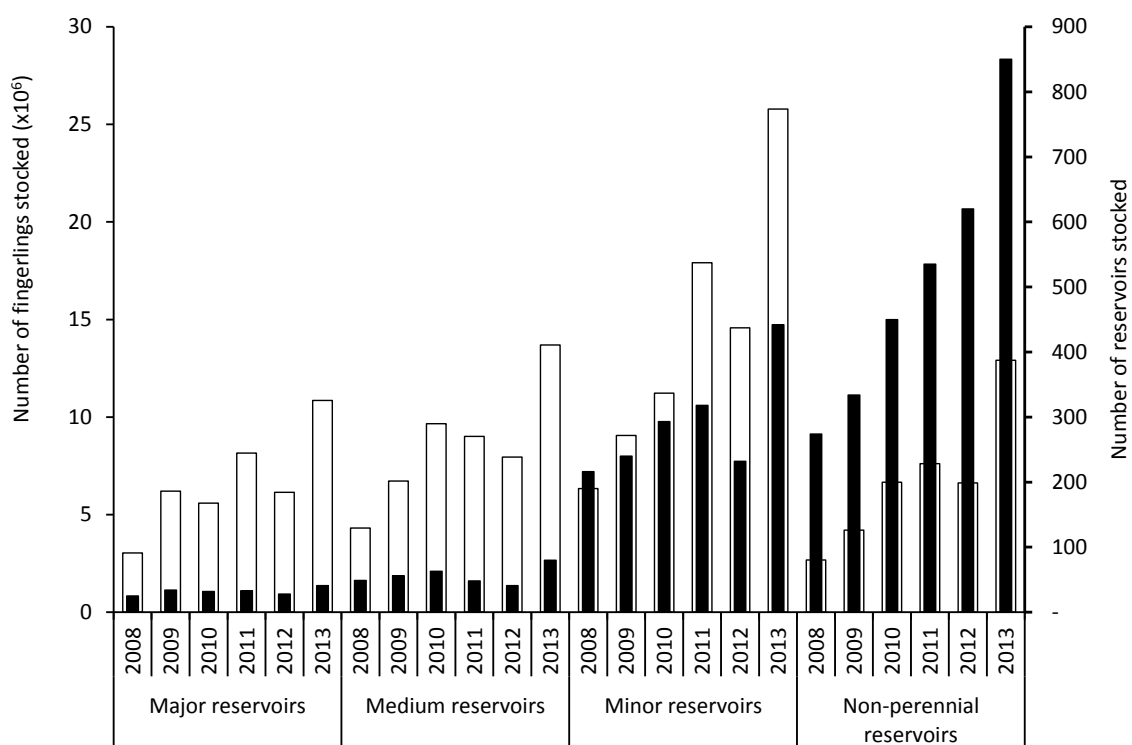
After implementation of the Asian Development Bank-funded ARDQIP during 2004-2007, many initiatives have been taken for the CBF development in Sri Lanka. They included infrastructure development in state-owned fish breeding centres, capacity building in through training field officers in the inland fisheries and aquaculture sector, setting-up of an information system for national inland fisheries and aquaculture which would include more accurate recording of fisheries and aquaculture production data, and establishment of mini-nurseries for fingerling rearing through community participation.

Establishment of mini-nurseries for fry to fingerling rearing

As stocking of inland reservoirs of different kinds is a regular fisheries enhancement strategy practised by fisheries authorities of Sri Lanka, availability of sufficient of fingerlings for stocking non-perennial reservoirs at the correct time is a major constraint to CBF development in the country. When fingerlings are required for stocking one category of reservoir (e.g., minor perennial reservoirs), fingerling requirement for CBF development in non-perennial reservoirs is severely constrained due to their limited supply (Figure 3).

Under the ADB-funded ARDQIP, this issue had been addressed and there were initiatives to establish mini-nurseries through community-based organisations (CBOs) to fulfil the demand for fingerlings for CBF. Through this initiative, initial capital investment was borne by ARDQIP on the condition that CBOs must pay back the total amount in 60 instalments to NAQDA (Anon. 2006). At present, there are about 29 mini-nurseries in different parts of the country. They have been established by rural community-based organisations, mainly AqMCs. Almost all these mini-nurseries are established as earthen pond systems, for which technical advice was provided to CBOs by NAQDA. Fish fry purchased from fish breeding centres of NAQDA

Figure 3. Number of reservoirs of different categories and number of fingerlings stocked during 2008-2013 (Drawn from the data reported at <http://www.fisheries.gov.lk/content.php?cnid=ststc>). White bars – number of fingerlings stocked; dark bars – number of reservoirs stocked.



are reared up to fingerling size in these mini-nurseries, which in turn are sold to CBF farmers. As the profit that the owners of mini-nurseries can earn is very significant, this strategy is bound to continue. The total number of non-perennial reservoirs stocked in 2013 was 850 (Figure 3), which is approximately 7 % of total number of small village reservoirs in the country. As such, opportunities exist for further development of CBF in small village reservoirs of Sri Lanka.

Freshwater prawn stocking

NAQDA's freshwater prawn hatchery, established in 2008 at Kahandamodara in southern Sri Lanka under the assistance by FAO, has a production capacity of 17 million post larvae per year. Aquaculture technology of *M. rosenbergii* is however, not yet well developed (in more accurate terms, well-developed technology elsewhere

has not yet been effectively transferred) in Sri Lanka and as such, there is an over-supply of *M. rosenbergii* post larvae from the NAQDA's hatchery.

Freshwater prawn post larvae were therefore stocked in different kinds of reservoirs and the total extent of reservoirs of various kinds and number of post larvae stocked are shown in Figure 4. As mentioned previously, night stocking was more effective for achieving high returns of CBF based on *M. rosenbergii*.

The stocking data and reported yields of *M. rosenbergii* in different types of reservoirs in Sri Lanka during 2012 (Table 3) indicate that there is potential for incorporating freshwater prawn into CBF development in the country. Jutagate and Rattanachai (2010) reported that in Pak Mun reservoir (a run-of-river type reservoir of about 185 km² surface area) in Thailand, stocking of 2 million post larvae of *M. rosenbergii* resulted in a yield of 3 kg ha/yr and by stocking 40 million post larvae in 2003, a yield of 11.5 kg ha/yr was achieved. These values show that

Figure 4. Number of reservoirs of different categories and number of freshwater prawn post larvae stocked during 2008-2013. White bars – number of fingerlings stocked; dark bars – number of reservoirs stocked. (Drawn from the data reported at <http://www.fisheries.gov.lk/content.php?cnid=ststc>).

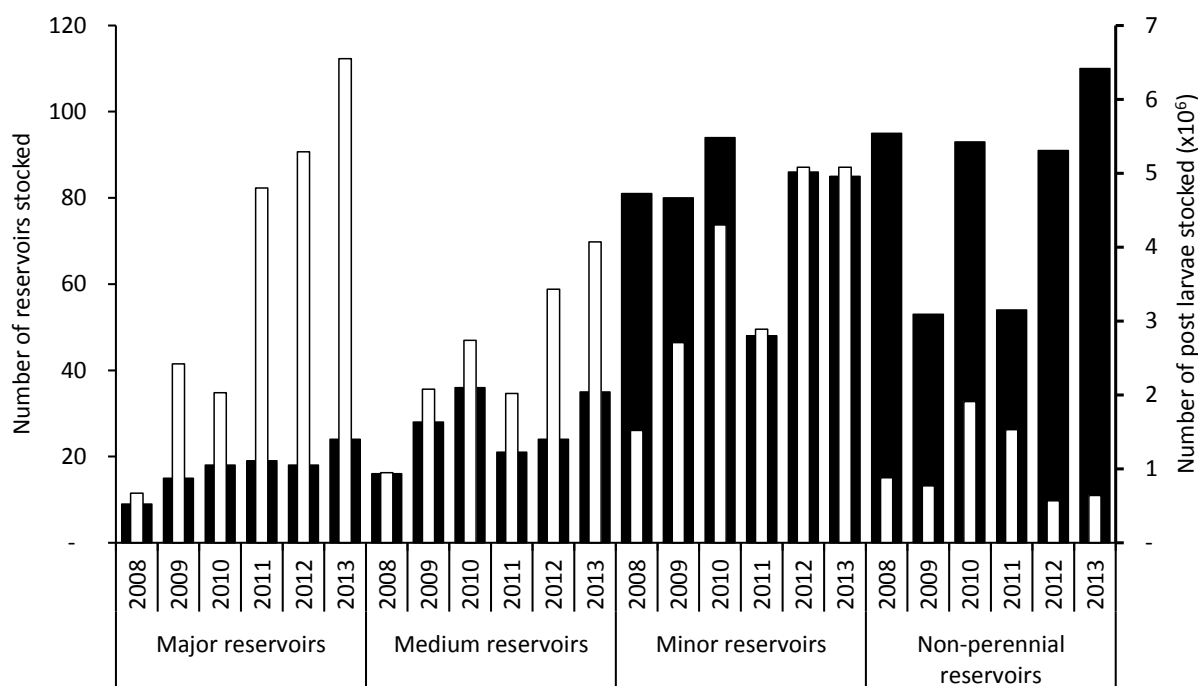


Table 3. Stocking densities and annual yields of freshwater prawn in different types of reservoirs during 2012 (Source: Asoka 2014; ranges are given in parentheses).

Category	Stocking density (number of post larvae/ha)	Yield (kg/ha)
Major reservoirs (>750 ha)	158.2 (46.9 – 297.4)	3.1 (0.02 – 22.8)
Medium reservoirs (200-750 ha)	250.5 (65.0 – 830.2)	5.5 (0.08 – 70.2)
Minor reservoirs (<200 ha)	757.3 (260 – 2600)	17.6 (0.2 – 143.3)

although stocking densities were very low, reasonably high yields of freshwater prawns were achieved in this Thai reservoir. In Sri Lankan reservoirs, fishers do not use special fishing methods to catch freshwater prawns but they are caught as by-catch in gillnets targeting fin fish species. It would therefore be possible to introduce horizontal cylindrical traps (Deap et al. 2003) for catching *M. rosenbergii* in reservoirs where they have been stocked, which might increase freshwater prawn yields in reservoirs. Although the freshwater prawn yield was much lower than finfish yields in CBF activities, there were obvious financial benefits to the fishers because of high farm-gate price of freshwater prawn (SLR 570 – 705) compared farm-gate price of SLR 150-200 for finfish species in CBF yields.

CBF in minor perennial reservoirs

As fingerlings are required for stocking in non-perennial reservoirs only after the peak rainy period in November-January in the dry zone of Sri Lanka, those which are produced in mini-nurseries during other periods can be used for CBF development in other types of inland water bodied such as minor perennial reservoirs. In 2003, NAQDA initiated through ARDQIP, a pilot-scale programme to introduce CBF in minor perennial reser-

voirs (<250 ha), where only subsistence level fisheries existed. Accordingly, in 15 minor perennial reservoirs, CBOs were formed and members were given training on basic aspects of entrepreneurship planning such as leadership, simple accounting, book keeping etc., together with aspects of community-based management of CBF.

The stocking density in CBF in minor perennial reservoirs ranged from 146 fingerlings/ha to 2780 fingerlings/ ha (Pushpalatha and Chandrasoma 2010). Unlike in non-perennial reservoirs, where harvesting is done at once during the dry season, CBF harvesting in minor perennial reservoirs is a year-round activity using gillnets of mesh sizes ranging from 8.5 to 20 cm. Before introduction of CBF in minor perennial reservoirs, mean annual fish yield was 57.3 kg/ha, with *Oreochromis niloticus* being the most abundant species forming over 80 % of the landings. However, after introduction of CBF, annual fish yield increased up to 208 kg/ha and *C. catla*, *L. rohita* and *C. carpio* formed major proportions of the landings. The contribution of *O. niloticus* to the landings reduced to 47.4 % (range 19.7- 66.5 %) (Pushpalatha and Chandrasoma 2010; Amarasinghe 2010).



Harvesting of fingerlings in a fry-to-fingerling rearing facility. Note that women of the community are taking part in the activity.

Co-management

Co-management is essentially the sharing of responsibilities of decision-making and responsibility for the management of resources between the community (local fishers) and government centralised management (Pomeroy and Berkes 1997). According to Brown et al. (2004), for successful co-management there are four pillars as follows:

- 1) An enabling policy and legal framework.
- 2) The participation and empowerment of communities (and other users).
- 3) Effective linkages and institutions.
- 4) Resources – a resource worth managing and the people and money to do it.

The CBF development strategies in Sri Lanka consist of these characteristics. As shown by Amarasinghe and Nguyen (2009), there are legal provisions to develop CBF in inland water bodies of the country under the *Agrarian Development Act* of 2000. Also, CBF development is a high priority area of fisheries development agenda of the country (Anon. 2007).

CBF in village reservoirs are conducted by FOs (agrarian communities) rather than fishers. In medium and major reservoirs, CBF is practised by fishers, who are also organised into fisheries management societies. Community-based aquaculture (for fingerling rearing in mini-nurseries) is also within the organisational mandate of FOs, whenever a farmer community decides to adopt it. The FOs are established under the *Agrarian Development Act* of 2000. The legal provisions in this Act facilitate empowering communities. The residents of a village involved in agriculture are essentially members of FOs. The small village reservoirs, whose command areas are less than 80 ha, come under the jurisdiction of



Fingerlings at a mini fry to fingerling rearing facility ready for transportation to a water body for stocking.



Village livestock are encouraged to use the water bodies to enhance fertility and hence overall fish yield.



A harvest being transported to the market.

Table 4. Selected examples of rural welfare activities carried out by CBF committees.

Reservoir	Major rural welfare activities
Galwale Wewa	Funds for maintaining public well; SLR 5,000 donated for construction of pagoda in village Buddhist temple; Providing fish for village household occasions such as weddings and funerals free of charge.
Meegas Wewa	An accumulated electricity bill of the village temple over a long period was paid by the aquaculture committee.
Pahala Sandanamkulama Wewa	CBF income is used for maintaining and rehabilitation of reservoir and canals; The agreement is that the aquaculture team must provide 60% of the fish harvest to the farmer organisation.
Mataluwawa Wewa	Organised educational tours for farmers, alms-giving ceremonies for Buddhist monks, and a felicitation programme for senior farmers.

Department of Agrarian Development and those which have irrigable area greater than 80 ha are under the control of Irrigation Department.

Divisional Agriculture Committees (DvACs) are the major district-level institutions, which are responsible for facilitating agricultural development. There are monthly meetings of DvACs and the Divisional Secretary presides the meeting. District Officer (DO) of Department of Agrarian Development, irrigation engineer, Samurdhi officer (government officer responsible for implementing state-sponsored poverty alleviation programmes), “Grama Niladhari” (village-level administrative officer), aquaculture extension officer are the middle level government officers in this committee. Agrarian Research and Production Assistants (ARPAs), who work under the supervision of DO, are the major contact persons of FOs. The officer bearers of FOs and ARPAs are also participants of monthly meetings of DvAC (Amarasinghe and Nguyen2009; Amarasinghe 2010). These institutional linkages provide a positive environment for introduction of co-management strategies for CBF.

Extensive availability of village reservoirs, which are not used for fisheries development, willingness of agricultural communities to take up CBF, and well-established CBOs for operating mini-nurseries for fingerling rearing are the resources prevailing for CBF development in the country. In some reservoirs, CBF committees have

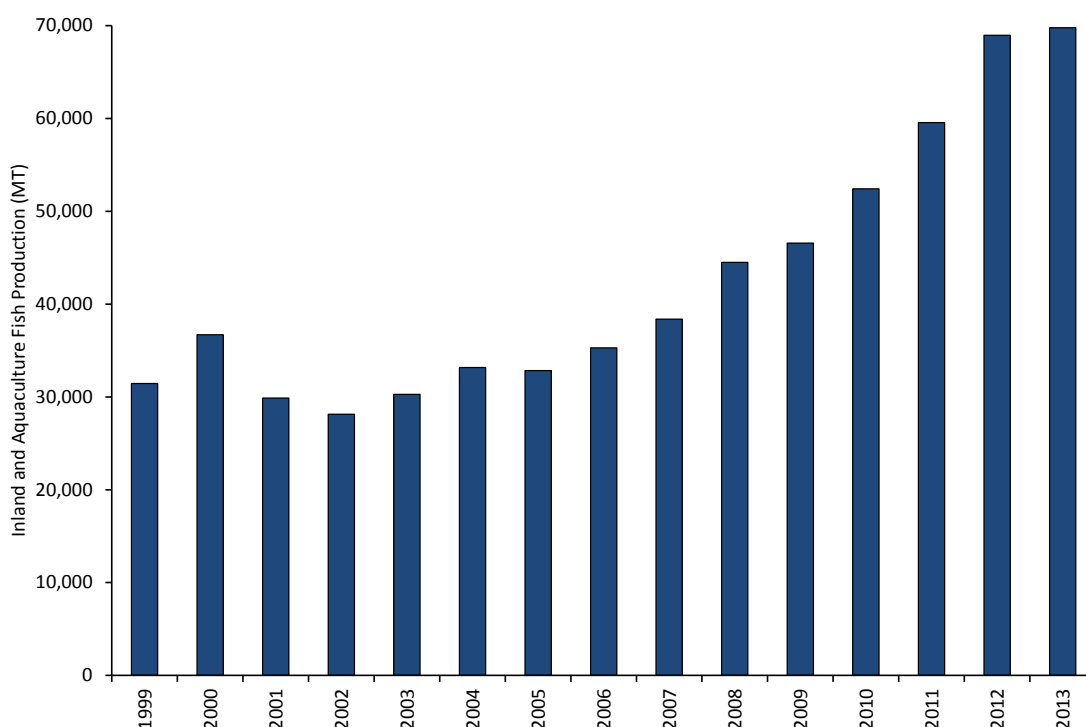
invested money to establish computer-assisted data bases for stocking harvesting, marketing and welfare fund mobilisation, due to promising financial benefits from CBF.

Members of CBF committees become partners of community-based enterprises and they invest in the community owned venture. Also, members share the financial benefits of CBF activities on an agreed basis, which ensures sustainability of the strategy. These features in CBF strategies in Sri Lankan reservoirs indicate potential for establishing co-management effectively. In fact, such co-management strategies exist in several reservoirs (Chandrasoma et al. this volume).

Benefits of CBF to rural development

The benefits CBF to rural communities associated with reservoirs where ACIAR-funded project(s) for CBF development were monitored few years after conclusion of the project. In many villages, due to elevated income through CBF among the members of aquaculture committees, there were significant contributions to develop public utilities. Some examples are summarised in Table 4. These rural welfare activities performed by CBF committees brought good reputation for the CBF.

Figure 5. Annual inland fisheries and aquaculture production in Sri Lanka (1999–2013). Drawn from the data reported at http://www.naqda.gov.lk/inland_Aquaculture.php.



Dissemination of research findings through various means such as production of a documentary film, publication of a monograph (De Silva et al. 2006) which was translated to several regional languages, and holding a series of regional workshops were instrumental for CBF development in the regional level.

The gains from CBF in Sri Lanka

It is ironic that a concept that was first suggested by Mendis (1965) for small water bodies in Sri Lanka is gaining a firm foothold in Sri Lanka inland fisheries, and for that matter elsewhere in the region. The evidence that the R&D efforts are best exemplified by the following facts and figures.

- A science based objective method for selecting non-perennial and perennial water bodies for CBF practices, thereby avoiding waste of resources and effort; these science based methods, with suitable modifications could be adopted for other tropical countries that wish to embark on CBF.
- After implementation of CBF large scale in village reservoirs systematically in early 2000s, annual inland fisheries and aquaculture production has significantly increased from about 28,000 MT in 2002 to about 69,800 MT in 2013 (Figure 5).
- The expansion of CBF development is evident from the significant increase of number of fingerlings stocked from 2.67 million in 274 non-perennial reservoirs in 2008 to 12.90 million in 2013 in 850 reservoirs (Figure 3). During this period cumulative extent of non-perennial reservoirs utilised for CBF development increased from 2,677 ha in 2008 to 11,475 in 2013 (<http://www.fisheries.gov.lk/content.php?cnid=ststc>).
- The gradual success of CBF based on the application of science and improved community organisation sparked off an ancillary sector of fry to fingerling rearing bringing about employment opportunities and economic gains to rural households.
- As detailed out by Chandrasoma et al. (the current volume) CBF has been successfully extended to medium and major perennial reservoirs that have resulted in large increases in fish yield, and consequent gains in the socio-economic status of fishers and related communities.
- Increased fish yields through CBF activities also have expanded the associated value and market chains benefiting rural communities through added employment opportunities.

The way forward

Based on case studies in Southeast Asian countries, Lorenzen (1995) has shown that density-dependent growth and size-dependent mortality of stocked species have significant impacts on CBF yields. As such, application of similar approaches in CBF in Sri Lanka will be useful to optimise CBF yields.

As CBF development is carried out in reservoirs which have been constructed primarily for irrigation, being a secondary use, CBF development should be carried out without compromising primary uses of water bodies. As such, synergy between water management related to downstream activities and fisheries enhancement should be ensured for sustainability of CBF. At the full scale of CBF development in Sri Lanka, there will be a glut of fish in the market so that it would be timely to develop post-harvest technology for value addition.

De Silva (2003) mentioned that CBF is an environmentally friendly form of aquaculture. However, it would be possible to acquire global recognition for CBF through implementation of the FAO code of conduct for responsible fisheries through an ecosystem approach to fisheries and aquaculture. This will also help achieving balance between conservation and fishery resources enhancement.

Conclusions

Being a country with extensive availability of freshwater reservoirs most of which a very small (< 50 ha) village irrigation reservoirs, not capable of supporting any commercial scale fisheries through natural recruitment, there is a high potential for the development of culture-based fisheries (CBF). The efforts made in 1980s to develop CBF in these water bodies were disrupted due to lack of proper scientific approaches for selection of suitable reservoirs. Under an R&D project conducted through financial assistance from Australian Centre for International Agricultural Research (ACIAR), a best practice approach was developed using multi-criteria decision making procedure. Several middle level scientists and academics were trained under this research project and the aquaculturists of National Aquaculture Development Authority were benefitted through such training. The development activities mainly on the technical aspects of Asian Development Bank funded Aquatic Resources Development and Quality Improvement Project (ARDQIP) which contained a major component for CBF development were considerably facilitated due to the involvement of trained staff under the ACIAR project.

Social mobilisation and development of entrepreneurship plan among rural communities under the ARDQIP, ensured sustainability of CBF in many reservoirs.

ARDQIP was also instrumental for establishing mini-nurseries for rearing of fingerlings of Chinese and Indian major carps, pilot scale CBF development in minor perennial reservoirs and establishment of computer-based effective data recording systems. Recent attempts at stocking *M. rosenbergii* post larvae in inland reservoirs as part of CBF contributed to significant elevation of rural income. In many rural communities, there had been spectacular trends that part of the profit earned by CBF had been mobilised for various welfare activities in the village. Opportunities exist for establishment of effective co-management strategies for CBF and in fact, such co-management procedures are in place.

Acknowledgements

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References

- Amarasinghe, U.S. and Nguyen, T.T.T., 2009. Enhancing rural farmer income through fish production: Secondary use of water resources in Sri Lanka and elsewhere. In: S.S. De Silva and F.B. Davy (Eds) *Success Stories in Asian Aquaculture*. pp. 103-130. Springer Science, Netherlands.
- Anon., 2006. Mini nursery program. *Aquaculture News*. NAQDA Newsletter (September–December 2006) 3; 1.
- Anon., 2007. *Ten Year Development Policy Framework of the Fisheries and Aquatic Resources Sector 2007-2016*. Ministry of Fisheries and Aquatic Resources, Colombo, Sri Lanka 24 pp.
- Asoka, J.M., 2014. *Comparative evaluation of performance of freshwater prawn, Macrobrachium rosenbergii (De Man) in different aquaculture systems in Sri Lanka*. Unpublished Ph.D. thesis, University of Kelaniya, Sri Lanka.
- Bardach, J.E., Ryther, J.H and McLarney, W.O., 1972. *Aquaculture: The Rearing and Husbandry of Freshwater and Marine Organisms*. Wiley Interscience, New York, USA.
- Carlson, R.E., 1997. A trophic state index for lakes. *Limnology and Oceanography*, 22 (2); 261 – 369.
- Chandrasoma, J. and Kumarasiri, W.S.A.A.L., 1986. Observations on polyculture of fish in seasonal tanks in Ratnapura and Monaragala district in Sri Lanka. *Journal of Inland Fisheries (Sri Lanka)*, 3; 49-55.
- Chandrasoma, J., Pushpalatha, K.B.C., and Fernando W.A.J.R. 2015. *Impact of introduction of culture-based fisheries on fish production in perennial reservoirs of Sri Lanka*. (This volume).
- De Silva, S.S., 1988. Reservoirs of Sri Lanka and Their Fisheries. *FAO Fisheries Technical Paper* 298. FAO, Rome; 128 pp.
- De Silva, S.S., 2003. Culture-based fisheries: an underutilised opportunity in aquaculture development. *Aquaculture*, 221; 221-243.
- De Silva, S.S., Amarasinghe, U.S. and Wijegoonawardena, N.D.N.S., 1996. Diel feeding patterns and daily ration of cyprinid species in the wild determined using iterative method, MAXIMS. *Journal of Fish Biology*, 49; 1153-1162.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T. (Eds), 2006. *Better-practice approaches for culture-based fisheries development in Asia*. ACIAR Monograph No.120, 96 pp.
- Deap, L., Degen, P. and van Zalinge, N., 2003. Fishing Gears of the Cambodian Mekong. Inland Fisheries Research and Development Institute (IFReDI), Phnom Penh. *Cambodia Fisheries Technical Paper Series*, Volume IV, 269 pp.
- FAO, 1997. *FAO Technical Guidelines for Responsible Fisheries*. No. 5. FAO, Rome, Italy. 40 pp.
- Hasan, M.R. and Middendorp, H.A.J., 1998. Optimising stocking density of carp fingerlings through modeling of the carp yield in relation to average water transparency in enhanced fisheries in semi-closed water bodies in western Bangladesh. In: (Petr. T. (Ed.) *Inland Fishery Enhancements. Papers Presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements*. Dhaka, Bangladesh, 7-11 April 1997, pp. 159-168. FAO Fisheries Technical Paper No. 374. Food and Agriculture Organization, Rome, Italy.
- Jarchau, P., Lidzba, C. and Jayasekara, S., 2008. Feasibility assessment of fish farming in seasonal reservoirs: Packaging technical, social and financial aspects. In: Wijeyaratne, M.J.S. and Amarasinghe, U.S. (Eds) *Participatory Approaches to Reservoir Fisheries Management: Issues, Challenges and Policies*. pp. 193-205. Sri Lanka Association for Fisheries and Aquatic Resources, Colombo, Sri Lanka.
- Jayasinghe, J.M.P.K. and U.S. Amarasinghe (in press). Inland Aquatic Resources. In: *Natural Resources of Sri Lanka: Conditions, Trends and Prospects*. National Science Foundation of Sri Lanka, Colombo.

- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2005. Trophic classification of non-perennial reservoirs utilized for the development of culture-based fisheries, Sri Lanka. *International Reviews of Hydrobiology*, 90; 209-222.
- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2006. Culture-based fisheries in non-perennial reservoirs of Sri Lanka: influence of reservoir morphometry and stocking density on yield. *Fisheries Management and Ecology*, 13; 157-164.
- Jayasinghe, A. and Amarasinghe, U., 2007. Buffaloes in favour of culture-based fisheries in Sri Lanka. *Aquaculture Asia Magazine*, 12(3); 3-7.
- Kularatne, M.G., Amarasinghe, U.S. and De Silva, S.S., 2008. Influence of socioeconomic heterogeneity on culture-based fisheries in non-perennial reservoirs of Sri Lanka. In: Wijeyaratne, M.J.S. and Amarasinghe U.S. (Eds.) *Participatory Approaches to Reservoir Fisheries Management: Issues, Challenges and Policies*. pp. 135-150. Sri Lanka Association for Fisheries and Aquatic Resources, Colombo, Sri Lanka.
- Kularatne, M.G., Amarasinghe, U.S., Wattage, P. and De Silva, S.S., 2009. Evaluation of community participation for the development of culture-based fisheries in village reservoirs of Sri Lanka. *Aquaculture Economics and Management*, 13; 22-38.
- Lorenzen, K., 1995. Population dynamics and management of culture-based fisheries. *Fisheries Management and Ecology*, 2; 61-73.
- Lorenzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., De Silva, S.S., Garaway, C.J., Hartman, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., Sugunan, V.V. and Swar, D.B., 2001. Strategic review of enhancements and culture-based fisheries. pp. 221-237. In: Subasinghe, R.P., Bueno, P.B., Phillips, M.J., Hough, C., McGladdery, S.E. and Arthur, J.R. (Eds), *Technical Proceedings of the International Conference on Aquaculture in the Third Millennium*, 20-25 February 2000, Bangkok, Thailand. NACA, Bangkok, Thailand and FAO, Rome, Italy.
- Meinzen-Dick, R. and Bakker, M., 1999. Irrigation systems as multiple-use commons: Water use in Kirindi Oya, Sri Lanka. *Agriculture and Human Values*, 16; 281-293.
- Mendis, A.S., 1965. A preliminary survey of 21 Ceylon lakes, 2: Limnology and fish production potential. *Bulletin of Fisheries Research Station, Ceylon*, 16; 7-16.
- Mendis, A.S., 1977. The role of man-made lakes in the development of fisheries in Sri Lanka. *Proceedings of Indo-Pacific Fisheries Council*, 17(3); 245-254.
- Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A. and New, M.B., 2004. *Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails*. FAO, Rome, Italy. 308 pp.
- Pomeroy, R. and Berkes, F., 1997. Two to Tango: the role of government in fisheries co-management. *Marine Policy*, 21(5); 465-480.
- Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15; 234-281.
- Sugunan, V.V. and Katiha, P.K., 2004. Impact of stocking on yield in small reservoirs in Andhra Pradesh, India. *Fisheries Management and Ecology*, 11; 65-69.
- Thayaparan, K., 1982. The role of seasonal tanks in the development of freshwater fisheries in Sri Lanka. *Journal of Inland Fisheries, Sri Lanka*, 1; 133-167.
- Weliange W.S., U.S. Amarasinghe, J. Moreau and M.C. Villanueva 2006. Diel feeding periodicity, daily ration and relative food consumption in fish populations in three reservoirs of Sri Lanka. *Aquatic Living Resources*, 19; 229-237.
- Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Athula, J.A., Pushpalatha, K.B.C. and De Silva, S.S., 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. *Fisheries Management and Ecology*, 12; 249-258.
- Wijenayake, W.M.H.K., Amarasinghe, U.S. and De Silva, S.S., 2007. Performance of GIFT strain of *Oreochromis niloticus* in culture-based fisheries in non-perennial reservoirs, Sri Lanka. *Sri Lanka Journal of Aquatic Sciences*, 12; 1-18.

Potential of culture-based fisheries in Indonesian inland waters

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Abstract: Fish stocking in Indonesian lakes and reservoirs has been conducted for a long time. Since 1999, culture-based fisheries (CBF) practices based on scientific evidence such as using suitable fish species, consideration of the primary productivity, stocking density, economic evaluation and community participation, have been conducted in some reservoirs and lakes and have showed encouraging results. Potential fish yield of a water body for CBF development is one of the important factors in determining its success. Potential fish yield of some lakes and reservoirs was estimated using a morpho-edaphic index or primary productivity approach, and the water bodies were classified based on morpho-limnological characteristics. Estimated potential fish yield of small reservoirs/lakes with an area between 1.0-200 ha showed the highest potential with an average yield of 2835 ± 623.6 kg/ha/yr compared to the others of larger area. In the future, therefore, development of CBF was highly recommended and prioritised in small reservoirs with an area less than 200 ha, mostly distributed in Sumatera, Java, and Nusa Tenggara with more than 2,000 reservoirs. However, about 80% of those reservoirs were categorised as idle presently.

Key words: Potential fish yield, lake, reservoir, culture-based fisheries, morpho-edaphic index.

Introduction

Development of inland fisheries in Indonesia is one of the strategies for increasing food fish production, providing employment and food security to communities deprived of easy access to food fish resources. In this context culture-based fisheries (CBF) are recognised as a strategy suitable for adoption in Indonesian inland waters.

CBF are defined as 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, which is sustainable through natural processes (FAO 2011). CBF consist of two phases, a farmed phase for the provision of stocking material, and a wild phase, which will however, be cared for to a certain degree. The natural processes of the water body will determine its potential.

This paper discusses the potential of inland waters, especially Indonesian lakes and reservoirs for CBF development. CBF development strategies in these water bodies based on the application of the lesson learnt from CBF elsewhere are also described.

Materials and methods

Data on the status of limnology, fish resources and fisheries, stock enhancement and CBF of Indonesian inland waters were collected from the literature. Potential fish yields of some lakes and reservoirs were estimated using primary productivity and or the morpho-edaphic index (a

ratio between conductivity and mean depth) approach (Oglesby 1982; Downing et al. 1990; Moreau and De Silva 1991; MRAG 1995; Kartamihardja 2009).

Lakes were classified into volcanic, tectonic-volcanic and floodplain lakes, while the reservoirs were classified into multipurpose, irrigation, and small or village reservoirs with an area less than 200 ha. Data on potential fish yield for each water body was plotted against area following the above classification.

Recommendations for prioritising water bodies suitable for CBF development were analysed through several criteria, such as CBF principles (De Silva et al. 2006); primarily, potential fish yield, relative easiness to manage, availability of fish seed and community preferences, opportunity on establishment of management institution and expected outcome impact on socio-economics of the community and sustainability of CBF.

CBF development strategies were formulated based on consideration of lessons learned on the successful CBF practices in Indonesia and opportunity of success and their impacts on socio-economic and livelihoods as well as welfare of the community.

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Results and discussion

Limnological characteristics of inland water resources

Indonesia has a vast area of inland waters covering 13.85 million ha (Sukadi and Kartamihardja 1995), which consists of river ecosystems and floodplains (12.0 million ha), lakes (1.8 million ha), and man-made lakes (reservoirs; 0.5 million ha). The total area of inland waters is about 65%, 23%, 7.8%, 3.5% and 0.7% in Kalimantan, Sumatera, Papua, Celebes and Java, Bali and Nusa Tenggara, respectively, but these proportions change annually because of seasonal water fluctuations (Sarnita 1986).

There are 5,590 major rivers 94,573 km in length and 65,017 tributaries. Indonesia also has 840 lakes, 162 major reservoirs and 735 small reservoirs and lakes ("situ" or "telaga") (Ministry of Public Work–Directorate General of Waters Resources 2013). Based on the areas, small reservoirs are classified into those between 50 and 200 ha (average of 75 ha), irrigation reservoirs between 2 and 50 ha (average of 15 ha), and small ponds between 0.50 and 2 ha (average of 1.0 ha). Most of the small reservoirs are distributed in Sumatera, Java, and Nusa Tenggara. Until recently, the small reservoirs have not been utilised for fisheries development.

Inland waters in Indonesia are also used by other sectors, such as agriculture, forestry, hydroelectric power and mining, and as water sources for home and industrial purposes, transportation (including navigation) and tourism. These multipurpose uses of inland waters compete with fisheries activities, in relation to the structural modifications, and quality and quantity.

Fish and fishery resources of inland waters

FishBase (2011) records indicate that the number of fish species inhabiting inland waters of Indonesia amount to 1,169. Kottelat and Whitten (1996) stated that the number of freshwater fish species in Indonesia to be approximately 1,300 species. These authors suggested that the biodiversity of Indonesian freshwater fish species was the second richest in the world next to that of Brazilia. The discovery of new species and revision of existing species continues (Hadiaty and Siebert 1998 2001; Ng et al. 2004; Page et al. 2007).

Indonesia is divisible into two ecological regions; western Indonesia is more influenced by the Asian mainland fauna, and the east is more influenced by Australasian fauna. Zoo-geographically, fish resources of inland waters of Indonesia are divided into fish that inhabit the Sundaland, Wallacea zone and Sahulland, which are inhabited by more than 1,000 fish species

(Kottelat et al. 1995). In the Sundaland more than 358 species of the order Ostariophysi and Labyrinthici dominate inland open waters, particularly in Sumatera and Kalimantan (Ondara 1982).

There are about 310 species of fishes recorded from the rivers and lakes of Wallacea, 75 of them being endemic. Although little is still known about the fishes of the Moluccas and the Lesser Sunda Islands, 6 species are recorded as endemic. In Sulawesi, there are 69 known species, of which 53 are endemic. The Malili lakes in South Sulawesi, with its complex of deep lakes, rapids and rivers, have at least 15 endemic thelmatherinid fishes, two of them representing endemic genera, three endemic *Oryzias*, two endemic halfbeaks, and seven endemic gobies.

Most of the species that inhabit inland waters of Indonesia are riverine, and only a few are lacustrine. This condition is one of the factors that is thought to be responsible for the relatively low fish production in lakes and reservoirs. Species that dominate lakes and reservoirs are generally of the cyprinid family such as *Puntius*, *Barbonymus*, *Hampala*, *Mystacoleucus*, *Osteochilus*, the silurid family such as *Mystus* and *Channa*, and cichlids, *Oreochromis mossambicus*.

FAO (2014) reported that globally, about 13% of the total inland fishery products (although in reality probably higher) is consumed by the local communities. For the people in Southern Sumatra, Kalimantan and Sulawesi, freshwater fish consumption is high, and for the local communities it is their main source of animal protein and micro-nutrients. Among Asian countries Indonesia is ranked 6th in inland fish production. Inland waters contribute 16% to the total fish production of Indonesia. In the period of 2005–2012, total fish production from capture fisheries and aquaculture (cage culture) of Indonesian inland waters were between 474,680–1,026,940 tonnes (average of 710,101.6 tonnes) (MMAF2012), as presented in Figure 1. The fish production from both activities tended to increase from year to year. In Indonesia, the fish production of CBF was reported under capture fisheries and consequently production data for CBF is not evident in the total fisheries production.

Stock enhancement and culture-based fisheries

Increasing fish production in reservoirs and lakes can be done through the application of appropriate stock enhancement practices, such as culture-based fisheries (CBF) technology. The purpose of the technology application is to improve the quality and quantity of fish production in the water body by utilising the natural food resources and habitats (niche ecology) which are un- or under-utilised. Since 1999, stock enhancement

Figure 1. Fish production of the Indonesian inland waters 2005-2012.

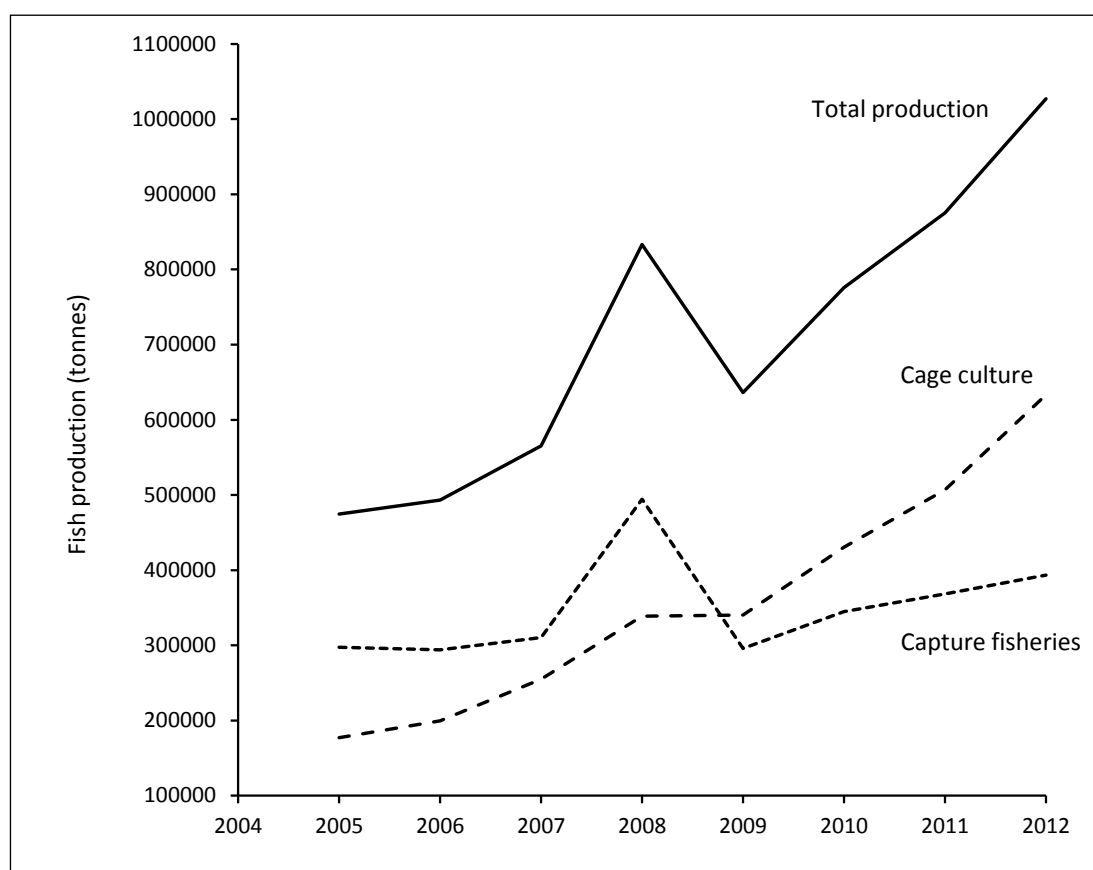


Table 1. Fish yield of some lakes and reservoirs before and after implementation of stock enhancement and CBF.

Water Body	Area (ha)	Species	Yield (kg/ha/yr)		Remarks
			Before	After	
Toba Lake	112,000	<i>Mystacoleucus padangensis</i>	22-28	350-400	Breed naturally
Wonogiri R.	7,800	<i>Pangasianodon hypophthalmus</i>	26-35	59-62	Breed naturally
Malahayu R.	275	<i>P. hypophthalmus</i>	60-75	105-129	Do not breed naturally
Darma R.	400	<i>Macrobrachium rosenbergii</i>	75-123	99-128	Do not breed naturally
Jatiluhur R	8,300	<i>Chanos chanos</i>	27-32	178-181	Do not breed naturally

of Indonesian lakes and reservoirs was generally based on scientific data and information on productivity and ecological niches of the waters body, structure of fish communities, life cycle and biology of the stocked fish (Kartamihardja 2007). Examples of successful fish stock enhancement and CBF in some lakes and reservoirs are presented in Table 1.

In 2003, bilih fish (*Mystacoleucus padangensis*), a fish endemic to Lake Singkarak in West Sumatra, were introduced to lake Toba in North Sumatra. This species grows and breeds naturally and now inhabits the pelagic area of the lake (Kartamihardja and Purnomo 2006). Since 2005 bilih production has increased from 653.6 to 30,000

tonnes in 2010, and has since increased sharply reaching 40,000 tonnes in 2012 (Kartamihardja and Sarnita 2010; Wijopriyono et al. 2010).

In the period 1999-2002, about 36,450 seed of Siamese catfish (*Pangasianodon hypophthalmus*) have been introduced into Wonogiri Reservoir in Central Java and since 2003 the catfish production has increased gradually. In 2004, the Siamese catfish yielded 112,215 tonnes valued at 785.5 million rupiahs (IDR)¹ adding to the income of each fisher approximately 1.2 million rupiahs (IDR) per year (Kartamihardja and Purnomo 2004). The Siamese catfish grow fast and its fecundity at a standard length of 67.0-82.7 cm and weight of 3,000-5,500 g ranged from

1. IDR 10,000= 1 US\$.

271,700–1,177,250 eggs (Adjie et al. 2006). The Siamese catfish can spawn naturally and the seed are distributed in the mouth of Keduwang River, one of the inlet rivers. In the period 2005–2010, catfish production levelled off, reaching between 142.925–191.210 tonnes. This indicated that the rate of recruitment from natural spawning was lower than that the rate of exploitation (Kartamihardja et al. 2011). In December 2011, about 400,000 fingerlings of Siamese catfish 5.0–7.5 cm in standard length and 15–20 g were also stocked in Malahayu reservoir (Central Java). The catfish grew fast, reaching an average of 300–600 g and standard length between 25–38 cm after 6 months (Kartamihardja 2012).

Giant freshwater prawn (*Macrobrachium rosenbergii*), introduced into Darma Reservoir, West Java in 2003, yielded 337.65 kg with a value of 13.5 million rupiahs (IDR) in 2004, even though the seed stocked was only 26,500 tails or 26,5% from the optimum amounts of stocking (Kartamihardja et al. 2004). If the prawn stocking was done optimally, the production value of 70–140 million rupiahs (IDR) per year could have been attained and bringing an additional income for 120 fishers.

CBF of milk fish, *Chanos chanos*, has been conducted in Jatiluhur Reservoir, West Java in 2008–2009. Fingerlings numbering 2 million (in 2008) and 4 million (in 2009) were stocked in the reservoir. Milk fish production reached 65 tonnes in 2009 and 180 tonnes in the period 2011–2012. Milk fish stocking also aimed to mitigate the impact of intensive cage culture, especially to control phytoplankton blooming (Abery et al. 2005; Maskur et al. 2010). The abundance and biomass of phytoplankton decreased significantly one month after stocking. The nitrogen and phosphorous contents also decreased significantly, and the frequent algal blooms and mass fish kills have since being avoided (Kartamihardja 2012). In August 2014, about 300,000 milk fish seed were also

stocked in Sempor Reservoir (275 ha; Central Java). The milkfish grew to an average weight of 260g per fish after 3 months of stocking (Umar 2014 pers. Com.).

The success of stocking fish in the waters bodies of area greater than 500 ha showed that catches of the CBF was high if the fish species introduced could fill the empty niche and be able to breed naturally.

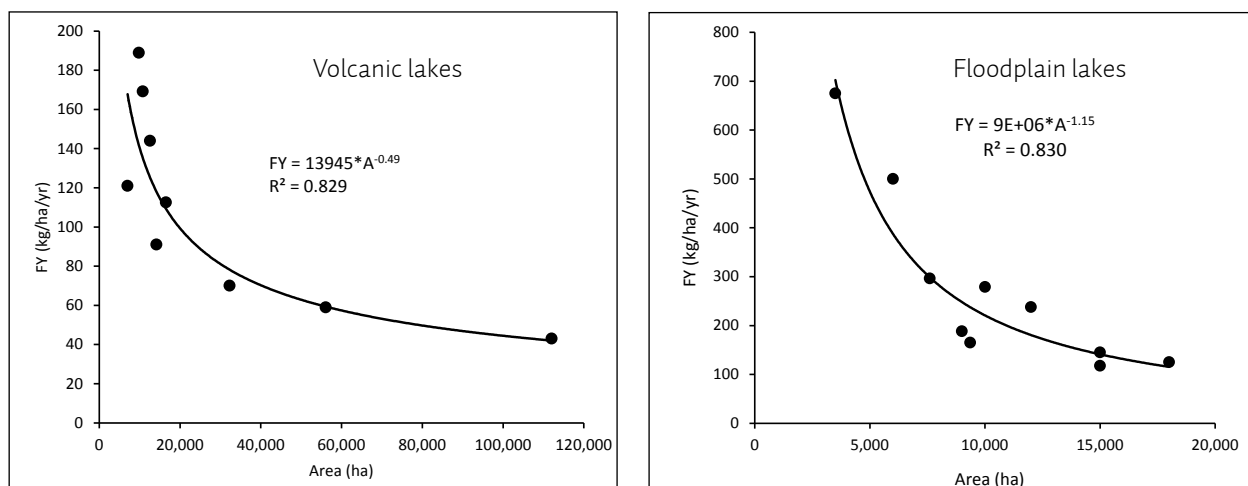
Potential and suitable water bodies for culture-based fisheries

Indonesia has thousands of lakes and reservoirs of which the major lakes are distributed in Sumatera, Kalimantan, Sulawesi and Papua. Most of the major lakes were formed by volcanic or tectonic forces or a combination of both, or river action as floodplain lakes. The major reservoirs (about 65%) are mostly situated in Java, while the small lakes and reservoirs or village reservoirs are mostly situated in Sumatera, Java, and Nusa Tenggara (Table 2). The number of small reservoirs has increase due to development of reservoir for collecting water in the rainy season, especially in Eastern Indonesia which has a long dry season. Most of the small reservoirs are utilised for agriculture, irrigation and drinking water for cattle.

Table 2. Distribution (numbers) of Indonesian small waters bodies.

Name of island	Lakes	Reservoirs	Total
Sumatera	329	217	546
Java	327	342	669
Bali	14	29	43
Nusa Tenggara	27	586	613
Sulawesi and Maluku	37	151	188
Papua	2	16	18
Indonesia	736	1,341	2,077

Figure 2. Relationship between potential fish yield (FY) and area (A) of lakes.



Potential yield of major lakes

Estimation of potential fish yield of the major lakes, classified into volcanic or tectonic-volcanic lakes and floodplains lakes with water surface area between 10,000-110,000 ha and 3,000-20,000 ha, respectively, was based on geo-morphological characteristics and productivity (Figure 2). The tectonic-volcanic lakes are deep, the littoral zone is followed by a steeper zone and are oligotrophic to mesotrophic, whereas flood plains lakes are relatively shallow, have greater seasonal water fluctuations and are mesotrophic to eutrophic (Lehmousloto and Machbub 1977; Kartamihardja 2006; Sulastrri 2006). The estimated potential fish yields of the volcanic lakes were between 43-189 kg/ha/yr (average of 111 ± 50.1 kg/ha/yr), and of the floodplains lakes were between 118-675 kg/ha/yr (average of 266 ± 188 kg/ha/yr).

Potential yield of reservoirs

Estimation of potential fish yield of reservoirs was done by categorising the reservoirs as: (a) multipurpose reservoirs with an area of >1,000 to 10,000 ha; (b) irrigation reservoirs with an area of >200-500 ha and (c) a small reservoirs with an area range from >1.0-200 ha. The estimated fish yield of the three groups are presented in Figure 3. The multipurpose, irrigation and small reservoirs have potential fish yields of between 239-320 kg/ha/yr (average of 273.0 ± 27.4 kg/ha/yr), 288-455 kg/ha/yr (average of 364.1 ± 51.9 kg/ha/yr), and 1,621-3,965 kg/ha/yr (average of $2,835 \pm 623.6$ kg/ha/yr), respectively. The small reservoirs have the highest productivity (primary productivity of phytoplankton based).

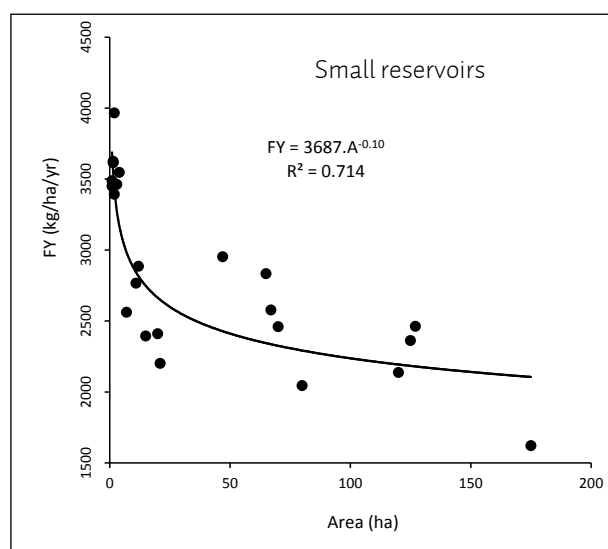
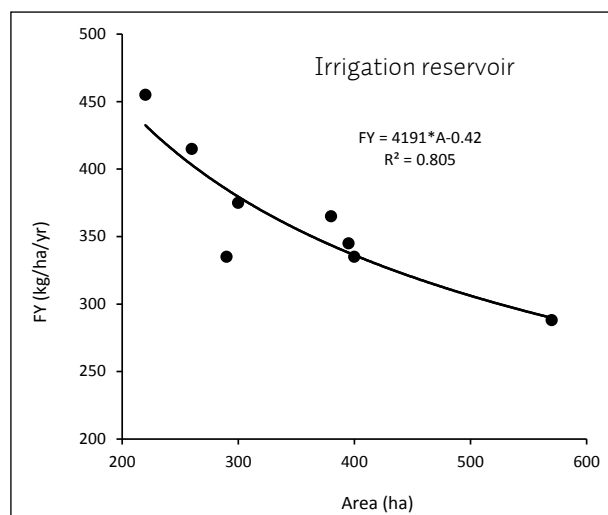
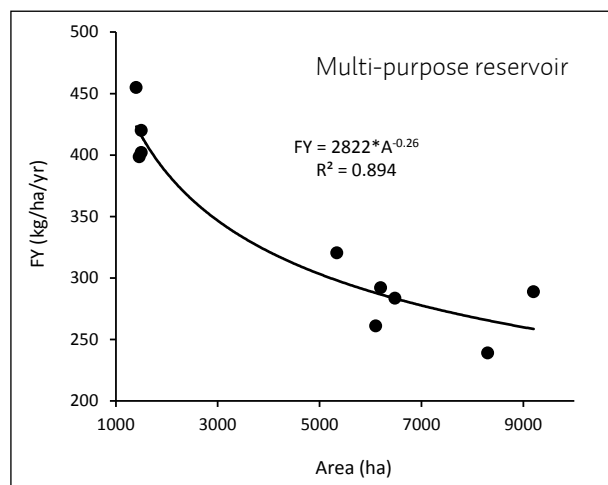
The relationship between potential fish yield and area of lakes and reservoirs can be utilised for optimisation of stocking density and expected fish production of those water bodies.

Water bodies suitable for CBF

In principle, all reservoirs and lakes are suitable for the development of CBF, however, in this case the CBF development will be focused on waters bodies such as small reservoirs/lakes with an area of less than 200 ha for the following reasons:

- Small reservoirs have the highest potential fish yield compared to the others
- Small reservoirs can be managed as a big fish pond so that the area is easy to control and manage properly
- There are many small reservoirs situated in the rural area that have not been utilised for fisheries development yet

Figure 3. Relationship between potential fish yield (FY) and area (A) of the reservoirs.



- Fish seed optimally needed for stocking is relatively easily procured
- Risk impacts of stocked fish on native fish diversity as well as their genetics is relatively negligible
- Fish production from CBF is primarily aimed for improving nutrition, food security and additional income for the rural people that live in the vicinity
- The fisher groups are an important management unit of CBF is relatively small in number and their ability as well as their capability are easily established and improved.
- Conflicts between the users of the waters bodies can be minimised because the fish stocked do not degrade the waters and not necessarily interfere with the other functions of a reservoir.

Development of CBF in small reservoirs should include technical considerations on ecological, socio-economic, and institutional aspects. From the ecological perspective, the water body should have good water quality for fish life, high natural food resources or high potential fish yield, and the water volume available throughout the year or at least eight months until the fish could grow to table size. Seed stocks should be available and procured easily and be species of economic value, preferred by the communities, and feed low in the trophic chain (plankton feeders, herbivores, or omnivorous), can utilise natural food resources, and non-invasive or not negatively impact on native fish species.

Some technical considerations in the implementation of CBF are fish seed supply, preconditions and acclimatisation, handling and transportation, stocking density, size or age of seed stocked and time as well as stocking mechanism.

Preconditioning and acclimatisation are needed for stocked species to adapt to a new aquatic environment and ensure a high survival rate. For example, stocking prawns in the Darma Reservoir and Siamese catfish stocking in the Jatiluhur, Wonogiri and Malahayu Reservoirs is done after the prawns and the Siamese catfish have been reared in a net cage in the reservoir for a month (Kartamihardja et al. 2004).

In the implementation of fish stocking programs, potential risks that will arise in relation to genetics, ecological and socio-economic environments should be anticipated in advance. In other words, the implementation of stocking should refer to the management of fisheries in charge (Code of conduct for responsible aquaculture/ fisheries) as well as FAO's "Blue Growth" - a coherent approach for the sustainable, integrated and socio-economically sensitive management of inland waters,

focusing on capture fisheries, aquaculture, ecosystem services, trade and social protection of coastal communities. The Blue Growth framework promotes responsible and sustainable fisheries and aquaculture by way of an integrated approach involving all stakeholders (FAO 2014).

Development strategy for culture-based fisheries

The problems faced in the implementation of CBF in waters bodies in Indonesia among others were:

- An understanding of science and technology of CBF by officers and the community, and the need for socialisation.
- In general, results of scientific studies indicated that CBF implemented in some water bodies were not carried out correctly, and protocols used were not adequate and clear.
- Monitoring and evaluation of the CBF implementation to determine the success or failure of the application of these technologies were not done.
- Regulation and institutions in the management of fisheries resources are not yet available.
- Management of fishery resources has not involved public participation.

With implementation of a strategic research phase in order to solve these problems, CBF developments in Indonesian waters bodies are expected to achieve a common goal, namely the establishment of the maximum utilisation of resources and its sustainability for the welfare of the society. The steps that must be done in the application of CBF technology are identification of water bodies, selection of the fish species, identification of fisheries activities and community engagement. Monitoring and evaluation of CBF should also be factored into their application.

Determining the water body productivity should include take into account water volume availability, water quality, the type and abundance of natural food resources, native fish species composition, and estimation of potential fish yield. Selection of the fish species to be stocked should include the number and quality of seed, aspects of biology, especially food and feeding habits and reproduction and habitat (mainly if the water body inhabited by native and endemic species), economic value, community preferences, and seed should be available and easy to obtain from hatcheries.

Identification of fishery activities include the number of fishers, the type and quantity of fishing gear, the species, composition and quantity of the fish catch are conducted if the fisheries activities already exist. Identification of communities around the water bodies include the amount or availability of fishing groups, monitoring and surveillance by the society or groups and other fisheries groups.

Identification of the costs required for the fish stocking activity, monitoring and evaluation of success should be anticipated before implementation of CBF. Monitoring activities should be carried out from the beginning of planning, during and after the application of CBF technology, and evaluation of the results of monitoring conducted to assess the success or failure of the application of CBF.

Conclusions

Indonesia has a large inland waters resource with thousands of small lakes and reservoirs which are suitable for CBF development. Moreover, the waters bodies have high potential yields, but those water bodies have not been utilised. CBF conducted in some lakes and reservoirs showed a significant increases in fish yield and the rural income of the community that live in the vicinity of the waters bodies. In the future, the development strategy for CBF should be based on scientific evidence, including identification of the water body productivity, providing fish seed/fingerling of herbivorous/omnivorous species preferred by the communities, optimisation of fish stocking density, development of fishing technology and market systems, training on fish processing and capacity building of fisheries institutions and management, and coordination with the lakes/reservoirs authorities. It is estimated that the best practices of CBF development in small lakes/reservoirs in Indonesia could result in yields exceeding one million metric tonnes.

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References

Abery, N.W., Sukadi, F., Budhiman, A.A., Kartamihardja, E.S., Koeshendrajana, S., Buddhiman and De Silva, S. S., 2005. Fisheries and cage culture of three reservoirs in west Java, Indonesia; a case study of ambitious developments and resulting interactions. *Fisheries Management and Ecology*, 12; 315-330.

Adjie, S., Utomo, A. D. And Muflikhah N. dan Krismono, 2006. Study on biology of siamese catfish, *Pangasius hypophthalmus* in Upper part of Solo River. *Proc. Indonesian Inland Open waters Forum III*. pp. 75-84 (in Indonesian).

De Silva S. S., Amarasinghe U. S. and Nguyen T. T. T. (eds), 2006. *Better-practice approaches for culture-based fisheries development in Asia*. ACIAR Monograph No. 120, 96pp.

Downing, J.A., Plante, C. and Lalonde, S. 1990. Fish production correlated with primary productivity, not the morpho-edaphic index. *Canadian Journal of Fisheries and Aquatic Science*, 47; 1929-1936.

FAO, 2014. *The state of World Fisheries and Aquaculture. Opportunities and challenges*. FAO, Rome 2014. 243 pp.

FAO, 2011. *Aquaculture glossary*. (Available at: <http://www.fao.org/fish/glossary/aquaculture/default.asp>) (Last accessed 14 April 2011).

Hadiaty, R.K. and Siebert, D.J., 1998. Two new species of *Osteochilus* (Teleostei: Cyprinidae) from Sungai Lembang, Suag Balim-bing Research Station, Gunung Leuser National Park, Aceh, Northwestern Sumatra. *Revue Francaise d'Aquariologie Herpetologie Journal*, 25 (1-2); 1-4.

Hadiaty, R.K. and Siebert, D.J., 2001. *Nemacheilus tuberigum*, a new species of loach (Teleostei: Balitoridae) from Aceh, north-western Sumatra, Indonesia. *Bulletin of the Natural History Museum, London (Zool.)*, 67 (2); 183-189.

Kartamihardja, E.S., 2006. *Status of environmental condition of Indonesian Inland open waters as fish habitat*. Paper presented in Limnology Forum, Research Center for Limnology, Indonesian Institute of Sciences. Jakarta 6th December 2006 (in Indonesian).

Kartamihardja, E.S., 2007. Fish stock enhancement: optional technology for increasing fisheries production in inland open waters of Indonesia. *Indonesian Fisheries Research Journal*, 1 (1); 1-10 (in Indonesian).

Kartamihardja, E.S., 2009. *Estimated Potential Fish Yield of Indonesian Lakes and Reservoirs for fisheries development*. Technical Report. Research Center for Fisheries Management and Fish Resources Conservation. Agency Research and Development for Marine and Fisheries. MMAF Rep. Indonesia, 20pp. (in Indonesian).

Kartamihardja, E.S., 2012. Stock Enhancement in Indonesian Lakes and Reservoirs Fisheries. *Inland Fisheries Research Journal*, 18(2); 91-100.

- Kartamihardja, E.S. and Purnomo, K., 2004. The successful of siamese catfish introduced and its impact on fish yield composition at Wonigiri Reservoir, Central Java. *Proc. Indonesian Inland Open waters Forum I*, Research Center for Capture Fisheries, Agency Research for Marine and Fisheries, MMAF, Indonesia (in Indonesian).
- Kartamihardja, E.S. and Purnomo, K., 2006. Sustaining bilih fish population to a new habitat at Toba Lake. Demersal. *From the Sea to Development*. March Edition 2006. Ministry of Marine Affairs and Fisheries (in Indonesian).
- Kartamihardja, E.S. and Sarnita, A.S., 2010. *Bilih Fish population in Toba Lake: Successful fish introduction, management implication and future prospects*. Research Center for Fisheries Management and Conservation, Agency Research and Development for Marine and Fisheries. MMAF Rep. Indonesia. 50 pp. (in Indonesian).
- Kartamihardja, E.S., K. Purnomo, S. Koeshendrajana and C. Umar. 2011. Limnological characteristics, population growth of striped catfish, *Pangasianodon hypophthalmus* introduced and fisheries of Wonogiri Reservoir, Central Java. *Indonesian Fisheries Policy Journal*, 3 (1); 37-50 (in Indonesian).
- Kartamihardja, E.S., Purnomo, K., Satria, H., Tjahjo, D.W.H. and Purnamaningtyas, S.E., 2004. Stock enhancement of Siamese catfish (*Pangasius hypophthalmus*) in Wonogiri reservoir, green catfish (*Mystus nemurus*) in Wadaslintang reservoir and Giant freshwater prawn (*Macrobrachium rosenbergii*) in Darma reservoir. *Proc. Research Results Seminar Year 2004*. Research Center for Capture Fisheries, Agency Research for Marine and Fisheries, MMAF of Indonesia. pp. 159-172 (in Indonesian).
- Kartamihardja, E.S., Purnomo, K., Tjahjo, D.W.H., Umar, C., Sunarno M.T.D. and Koeshendrajana, S., 2010. *Technical Guideline, Fisheries Enhancement at Inland open waters of Indonesia*. Research Center for Fisheries Management and Conservation, Agency Research and Development for Marine and Fisheries. MMAF Rep. Indonesia. 72 pp. (in Indonesian).
- Kottelat, M, Whitten, A.J., Kartikasari, S.R. and Wirjoatmojo, S., 1995. *Freshwater Fishes Of Western Indonesia and Sulawesi*, Ikan Air Tawar Indonesia Bagian Barat dan Sulawesi. Periplus edition (HK) Ltd. 293 pp+84 plate.
- Lehmusluoto, P. and Machbub, B., 1977. National Inventory of the major lakes and reservoirs in Indonesia. *General Limnology. Revised Ed.* Expedition Indodanau Tech. Rep. Res. Inst. Water Resources Dev. Rep of Indonesia and Dept Limnology and Envi. Protect., Univ. Helsinki. Finland, 72pp.
- Maskur, M., Kartamihardja, E.S. and Koeshendrajana, S., 2010. Inland Fisheries Resources Enhancement and Conservation in Indonesia. In M. Weimin, S.S. De Silva and B. Davy (eds). *Inland Fisheries Enhancement and Conservation in Asia*. RAP Publication 2010/22. FAO., UN, Regional Office for Asia and the Pacific, Bangkok. pp. 61-76.
- MMAF (Ministry of Marine Affairs and Fisheries). 2012. *Fisheries Statistics of Indonesia*. MMAF, Republic of Indonesia, 180pp.
- Ministry of Public Work–Directorate General of Waters Resources. 2013. *Water Resources Data Center*. <http://sda.kimpraswil.go.id>.
- Moreau, J. and S.S. DeSilva. 1991. Predictive fish yield models for lakes and reservoirs of the Philippines, Sri Lanka, and Thailand. *FAO Fisheries Technical Paper*, No. 319, Rome.
- MRAG, 1995. *A Synthesis of Simple Empirical Models to Predict Fish Yields in Tropical Lakes and Reservoirs*. Final Report. Fisheries Management Science Programme, Overseas Development Administration. 109 pp.
- Nasution, Z., Utomo, A.D. and Prasetyo, D., 1993. Auction of floodplains area at South Sumatera as a tool for fisheries management of inland waters. *Proc. Inland Fisheries Workshop on Potential Fish Assessment and Development Prospects at the Southern Sumatera*. Palembang 12-13th February 1992. Agency of Agricultural Research and Development, Ministry of Agriculture. pp.122-134 (in Indonesian).
- Ng, H.H., Wirjoatmodjo, S. and Hadiaty, R.K., 2004. *Kryptopterus piperatus*, a new species of silurid catfish (Teleostei: Siluri-formes) from northern Sumatra. *Ichthyological Exploration of Freshwaters*, 15(1); 91-95.
- Oglesby, R.T. 1982. The mophoedaphic index and reservoir fish production. *Trans. Am. Fish. Soc.*, 111:113-40
- Ondara, 1982. Some notes on freshwaters fish fauna of Indonesia. *Proc. Indonesian Inland Waters Seminar*, Jakarta, 19-21th August 1981. Center of Fisheries Research and Development, Agency of Agriculture Research and Development. Ministry of Agriculture, Indonesia (in Indonesian).
- Page, L.M., Hadiaty, R.K., Lopez, J.A., Rachmatika, I. and Robins, R.H., 2007. Two new species of the *Akysis variegatus* species group (Siluriformes: Akysidae) from Southern Sumatra and a redescription of *Akysis variegatus* Bleeker, 1846. *Copeia* 2007(2): 292-303

Sarnita, A.S., 1986. Introduction and stocking of fish in lakes and reservoirs in Southeast Asian countries with special reference to Indonesia. *Reports and Papers presented at the IPFC expert consultation on Inland Fisheries of the Larger Indo-Pacific Islands*. Bangkok Thailand, 4-6 August 1986. FAO Fish. Rep. No. 371 Suppl. FIRI/R371.

Sulastrri, 2006. *Inland water resources and limnology in Indonesia*. Research Center for Limnology, Indonesian Institute of Sciences, Cibinong, Bogor, Indonesia. 11 pp.

Sukadi, M. F. and Kartamihardja, E.S., 1995. Inland fisheries management of lakes and reservoirs with multiple uses in Indonesia. *Regional Symposium on sustainable development of inland fisheries under environmental constraints*, Bangkok, Thailand, 19-21 October 1994, FAO, UN.

Wijopriyono, Purnomo, K., Kartamihardja, E.S. and Fahmi, Z., 2010. Fishery resources and ecology of Toba Lake. *Inland Fisheries Research Journal*, 16(1); 7-14.

Impact of introduction of culture-based fisheries on fish production in perennial reservoirs of Sri Lanka

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Abstract: Sri Lanka is blessed with a large number (>12,000) of irrigation reservoirs. Depending on their hydrological regimes, they are broadly categorised into perennial and seasonal reservoirs and are secondarily used for inland fisheries. Culture-based fisheries (CBF) in seasonal reservoirs was initiated in the 1980's and it is well documented. The Government of Sri Lanka has recognised CBF as an effective way of increasing fish supplies in rural areas, at affordable prices, while also providing employment and additional income to rural farmers and thereby contributing towards alleviation of poverty. There are around 200,000 ha of perennial reservoirs in Sri Lanka. These reservoirs are divided into three broad size categories, minor (<200 ha), medium (200 – 800 ha) and major (>800 ha). In this paper the impact of introduction of CBF on fish production in minor, medium and major perennial reservoirs are assessed using the fish production data from eight minor, seven medium and two large reservoirs. In all three categories of reservoirs post CBF resulted in very significant increases in fish production, such as for example increases of 206 and 319 % average annual fish production in minor and medium sized reservoirs, respectively.

Available provisions under the *Fisheries and Aquatic Resources Act No. 02 (1996)* to ensure ownership of the fish harvest to the fisher community, a crucial element in the success of CBF, are also highlighted. Further, the role of fisher community based organisations and fisheries management measures introduced for effecting successful CBF practices are also discussed.

Key words: Nile tilapia, Indian major carps, *Macrobrachium rosenbergii*, stocking, fish yields, fisheries co-management.

Introduction

Sri Lanka is blessed with a large number of irrigation reservoirs. In Sri Lanka, reservoir construction and use have always been an integral part of human activity, with some major reservoirs more than 2000 years old. Most of these reservoirs are concentrated in the dry zone (1250 – 1900 mm annual rainfall) of the country. The total reservoir extent is about 300,000 ha. On average size of these reservoirs range from a few ha to 8000 ha and depending on their hydrological regimes they are either, perennial or seasonal. These reservoirs with a few exceptions are irrigation reservoirs and are very diverse in size, age, hydrology and catchment features (Amarasinghe et al. 2004). Perennial reservoirs (around 200,000 ha) are divided into three broad categories; large, (> 800 ha), medium (200 – 800 ha) and small (< 200 ha) based on the water spread at full supply level.

These irrigation reservoirs have been secondarily used for inland fisheries. Development of inland fisheries in Sri Lanka commenced with the introduction of the exotic tilapia, *Oreochromis mossambicus*, in 1952. Fisheries in reservoirs yielded around 55,020 tonnes in 2013, contributing 82% to the total inland fish production.

The Government of Sri Lanka has recognised culture-based fisheries (CBF) as an effective way of increasing fish supplies in rural areas at affordable prices. CBF

provide employment opportunities and additional income to rural communities and thereby contributing towards alleviating poverty.

CBF in seasonal reservoirs of Sri Lanka initiated in early 1980's and its development was well documented (Thayaparan, 1982; Chakrabarty and Samaranayake, 1983; Chandrasoma, 1986; Chandrasoma and Kumarasiri, 1986; De Silva et al. 2006). CBF in perennial reservoirs in Sri Lanka is a recent development. Introduction of CBF into minor perennial reservoirs commenced in 2004 and gradually expanded to cover the other two size categories of perennial reservoirs, medium and large reservoirs.

This paper evaluates the impact of introducing CBF on fish production in three size categories of perennial reservoirs of Sri Lanka. Results of introduction of CBF in eight minor, seven medium and two major perennial reservoirs are used in the evaluation. Further contributions of stocked fish species to the catch are also discussed. The role of community based organisations

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on the introduction of CBF and facilitation of CBF, based on the provisions provided in the *Fisheries and Aquatic Resources Act*, are also discussed.

Materials and methods

Fish production from eight minor, seven medium and two major perennial reservoirs were used to evaluate the impact of introduction of CBF. Locations and water spread at full supply level of the reservoirs selected for this study are shown in Figure 1. Selection of these water bodies was on the availability of long time reliable data with at least a minimum of five years data after the introduction of CBF. Further, these were closely monitored by the Extension Officers of the National Aquaculture Development Authority (NAQDA), thereby enabling further authentication of the information provided. Fish yields and species composition of fish catches in these reservoirs during pre-CBF periods were compared with that from after introduction of CBF.

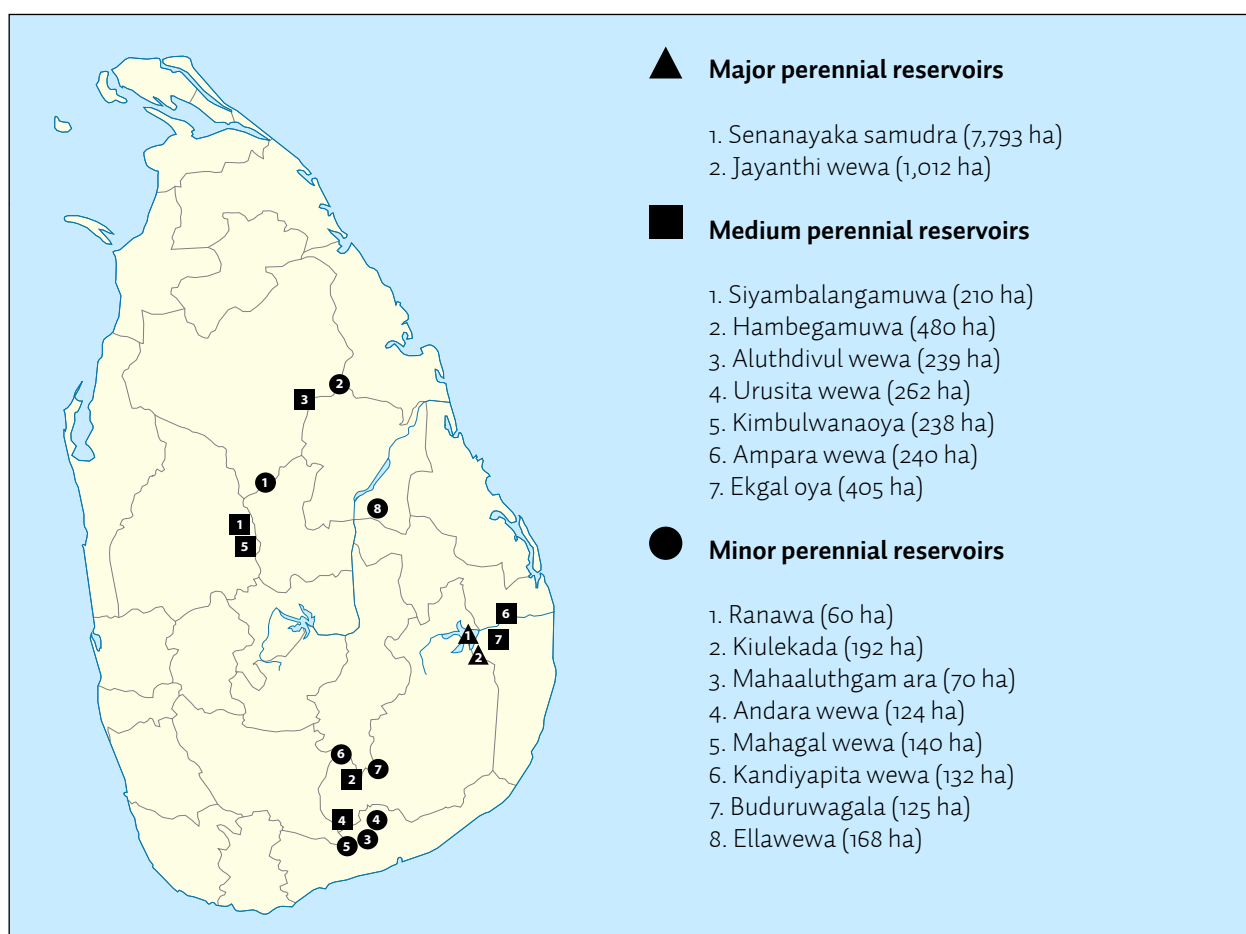
Fisher community based organisations

As a pre-requisite to undertake CBF, fisher community based organisations (CBOs) were formed or reorganised, where applicable, with the participation of fishers and would be fishers in each reservoir. Members of the fisher CBOs of each reservoir were given training in basic aspects of CBF. Further, they were provided with training in community based organisation management, leadership, simple accounting, book keeping etc.

Stocking

Stocking has been a continuous activity with the introduction of CBF with hatchery produced Nile tilapia (GIFT strain of *Oreochromis niloticus*); the Indian major carps catla, *Catla catla*, rohu, *Labeo rohita* and mrigal, *Cirrhinus mirigala*; and freshwater prawn, *Macrobrachium rosenbergii*. The average annual stocking rate was 1,037 individuals/ha/yr (range 251 – 1,940) and 1,023 individuals/ha/yr (range 533 – 2,315) for minor and medium reservoirs, respectively. The average annual

Figure 1. Locations and water spread at full supply level of 8 minor, 7 medium and 2 major perennial reservoirs referred to in this study.



Base map outline by Uwe Dederig (Creative Commons Attribution-Share Alike 3.0 Unported license).

stocking was 192 individuals/ha/yr and 804 individuals/ha/yr, respectively, in Senanayake Samudra and Jayanthi wewa, the two large reservoirs used in the study. Fish species to be stocked, stocked numbers, time of stocking, source of fish seed etc. were determined by the fisher CBOs. In taking decisions on the species to be stocked, CBOs gave due consideration to consumer preference and availability of fish seed. The species for stocking and the stocking numbers revised in subsequent years, depending on the stocking outcome.

Fisheries management measures

Fisher CBOs were actively involved in implementation of fisheries management measures. Regulations of the *Fisheries and Aquatic Resources Act (FAR Act)* of 1996 were strictly adhered to and only gill nets were used for catching. Although minimum mesh size of gill nets allowed is 85 mm, CBO members in most reservoirs collectively agreed and used gill nets with mesh size of 115 mm and above. A fixed time period for fishing operations and the use of one landing site for fishing crafts for each reservoir are two other important fisheries management measures adopted by fisher CBOs, all measures that facilitate monitoring.

Harvesting

Harvesting of fish is a year round activity. Non-mechanised fiber glass, dug out, outrigger canoes (4m in length) are used for fishing. Fishing gear are gill nets with stretched mesh sizes ranging from 85 mm to 200 mm.

In general, each boat is operated by two fishers, who place their nets in the evening and haul them in the next morning.

Data collection

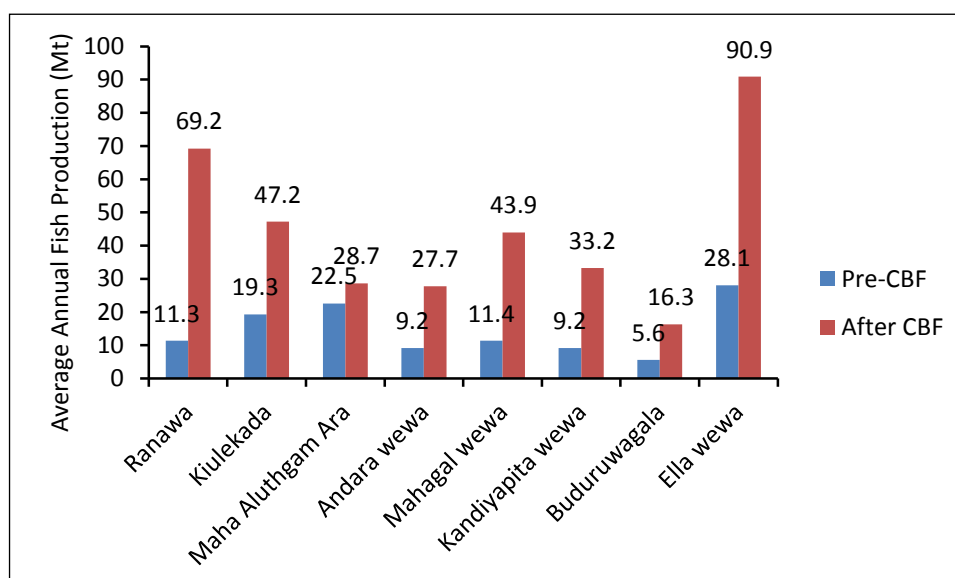
Species wise catch data were collected by the respective CBOs on a daily basis and maintained in a log book or in a computerised data base.

Results

Fish production

Average annual fish production of the reservoirs considered under this study in the minor, medium and major categories, during the pre-CBF period and after introduction of CBF are shown in Figures 2, 3 and 4, respectively. Figure 5 gives the details of annual fish production in two major reservoirs considered in this paper. In all the reservoirs introduction of CBF resulted in significant increases in fish production. Percent overall increase in average annual fish production in minor reservoirs increased after the introduction of CBF by 206.5% ranging from 144.8% in Kiulekada to 510.0% in Ranawa. Similarly, overall annual fish production in medium reservoirs increased by 318.5% ranging from 49.0% in Urusita wewa to 668.5% in Aluth Divul wewa. In Senanayake Samudra and Jayanthi wewa the two reservoirs in the major category percent increase in average annual fish production was 184.7% and 266.9%.

Figure 2. Average annual fish production of minor perennial reservoirs during pre-CBF period and after the introduction of CBF.



Fish production per unit area

Average fish production per unit area in respect of reservoirs of minor, medium and major categories are given in Figures 6, 7 and 8. Significant increases in unit area fish production were observed in all three categories of reservoirs. Average fish production per unit area increased to 353.3 kg/ha/yr from 131.5 kg/ha/yr and to 310.1 kg/ha/yr from 71.1 kg/ha/yr in minor and medium reservoirs, respectively. In Senanayake Samudra and Jayanthi wewa unit area production increased from 14.3 and 31.6 kg/ha/yr to 40.8 and 116.8 kg/ha/yr, respectively.

Species composition

Nile tilapia was the dominant fish species, contributing 80-90% to the total fish catch in all three categories of perennial reservoirs prior to the introduction of CBF. Species composition of the catches of all three categories of reservoirs after the introduction of CBF are given in Figures 9 (a), (b), (c) and (d). Contribution of Nile tilapia decreased to 57.6% (ranging from 53.1% in Mahaaluthgamara to 72.1% in Andara wewa) and 59.3% (ranging from 8.3% in Ekgal Oya to 91.6% in Ampara wewa) in minor and medium reservoirs, respectively,

Figure 3. Average annual fish production of medium perennial reservoirs during pre-CBF period and after the introduction of CBF.

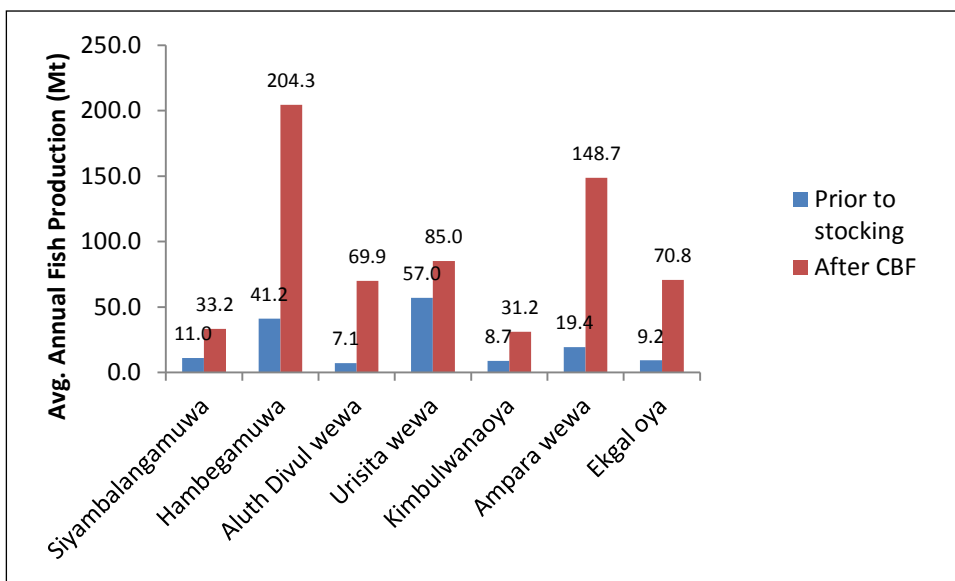
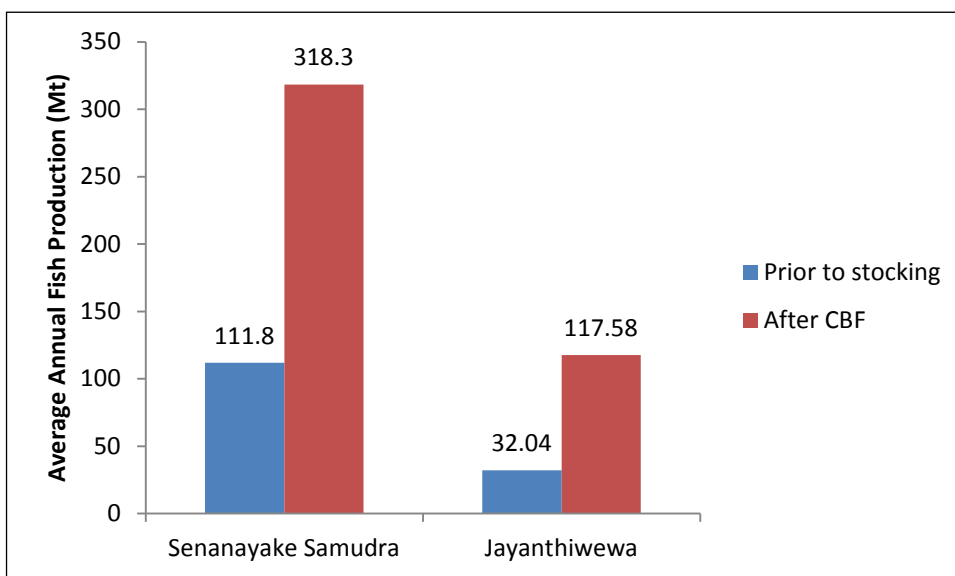


Figure 4. Average annual fish production of major perennial reservoirs during pre-CBF period and after the introduction of CBF.



and similar trends were observed in the two major reservoirs under consideration. Contribution of Nile tilapia decreased to 64.6% and 57.1% in Senanayake Samudra and Jayanthi wewa, respectively. Although there had been a decrease in the present contribution of Nile tilapia to the total fish catch, tilapia harvest increased significantly in all the categories of reservoirs, for example landings increased by 158.0%, 183.8%, 74.7% and 287.5% in minor perennials, medium perennials, Senanayake Samudra and Jayanthi wewa, respectively. Other significant contributors to the fish catch were stocked exotic carp varieties, with contribution of 41.9%, 39.5%, 29.1% and 38.0% in minor perennials, medium perennials, Senanayake Samudra and Jayanthi wewa,

respectively. Catla was the dominant species among the carps in fish catches followed by rohu in all categories of reservoirs. Contribution of freshwater prawn to catches was 1.6%, 0.5%, 0.4% and 1.0% in minor perennials, medium perennials, Senanayake Samudra and Jayanthi wewa, respectively.

Discussion

Development of CBF in perennial reservoirs is a relatively recent development in Sri Lanka, although there were attempts to develop CBF almost three to four decades ago (e.g. Mendis 1967). Details of well managed CBF

Figure 5. Annual fish production in Senanayake Samudra and Jayanthi wewa after introduction of CBF.

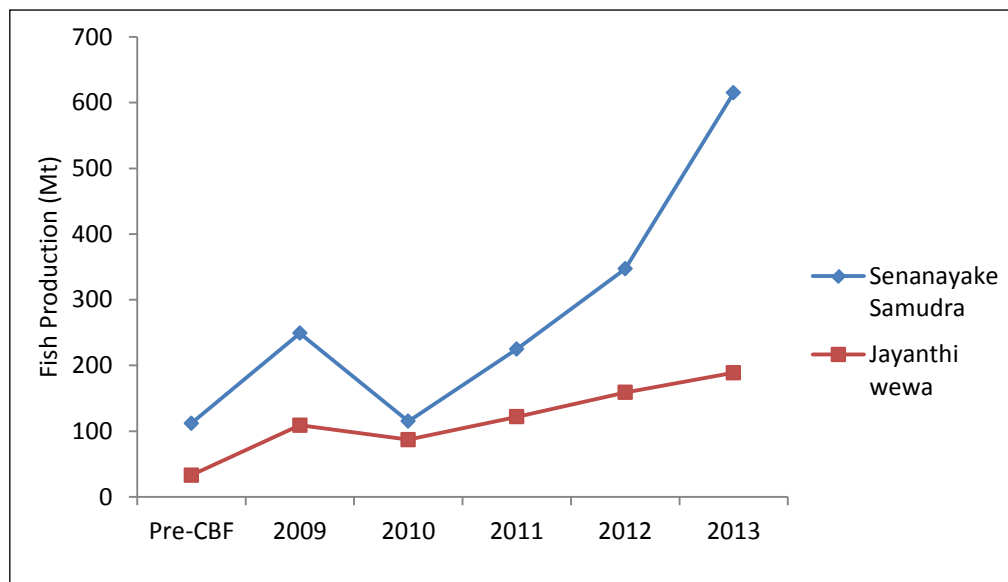
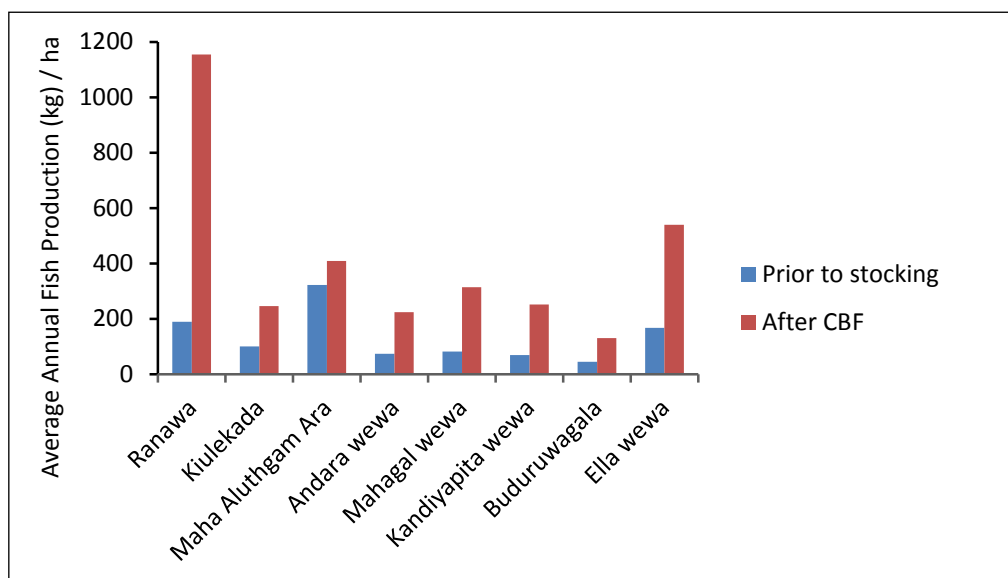


Figure 6. Average fish production per unit area in minor perennial reservoir during pre- and post-CBF.



in Chinese perennial reservoirs have been reported by Li (1987) and Xu (1987). Stocking, coupled with proper management in all three categories of perennial reservoirs, has resulted in significant increases in fish production. Pushpalatha and Chandrasoma (2009) reported an overall production increase of 263% (range 42.8% to 1344%) after the introduction of CBF in 15 minor perennial reservoirs, which is comparable to the fish production increase of 206.5% reported for minor perennial reservoirs under this study. Similarly, production increases observed for medium perennial reservoirs (318.5%), Senanayake Samudra (184.7%) and Jayanthi wewa (266.9%) shows the potential of these reservoirs for enhanced fish production through stocking

and introduction of management measures. Fish yields observed under the present study were 353.3 (minor), 310.1 (medium), 31.6 (Senanayake Samudra) and 116.8 (Jayanthi wewa) kg/ha/yr. Although above fish yields are the average fish yield after the introduction of CBF, by 2013 fish yields of Senanayake Samudra and Jayanthi wewa had risen to 78.9 and 187.0 kg/ha/yr. Li (1987) reported fish yields of 75 – 675 kg/ha/yr in five reservoirs (in China) ranging in size from 160 to 40,000 ha. It is interesting to note the increasing trend in annual fish production indicating that full potential is yet to be realised in two major reservoirs.

Figure 7. Average fish production per unit area in medium perennial reservoir during pre- and post- CBF.

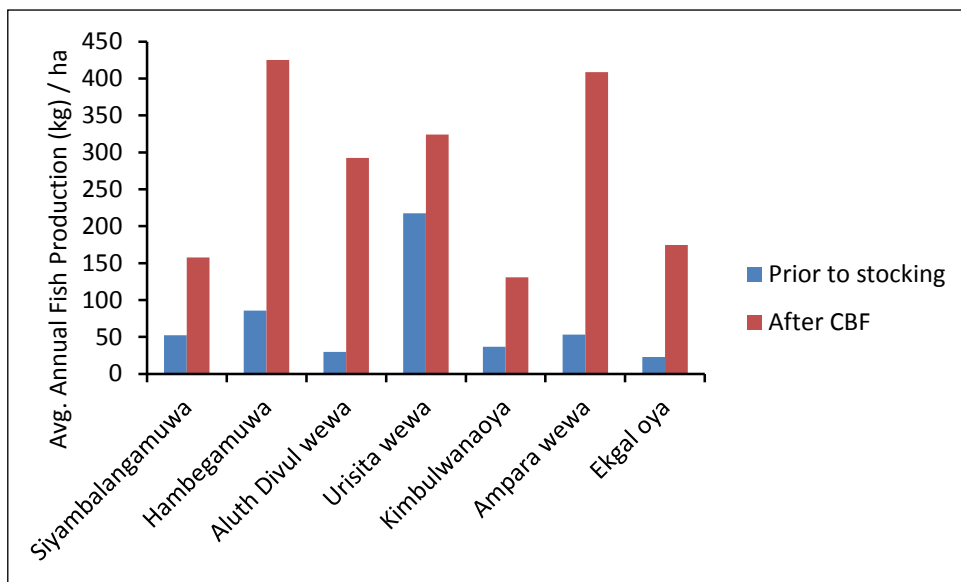
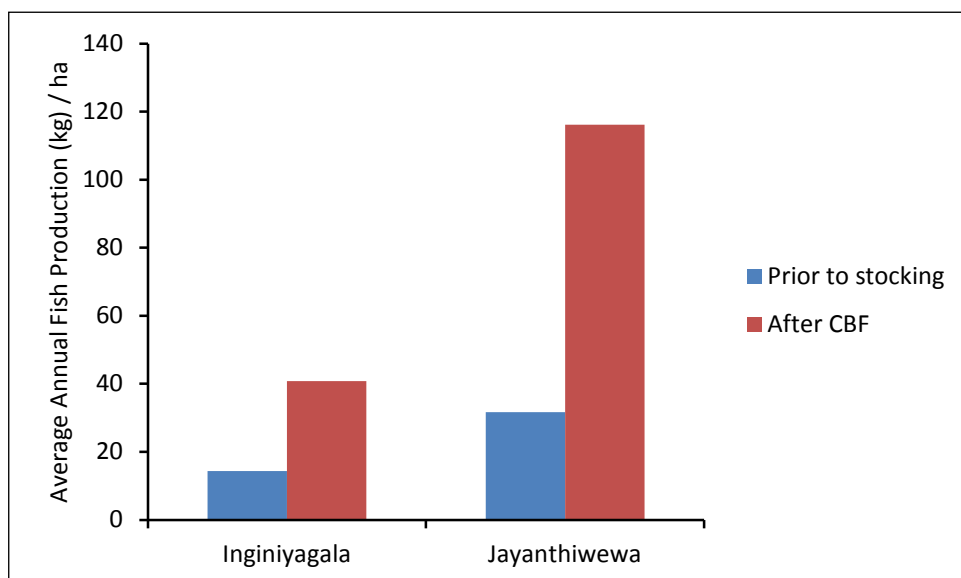


Figure 8. Average fish production per unit area in major perennial reservoir during pre- and post-CBF.



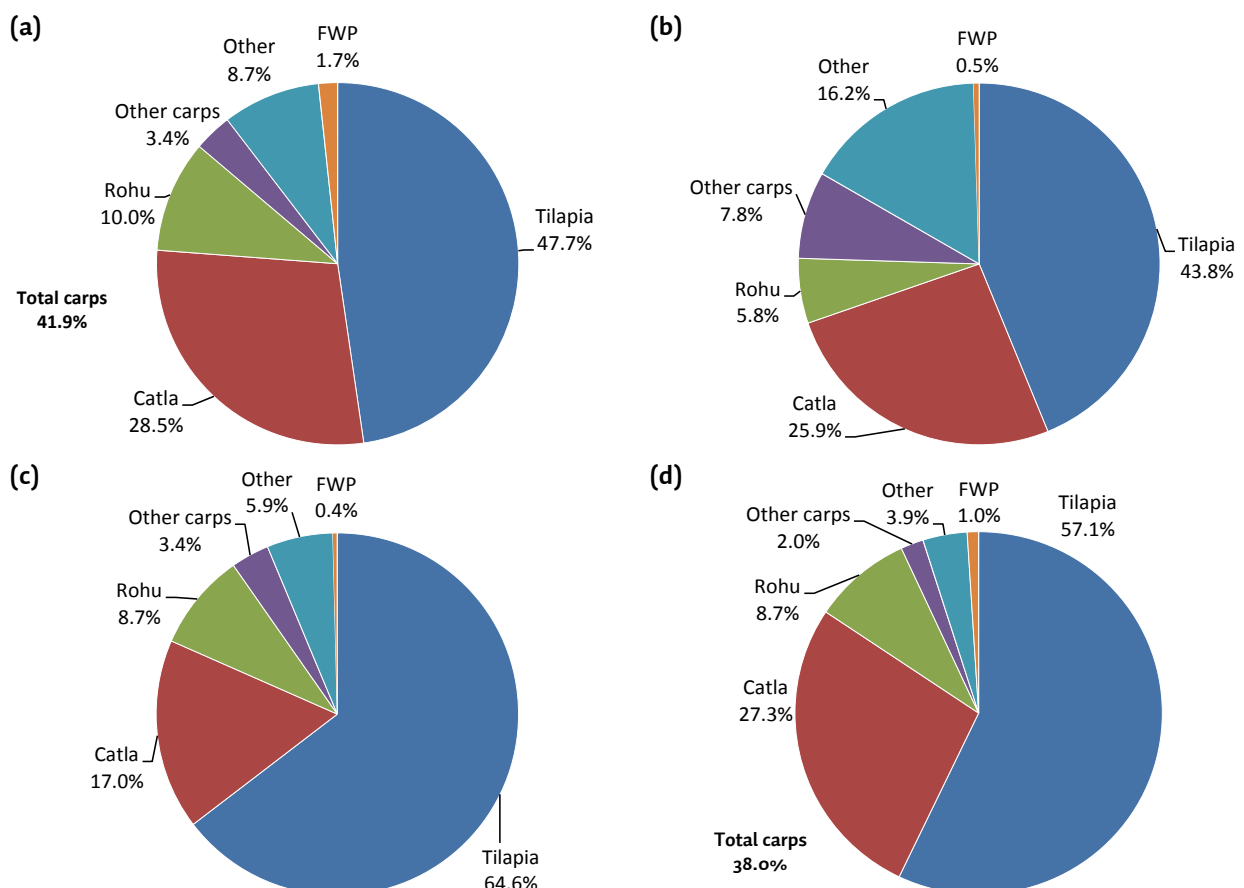
All categories of reservoirs had Nile tilapia as the dominant species in the catches, contributing 80 – 90% prior to introduction of CBF. Although the percent contribution of Nile tilapia to fish catches of all three categories of reservoir has decreased, it is interesting to note a significant increase in landings of Nile tilapia after introduction of CBF. This probably indicates an inadequacy of natural recruitment of Nile tilapia. Stocking of Indian carp species, in particularly catla and rohu, has resulted in a significant contribution of these species to the landings in all three categories of reservoirs indicating availability of suitable conditions for these species including food. It is interesting to observe that mrigal, which was stocked in these reservoirs in late 2013, have started to appear in fish catches in significant numbers in some reservoirs (personnel observations of the first author) and it is anticipated this will further facilitate increases in fish production and contribution of carps to fish catches. Although the contribution of freshwater prawn in fish catches is low, stocking of freshwater prawn has become attractive to fishers as this commodity fetches a higher price and is economically feasible. Fishing gear used in these reservoirs is gill nets and it is not efficient fishing gear for catching freshwater

prawn. Introduction of new fishing gear, such as traps may facilitate an increase in landings of freshwater prawns.

The legal framework existing under the *Fisheries and Aquatic Resources Act* of 1996 facilitated the implementation of activities related to CBF. These provisions included registration of fishing crafts, need for a license to engage in fishing operations and use of gillnets with mesh size above 85 mm etc. The requirement for obtaining a license for fishing operations prevents open access to fishing and ensures the ownership of the fish catch to a group of fishers, who has organised into a CBO. In addition, there are provisions to limit the number of licenses issued in each reservoir and also to limit the number of units of fishing gear (gill nets) that can be used by a fisher in a reservoir. Accordingly, the above provisions ensure that CBF as practised in Sri Lankan reservoirs, irrespective of the size of the water body, fall within the realm of aquaculture as per the definition of the FAO (FAO 1994).

Continued and adequate stocking, and the presence of an active CBO, are important for successful implementation of CBF. Fisher CBOs were involved in decision

Figure 9. Species composition of fish catches of (a) minor perennial reservoirs, (b) medium perennial reservoirs, (c) Senanayake Samudra and (d) Jayanthi wewa.



making in all aspects of CBF and actively involved in management of CBF. CBF members not only refrain from using illegal fishing gear but also prevent any unauthorised fishing in reservoirs through close surveillance. It was interesting to note that CBO members in most reservoirs collectively agreed and used gill nets with mesh size of 115 mm and above. The results of this change is yet to be fully realised and or assessed, but does indicate the active and ongoing involvement of CBOs in the overall management strategy of CBF.

The fixed time period for fishing operations and the use of one landing site are two other important management measures, which facilitated prevention of use of illegal fishing gear and unauthorised fishing. Further these measures facilitated data collection of landings. Funds required for stocking was generated by levying a fee for every kilogram of fish landed. Involvement of CBOs in collection and maintenance of stocking and catch data has resulted in availability of very accurate data, which are useful for the CBO as well as for fisheries authorities for planning and further development of CBF. The management of the fisheries in these reservoirs has all the ingredients of a co-management system (Amarasinghe and De Silva 1999). The fisheries community users were actively involved in decision making through their fisher CBOs. Tasks have been allocated to primary stakeholders and implementation of tasks were satisfactory. There has been very close cooperation between relevant Government Authorities and fishers.

The introduction of CBF in these reservoirs has resulted in significant increases in fish production, in turn enhancing income of fishers, availability of fresh fish for rural communities and livelihood opportunities. Adequate stocking of reservoirs with suitable fish species, involvement of active CBOs, their involvement in decision making and legal framework for ensuring ownership of the harvested fish and the implementation of sustainable management measures are the key factors for successful introduction and implementation of CBF.

CBF are essentially a form of extensive aquaculture, or a farming practice conducted in small water bodies (generally less than 100 ha) (De Silva et al. 2006). Experiences in China and Sri Lanka show that CBF could be practised in larger water bodies. Perhaps CBF is a strategy that needs to be adopted by most developing countries to increase the food fish supplies to rural communities, and also increase the overall contribution from inland fisheries to global food fish production (Beard et al. 2011).

References

- Amarasinghe, U.S. and De Silva, S.S., 1999. The Sri Lankan reservoir fishery: a case for introduction of a co-management strategy. *Fisheries Management and Ecology*, 6; 387-400.
- Beard Jr . T. Douglas, Arlinghaus Robert, Cooke Steven J., Peter, McIntyre, De Silva Sena, Bartley Devin and Cowx I.G., 2011. Ecosystem approach to inland fisheries: research needs and implementation strategies. *Biology Letters*, 7; 481-483.
- Chakrabarty, R.D. and Samaranyake, R.A.D.B., 1982. Fish culture in seasonal tanks in Sri Lanka. *Journal of Inland Fisheries, Sri Lanka*, 2; 125-140.
- Chandrasoma, J., 1986. Primary productivity and fish yield in ten seasonal tanks in Sri Lanka. *Journal of Inland Fisheries, Sri Lanka*, 3; 56-62.
- Chandrasoma, J. and Kumarasiri, W.S.A.A.L., 1986. Observations on polyculture of fish in seasonal tanks in Ratnapura and Moneragala districts in Sri Lanka. *Journal of Inland Fisheries, Sri Lanka*, 3; 49-55.
- De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T., 2006. *Better practice approaches for culture based fisheries development in Asia*. ACIAR Monograph No. 120, 96 pp.
- FAO (Food and Agriculture Organization of the United Nations), 1994. Aquaculture production 1986-1992. *FAO Fisheries Circular*, Vol. 815, Revision 6. Rome, Italy, 214 pp.
- Li, S., 1987. The principles and strategies of fish culture in Chinese reservoirs. In: *Reservoir Fishery Management and Development in Asia*. Proceedings of a workshop held in Kathmandu, Nepal, 23-28 November 1987, pp. 214-223.
- Mendis, A.S., 1977. The role of man-made lakes in the development of fisheries in Sri Lanka. *Proceedings of the Asia-Pacific Fisheries Council*, 17; 247-254.
- Pushpalatha, K.B.C. and Chandrasoma, J., 2009. Culture-based fisheries in minor perennial reservoirs in Sri Lanka. Variability in production, stocked species and yield implications. *Journal of Applied Ichthyology*, 26; 98-103.
- Thyayaparan, K., 1982. The role of seasonal tanks in the development of freshwater fisheries in Sri Lanka. *Journal of Inland Fisheries, Sri Lanka*, 1; 133-167.
- Xu, S., 1987. Fishing Techniques in Chinese Reservoirs. In: *Reservoir Fishery Management and Development in Asia*. Proceedings of a workshop held in Kathmandu, Nepal, 23-28 November 1987, pp. 169-175.

Culture-based fishery of giant freshwater prawn: Experiences from Thailand

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Abstract: Releasing of giant freshwater prawn (*Macrobrachium rosenbergii*) for the purposes of stock enhancement and to create a fishery has been conducted in Thailand since the 1980s. In each year, over a hundred million post larvae (30 day old post larvae of -1 cm) of *M. rosenbergii* have been released into inland waters nationwide. The stocking density is, generally, about 2,500 prawn larvae/ha. Average age at harvest is around 6 to 8 months, with an average total length of 20 cm. The individual weights can range between 100 and 200 g after a year of release. Common fishing gears are gillnet, long-lines and traps, the latter designed exclusively for *M. rosenbergii*. Overall, the success of stocking *M. rosenbergii* is poor since the recapture rate is generally less than 5%. However, the economic return is high. Average market price of *M. rosenbergii* is 150 Thai Baht/kg, which is about 3 times more than the average price of marketed freshwater fish. The profit is reported to be as high as 800%. Moreover, the high market price of *M. rosenbergii* benefits traders at various levels, job creation and income for all related sectors. Although the economic profit is very high, the low rate of recapture of stocked *M. rosenbergii* makes this culture-based practice not entirely satisfactory. The major problem is that there are no guidelines in regard to the optimum size of seed for release as well as appropriate time and location to be stocked, that could enhance the rate of return and economic returns.

Key words: *Macrobrachium rosenbergii*, culture-based fishery, Thailand, stocking practices, rate of recapture.

Introduction

Culture-based fisheries of inland water-bodies in Thailand have been operated since the 1950s, by the Department of Fisheries (DoF), but the regular stocking program commenced in 1978 under “the nation-wide fish stocking program” for communal ponds, lakes and reservoirs (Virapat, 1993; Jutagate and Rattanachai 2010). This activity is currently conducted under the strategy issue 1 of DoF “Fish Production Enhancement”, which aims to improve potential fish production in natural waters by at least two percent per year (DoF 2012). The commonly stocked species were the exotic Chinese carps, Indian major carps and tilapia (Bhukaswan 1989). However, because these species, except for tilapias, cannot form sufficiently large populations that could be exploited commercially, the major species stocked have shifted to indigenous species since the 1980s. In each year, about 2,000 million fish seed are stocked into inland water bodies countrywide, of which about 55 to 65% are indigenous species (Jutagate and Rattanachai 2010). The giant freshwater prawn, *Macrobrachium rosenbergii*, is the only shellfish that has been stocked regularly for fishery purposes, of which about 350 million seed have been released annually (Jutagate and Rattanachai 2010). Other than in Thailand, culture-based freshwater prawn fisheries have been conducted in India and Sri Lanka as well as trialed in other Asian countries (New and Kutty

2010). This is one of the relatively uncommon examples of a culture-based fishery with a non-fish species in inland waters (De Silva and Funge-Smith 2005).

M. rosenbergii is the largest freshwater prawn in Asia and in Thailand it occurs naturally in large rivers that are connected to the coastal area countrywide, from the Moei River in the north to the Pattani River in the south as well as large swamps (e.g. Bueng Boraped) and lakes (e.g. Songkhla Lake) that are connected to these rivers (Amarttayakul and Bhukaswan 1974). The yield of *M. rosenbergii* from capture fisheries had continuously decreased from 3,000 to 500 tonnes per year from 1974 to 1994 (Fishery Economic Division 1996). This is mainly due to fishing pressure because this prawn is among the most targeted species of the inland fishery and has the highest economic value. *M. rosenbergii* is priced about 150 Thai Baht per kg (1 US \$= 30 Thai Baht), whereas other freshwater fishes and shellfishes are priced around 50 Thai Baht per kg (Figure 1). However, production of *M. rosenbergii* from capture fisheries recently increased to around 1,000 tonnes per year and this increase was mostly attributed to the success of the stocking program (Fishery Economic Division 2013).

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Because *M. rosenbergii* is catadromous, their production from communal ponds and reservoirs as well as rivers that are not connected directly to the sea, e.g. the tributaries of Mekong River, are totally based on regular stocking to sustain the fisheries, i.e. culture-based fisheries. These fisheries bring direct benefits to the community through increased availability of fish (De Silva, 2003), high income, and thus improving livelihoods. In this paper, the experiences of the culture-based *M. rosenbergii* fishery in Thailand are synthesised and future research needs are examined with a view to improving the current practices of this fishery.

Stocking practices

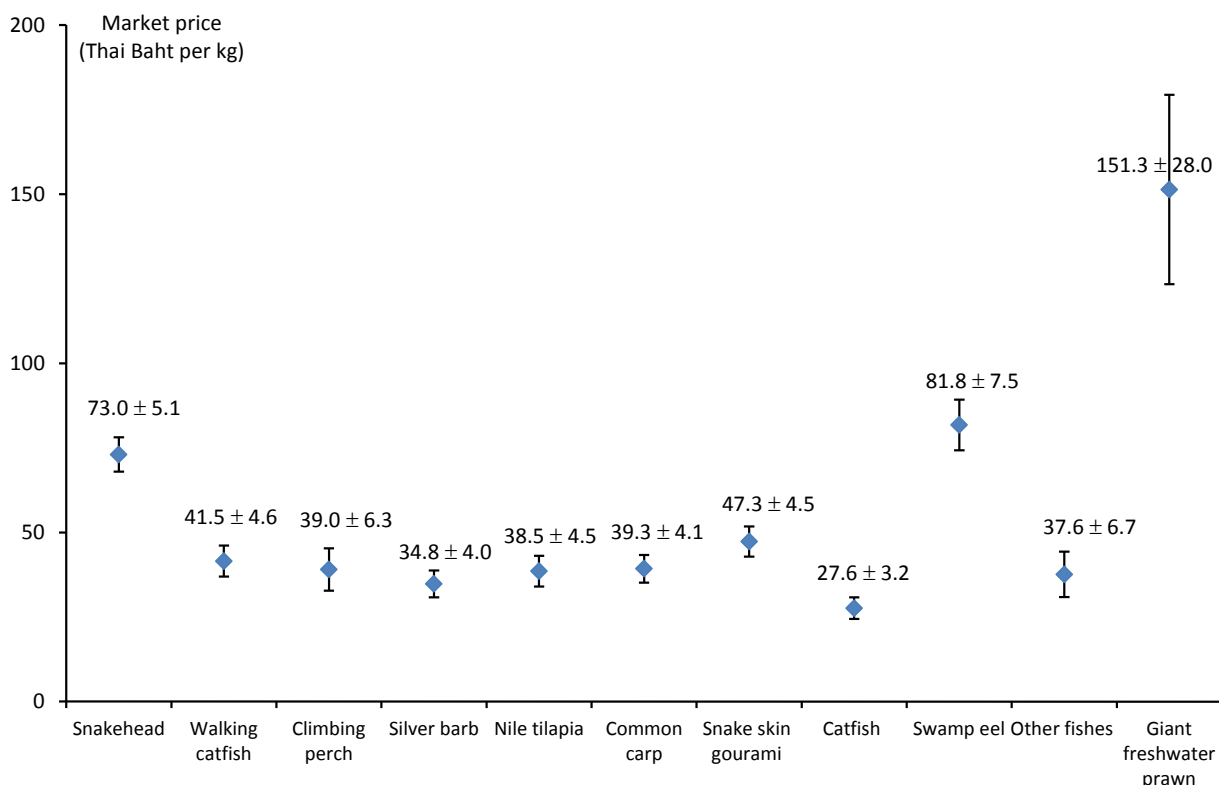
M. rosenbergii is normally released as 30 day old post larvae (PL), i.e. stage PL30 (Sripatrprasite and Lin 2003). At this stage, the seed size ranges from about 0.8 to 1 cm, and weigh about 0.01 g. This is also the commonly released size for culture-based prawn fisheries in other Asian countries (New et al. 2000). The exceptions were found in Sri Lanka, where 45 day post larvae i.e. stage PL45 are stocked (Pushpalatha and Chandrasoma 2010), and PL60 and PL 90 were released in Tonle Sap, Cambodia (Thuok et al. 2011). Stocking of larger PL60, i.e. about 1.5 cm, has also been trialed in Ubolratana Reservoir in 1981 (DoF 1986). The commonly practised

stocking density, by the Department of Fisheries, ranged between 400 – 500 prawns per rai¹ or 2,500 – 3,000 prawns per ha (i.e. 0.25 – 0.3 seeds/m²; Jaiyen 2003). The seed are normally packed in 15 L plastic bags containing 2,000 prawns, in which the ratio between oxygen and water is 3:1, and transported from hatcheries to the releasing sites in a cool container maintained at 18°C by trucks or vans (Jaiyen 2003; Sripatrprasite and Lin 2003). The stocking program in each year is conducted during two major events viz., firstly, during the Songkran Festival, between 12 and 15 April and, secondly, on 21 September, the National Fishery Day. The first event is the transitional period to the rainy season and the latter is the end of the rainy season. Stocking during the rainy season is to guarantee an abundance of natural food and shelter for the stocked seed, especially in flooded forests of the respective water bodies (Jutagate and Rattanachai 2010).

There are a number of cases where arbitrary stocking densities have been used. However, a more important concern is the number of releasing events. Examples of these cases are from the stockings by the Provincial Office and the Sub-district Administrative Organisations for communal ponds or by private companies for

1. Rai is the Thai measurement for unit of area. A rai is equal 1,600 square metres.

Figure 1. Average prices (Thai Baht per kg) of common freshwater fishes and giant freshwater prawn in Thailand.



performing their corporate social responsibilities. There is also the case of stocking for conservation purposes; for example, 84 million *M. rosenbergii* post-larvae were released into the Chao Phraya River in 2014 as a part of the celebrations of Her Majesty Queen Sirikit's 84th birthday (DoF 2014a).

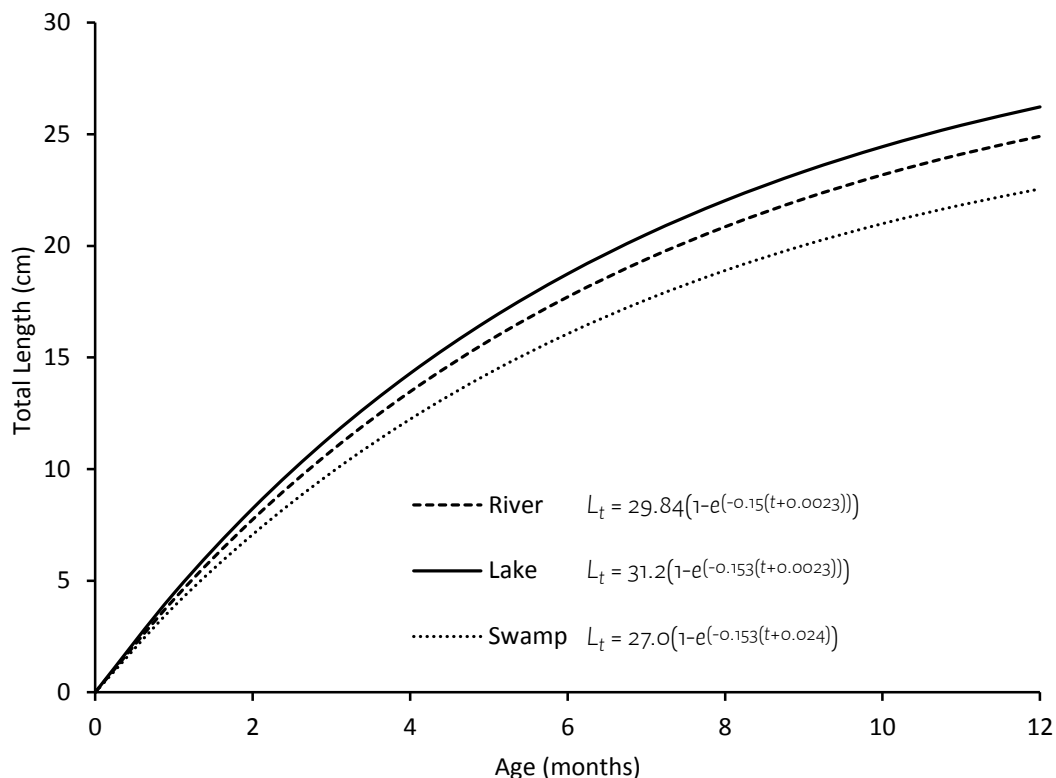
Growth performance

The life span of *M. rosenbergii* can be as long as two years (Vogt 2012). The males can reach a total length (from tip of rostrum to tip of telson) of 320 mm, and females 250 mm (Brown et al. 2010). However, the largest male (350 mm TL) and female (280 mm TL) have been reported from Songkhla Lake about 45 years ago (Pongsuwan et al. 1967). For the stocked populations, their growth varied according to habitat type. Although *M. rosenbergii* exhibits a "leapfrog" growth pattern (Ra'anan and Cohen 1985), its growth curve conforms to a von Bertalanffy equation (Figure 2), which indicates the growth rate is high during the first month after stocking and decreases later (New and Valenti 2000). The asymptotic length (i.e. average length of the oldest group) of the stocked *M. rosenbergii* in Thai waters ranged between 270 to 310 mm TL, and the highest value was observed in a population in a brackish water system, i.e. Songkhla Lake. Meanwhile, *M. rosenbergii* can reach a size of 230 cm TL within 6 months after stocking in intensive culture

in earthen pond at a stocking density of 0.3 seeds/m², i.e. a similar stocking density to the culture-based fishery (Sampio and Valenti 1996).

It takes about 6 to 8 months for the prawns to approach a harvestable size, of individual weight between 60 and 100 g (i.e. size around 200 mm TL), and could be up to 150 to 200 g, one year after stocking (Jaiyen 2003). Sripatrprasite and Lin (2003) reported that the stocked *M. rosenbergii* in "run-of-the river" Pak Mun Reservoir could grow to 110.6 g within 8 months, with an average growth rate of 28.6 g per month. In large reservoirs (e.g. Rajjaprabha Reservoir) an average weight of 107 ± 5 g were observed one year after stocking (Jindapun and Sungkapaitoon 2006). By stocking larger sized PL, however, prawns can reach a size of 200 g within one year (DoF 1986). Similar results have been obtained from Tonle Sap (Thuok et al. 2011). Moreover, *M. rosenbergii* could grow as large as 350 mm and weight of 450 g 15 months after stocking in this reservoir (Pawaputanon and Boonpew 1983). Similar results of a one year size was also reported in a medium-sized swamp in the northeast, where the stocked prawn had an average size of 235 ± 0.25 mm and 170.6 ± 6.5 g (Supsooksamran et al. 2001). A size around 250 cm and weight 350 g of one year old *M. rosenbergii* was also reported from the Chi River (Chaiyapoom Inland Fisheries Station 2009).

Figure 2. Total length at age (cm) of the giant freshwater prawn from different habitats in Thailand.



Fishing gears

Adult *M. rosenbergii* are active at night while during the day they remain in shaded areas (Brown et al. 2010), thus most of the fishing gears are operated during night time. The common fishing gears are traps, long-lines, gillnets, cast-net and spear (Pawaputanon and Boonpew, 1983; DoF 1986; Potaros, 1993; Jaiyen 2003), and the prawns are occasionally caught by the bug lift net. Cast-net and spear are the most selective gear for large sized prawns, i.e. larger than 20 cm TL, whereas other gear will catch a wide size range (Potaros 1993; Sripatprasite and Lin 2003). A survey conducted by the Pak Mun Fisheries Research Station between May and August 2004 (Kwangkhang, unpublished data) revealed that ranges of the catches by common fishing gears ranged between 5 and 30 cm TL. The number of catches by the “Jann” trap (Figure 3), the gear that is designed exclusively for catching *M. rosenbergii*, was about double that of other common gears used, and also the larger sized prawns were most often caught by this gear (Figure 4). There is no clear trend on the fishing season but catches were observed to be higher from February to July, when the water is relatively clear, and decrease afterwards (DoF 1986; Potaros 1993).

Evaluation

The recapture rate of stocked fish is generally high with an average of over 10 %, and could be as high as 50 % in communal ponds and swamps, whereas the recapture rate of the *M. rosenbergii* is generally poor and less than 5

Figure 3. “jaan” trap, which is used exclusively for fishing giant freshwater prawn.



% (Jutagate and Rattanachai 2010). The highest recapture rate of about 10 % for *M. rosenbergii* was experienced in the natural lake, Beung Borapet, which had been stocked in 1995 with 3 million PL (Rithcharung and Srichareondham 1998). In Ubolratana Reservoir, where 536,000 PL were stocked in 1983, 11,455 prawns (2 %) were returned. Moreover, the overall recapture rate of the whole project, i.e. between 1981 and 1986, was also about 2 % (i.e. 5,081,000 releases and 98,859 returns) (Chumnongsittsthum 1987). A similar rate of recapture was also observed in Bangphra Reservoir (Renunual and Silapachai 2005). In an attempt to create a new fishery in Pak Mun Reservoir, Jaiyen (2003) showed that the recapture rate of *M. rosenbergii* was very low (<1 %), and most of the catches were small-sized prawns, with individuals weighing <100 g. It was assumed that some stocked prawns moved downstream through spillways and turbines (New and Kutty 2010). However, there is also evidence suggesting that higher stocking levels could yield greater recaptures in the Pak Mun Reservoir. Stocking of 5 million prawns, during 1995 – 1998, resulted in 1 % recapture, meanwhile stocking of 40 million prawns, between 2003 and 2007, returned 2.5 % (Kwangkhang, unpublished data).

In terms of production, the experience from the Pak Mun Dam was that stocking of 2 million *M. rosenbergii* PL resulted in a production of 3 kg/ha/yr (Sripatprasite and Lin 2003), and by stocking 40 million PLs, the production was as high as 11.5 kg/ha/yr (Jaiyen 2003). Rithcharung and Srichareondham (1998) reported that, by stocking 3 million PL to Bung Boraped, the catch per unit effort increased from month-5 to month-11 after stocking. Meanwhile, of about 5 million PL that had been continuously stocked into Ubolratana Reservoir between 1981 and 1986, a return of about 24.5 tonnes of the *M. rosenbergii* was obtained (Chumnongsittsthum 1987).

The economic benefit from *M. rosenbergii* is higher than for any other stocked fish species. Sripatprasite and Lin (2003) reported that catches of prawn contributed 53.8 % to the total fish catch by weight, but 97 % to the economic value of the landings in the Pak Mun Reservoir. A five year monitoring program undertaken by Chumnongsittsthum (1987) revealed that the economic profit of stocked *M. rosenbergii* in Ubolratana Reservoir was 382 %. Renunual and Silapachai (2005) found that only with a low recapture rate of 1.8 % of stocked *M. rosenbergii* in Bangphra Reservoir, economic profit was 722 %.

The high economic return reflects the high market demand of *M. rosenbergii* and large difference between the cost of production of seed and market price. The cost of the *M. rosenbergii* PL is about 0.15 Thai Baht², whereas those for the fingerlings of Chinese carps

2. 1 US dollar = approximately 30 Thai Bah t.

and Thai indigenous fishes, are about 0.3 and 1.0 Thai Baht, respectively (DoF 2014b). The market prices of the stocked Chinese carps and Thai indigenous fishes average 20 and 50 Thai Baht/kg, whereas the market price of the *M. rosenbergii* is ranges from about 150 Thai Baht/kg from the fishers to as high as 600 Thai Baht/kg to the consumers. Stocked *M. rosenbergii*, therefore, benefits traders at various levels of the market chain(s), and provides employment opportunities and income for all related sectors (Jaiyen 2005).

Conclusion

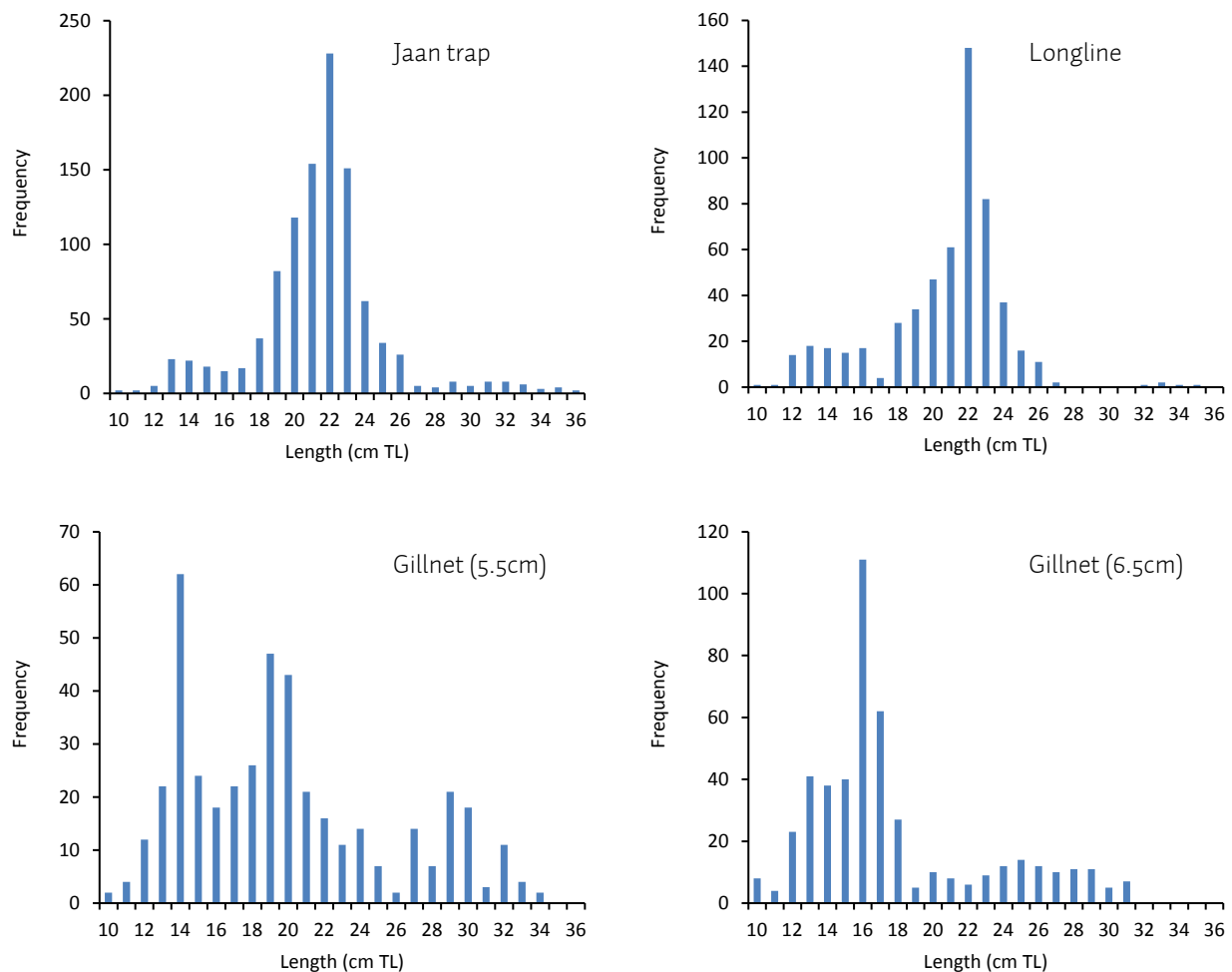
The information available on *M. rosenbergii* culture-based fisheries in Thailand suggests that the fishery has achieved considerable success, especially in terms of economic benefits, even though the recapture rate is low compared to stocked fish species. Stocked prawns are generally harvested after 6-8 month at a size and weight around 20 cm TL and 80 g, respectively. Despite considerable success in CBF development based on *M. rosenbergii*, there is a lack of information on appropriate

stocking strategy (ies), ecological impacts of stocked populations. Guidelines with regard to the optimum size of released seed as well as appropriate time and location to be stocked are required to optimise CBF yields of *M. rosenbergii*.

References

- Amarttayakul, C. and Bhukaswan, T., 1974. Report on the distribution of the giant freshwater prawn *Macrobrachium rosenbergii* in Thailand. *Technical Report No. 13*. Department of Fisheries, Bangkok, 24 pp. (in Thai).
- Benjakarn, M., 1985. Monitoring of stocked giant freshwater prawn in Ubolratana Reservoir. *Technical Report No. 1/1985*. Department of Fisheries, Bangkok, 9 pp. (in Thai).
- Bhukaswan, T., 1989. The use of cyprinids in fisheries management of the larger inland water bodies in Thailand In: Petr, T. (ed.) Indo-Pacific Fisheries commission, Papers contributed to the Workshop on the Use of

Figure 4. Size variations of catches of giant freshwater prawn from four different fishing gears used in Thailand.



- Cyprinids in the Fisheries Management of Larger Inland Water Bodies of the Indo-Pacific. *FAO Fisheries Report*, 405; 142-150.
- Brown, J.H., New, M.B. and Ismael, D., 2010. Biology. In: New, M.B., Valenti, W.C., Tidwell, J.H., D'Abramo, L.R., Kutty M.N. (eds.) *Freshwater Prawns: Biology and Farming*. Blackwell, Oxford. pp. 18–39.
- Chaiyapoom Inland Fisheries Station, 2009. *Monitoring of stocking giant freshwater prawn in the Chi River at NongBua Dang District, Chaiyapoom*. Chaiyapoom Inland Fisheries Station, Chaiyapoom. 4 pp. (in Thai).
- Chumnongsittsthum, B., 1987. Stocking of giant freshwater prawn, *Macrobrachium rosenbergii* in Ubolratana Reservoir during 1981-1986. *Proceedings of the seminar on fisheries 1987 of the Department of Fisheries*, Department of Fisheries, Bangkok, pp. 279 – 285.
- De Silva, S.S., 2003. Culture-based fisheries: an underutilised opportunity in aquaculture development. *Aquaculture*, 221; 221–243.
- De Silva, S.S. and Funge-Smith S.J., 2005. A Review of Stock Enhancement Practices in the Inland Water Fisheries of Asia. *RAP Publication No. 2005/12*. Asia-Pacific Fishery Commission, Bangkok. 93 pp.
- DoF, Department of Fisheries, 1986. *Enhancement of the giant freshwater prawn's production in Ubolratana Reservoir*. Department of Fisheries, Bangkok. 18 pp. (in Thai)
- DoF, Department of Fisheries, 2012. *Strategies of the Department of Fisheries between 2013 and 2016*. <http://www.fisheries.go.th/planning/files/Presentation.pdf> (in Thai).
- DoF, Department of Fisheries, 2014a. *News on stocking giant freshwater prawn to the Chaoprya River*. http://www.fisheries.go.th/secretary/pr_old/news_detail.php?news_id=538 (in Thai).
- DoF, Department of Fisheries, 2014b. *Prices of the seeds of freshwater fishes*. <http://www.inlandfisheries.go.th/images/project/money/prie.pdf> (in Thai).
- Fishery Economic Division, 1996. *Fishery statistics of Thailand in 1994*. Department of Fisheries, Bangkok. 86 pp. (in Thai).
- Fishery Economic Division, 2013. *Fishery statistics of Thailand in 2012*. Department of Fisheries, Bangkok. 88 pp. (in Thai).
- Jaiyen, P., 2003. *Evaluation of stocking giant freshwater prawn in 2003 in Pak Mun Dam, Ubon Ratchathani Province*. Department of Fisheries, Bangkok. 38 pp. (in Thai).
- Jindapun, N., and Sungkapaitoon, S., 2006. *The stocking of giant freshwater prawn, Macrobrachium rosenbergii De Man in Rajjaprabha Reservoir, Suratthani Province*. Suratthani Inland Fisheries Research and Development Center, Suratthani. 6 pp. (in Thai).
- Jutagate, T. and Rattanachai, A., 2010. Inland fisheries resource enhancement and conservation in Thailand In: De Silva, S.S, Davy B., Wiemin M. (eds.) *Inland Fisheries Resource Enhancement and Conservation in Asia-Pacific*. FAO/RAP Publication 2010/22. FAO/RAP, Bangkok. pp. 133-146.
- New, M.B. and Kutty, M.N., 2010. Commercial freshwater prawn farming and enhancement around the world In: New, M.B., Valenti, W.C., Tidwell, J.H., D'Abramo, L.R., Kutty, M.N. (eds.) *Freshwater Prawns: Biology and Farming*. Wiley-Blackwell, Oxford. pp. 346-399.
- New, M.B., Singholka S. and Kutty, M.N., 2000. Prawn capture fisheries and enhancement In: New M.B. and Valenti W.C. (eds.) *Freshwater prawn culture: The farming of Macrobrachium rosenbergii*, Blackwell Science Ltd., Oxford. pp. 411-428.
- New, M.B. and Valenti, W.C. (eds.), 2000. *Freshwater prawn culture: The farming of Macrobrachium rosenbergii*. Blackwell Science Ltd., Oxford. 443 pp.
- Pawaputanon, U. and Boonpew, L., 1983. *Result of stocking Macrobrachium rosenbergii in Ubolratana Reservoir*. Inland Fisheries Division, Department of Fisheries, Bangkok. 12 pp. (in Thai).
- Pongsuwan, A., Phrommanon, P., and Sahawatcharin, T., 1967. Preliminary study on the life history of *Macrobrachium rosenbergii* in Songkhla Lake. *Annual report 1966 – 1967, Songkhla Marine Fisheries Station, Songkhla*. pp. 145-173. (in Thai).
- Potaros, M., 1993. The study on status of giant freshwater prawn (*Macrobrachium rosenbergii* De Man) resource in Songkhla Lake, *Technical Report No. 1/1993*. Department of Fisheries, Bangkok. 159 pp. (in Thai).
- Pushpalatha, K.B.C., Chandrasoma, J., 2009. Culture-based fisheries in minor perennial reservoirs in Sri Lanka: variability in production, stocked species and yield implications. *Journal of Applied Ichthyology*, 26; 99-104.
- Ra'anani, Z. and Cohen, D., 1985. Ontogeny of social structure and population dynamics in the giant freshwater prawn *Macrobrachium rosenbergii* (De Man). In: Wenner, A.M., Schram, F.R. (eds.) *Crustacean Issues, Vol. 2: Crustacean Growth*. A.A. Balkema, Rotterdam. pp. 277–311.

- Renunual, A. and Silapachai, W., 2005. *Evaluation on the stocking program of the giant freshwater prawn (Macrobrachium rosenbergii de Man) in Bang Phra Reservoir, Chon Buri Province*. Chon Buri Inland Fisheries Research and Development Centre, Chon Buri. 37 pp. (in Thai).
- Rithcharung, S. and Srichareondham, B., 1998. *Evaluation on the stocking program of the giant freshwater prawn (Macrobrachium rosenbergii de Man) in Beung Borapet, Nakhonsawan Province*. Nakhonsawan Inland Fisheries Research and Development Centre, Nakhonsawan. 40 pp. (in Thai).
- Sampio, C.M.S. and Valenti, W.C., 1996. Growth Curves for *Macrobrachium rosenbergii* in Semi-Intensive Culture in Brazil. *Journal of the World Aquaculture Society*, 27; 353-358.
- Sripatrprasite, P. and Lin, C.K., 2003. Stocking and recapture of freshwater prawn (*Macrobrachium rosenbergii* De Man) in a run of-river type dam (Pak Mun Dam) in Thailand. *Asian Fisheries Science*, 1; 167-174.
- Supsooksamran, M., Uiprasit, P. and Siripraiwan, S., 2001. *Assessment of the stocking freshwater prawn (Macrobrachium rosenbergii De Man) in Bung Laharn, Chaiyapoom (Abstract)*. Chaiyapoom Inland Fisheries Station, Chaiyapoom. 5 pp. (in Thai).
- Thuok, N., Nam, S. and Phein, C., 2011. Rebuilding stocks of once-abundant freshwater prawns around the Tonle Sap. *Mekong Fish: Catch and Culture*, 17; 10 – 13.
- Virapat, C., 1993. *Bionomics of fish stocking in two Thai reservoirs; biological, management and development perspectives*. Ph.D. Thesis, Dalhousie University, Nova Scotia, 428 pp.
- Vogt, G., 2012. Ageing and longevity in the Decapoda (Crustacea): A review. *Zoologischer Anzeiger*, 251; 1–25.

Culture-based fisheries in lakes of the Yangtze River basin, China, with special reference to stocking of mandarin fish and Chinese mitten crab

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Abstract: Lakes amount to 15% of the total freshwater surface area in China and are important for land-based fisheries. More than 10 species are stocked into lakes to increase production and/or improve water quality. The most common species stocked are the Chinese major carps, i.e. silver carp, bighead carp, grass carp and black carp. In recent years, increasing amount of high valued species such as mandarin fish, mitten crab, yellow catfish and culters were stocked. However, the stocking of mandarin fish and mitten crab perhaps are the most successful because stock enhancement of these two species has been systematically conducted.

In this paper, the culture-based fisheries in lakes are presented, with special reference to mandarin fish and mitten crab stocking in lakes in China. The stocking rate of mandarin fish is determined by food consumption rates, which are mainly related to water temperature and fish size, and prey fish productivity. A bioenergetics model of mandarin fish was established to predict the growth and consumption of prey fish in stocked lakes. Impacts of stocked mandarin fish on wild mandarin fish populations are also dealt with. The stocking model of mitten crab in of culture-based fisheries was also determined based on biomass of macrophyte coverage, benthos biomass and ratio of Secchi depth to mean water depth in lakes.

Since increasing attention is being paid to eutrophication of lakes in China, land-based fisheries development now prioritise maintaining integrity of water quality and biodiversity conservation. Integrated stocking of different species and lakes fisheries management are also addressed.

Keywords: Culture-based fisheries, stock enhancement, Chinese mitten crab, mandarin fish, lakes, Yangtze River basin.

Introduction

Aquaculture, a millennia old tradition, is thought to have originated in China over 2,500 years back and have achieved great success in global food security and social economy (Wu et al., 1992). China is the largest inland fishery producer in the world, with a total production of 28.74 million tonnes corresponding to 54.5% global inland fishery production (52.78 million tons) including capture and aquaculture production totally in 2012 (FAO, 2014).

Culture-based fisheries (CBF), a mode of fisheries enhancement, are mostly or entirely maintained by the regular stocking of certain fish species (De Silva, 1991; 2003) which rely on the natural productivity of the water body for growth, and on artificial stocking for recruitment (Lorenzen, 1995; Welcomme and Bartley, 1998). Although CBF are very diverse in nature in the type of water bodies utilised, species stocked, harvesting techniques, and management strategies (De Silva, 2003), they are conducted almost exclusively for food

fish production in the developing world. In this regard, for the management of CBF in the developing world, attempts have been made to relate yield to parameters such as morphometric parameters of lakes or reservoirs, species combinations and overall stocking rates and physico-chemical parameters (Hasan and Middendorp, 1998; Nguyen et al., 2001; Gomes et al., 2002; Nguyen et al., 2005; Wijenayake et al., 2005; Jayasinghe et al., 2006; Pushpalatha and Chandrasoma, 2010). Developments of CBF, however, need to have a scientific basis that includes information on optimal stocking rates, species combinations and ratios thereof, optimal time of harvesting and the like, if they are to realise the full potential and become a significant contributor to inland fish production (Wijenayake et al., 2005).

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In China, CBF, an indispensable fishery form for its contribution to the volume of the inland fishery, are enjoying an enhanced reputation for its ability of producing aquatic food with high nutritional quality and high level of food safety. CBF practices in Chinese reservoirs have been well documented (Li and Xu, 1995). Jia et al. (2013) dealt with lake fisheries including cage culture, pen culture and integrated aquaculture in China. However, there are few accounts exclusively on CBF in Chinese lakes, especially on aspect of the development of techniques and environmental protection. This paper attempts to trace the development trends, techniques used and environment protection in CBF in lakes of the Yangtze River basin. It should also be noted that in view of the great diversity of CBF practices in China, it will be futile to attempt to review all these. We have endeavored here to address with suitable and special reference to mandarin fish *Siniperca chuatsi* and Chinese mitten crab, *Eriocheir japonica sinensis*, widely stocked in Chinese lakes.

Contribution of CBF to inland fisheries of China

CBF in China are well developed and practised in most lakes and reservoirs, making a significant contribution to inland fisheries (Li and Xu, 1995). Overall, CBF production has continued to increase over the last three decades (Wang et al., 2014). Based on 5-year average production and area for each type of water bodies from 2006 to 2010 in China, the CBF production from lakes and reservoirs accounted for 6.9% (1,482,187 t) and 11.9% (2,556,932 t) of inland aquaculture production, respectively. The area of lakes and reservoirs used for CBF accounted for 14.8% (997,007 ha) and 24.6% (1,656,105 ha) of inland aquaculture area, respectively (Fig. 1). CBF production from lakes showed a regular increase through the years from 67,568 t (1981) to 1,614,977 t (2012) corresponding to a unit production of 91 kg/ha to 1,576 kg/ha, a significant increase through the years, averaging 46.4 kg/ha/year (Fig.2).

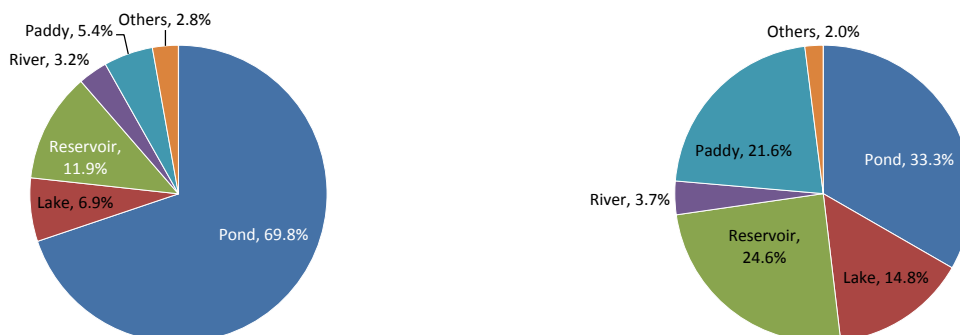
Overall, the increase of CBF production over the years has resulted from better management of the fishery resources, adoption of proper stocking and harvesting strategies (e.g. time window of harvest, size at harvesting and techniques used) in Chinese lakes.

Brief history of CBF in China and main techniques used

China has a long history of CBF in lakes. Prior to the 1960s, and before the development and extension of artificial propagation techniques for the four Chinese major carps species (*Mylopharyngodon piceus* (Richardson 1846), *Ctenopharyngodon idellus* (Valenciennes 1844), *Hypophthalmichthys molitrix* (Valenciennes 1844) and *Aristichthys nobilis* (Richardson 1845)), wild capture fisheries predominated the freshwater fisheries in the country. Since the 1970s, stock enhancement of the four Chinese major carps in lakes has been practised. In the 1980s, cage culture and pen culture dominated the fisheries in lakes. Since the 1990s, high valued species such as Chinese mitten crab, mandarin fish, Mongolian culter (*Culter mongolicus* (Basilewsky, 1855)) have been stocked in lakes.

In the new millennium, China began to address issues related to primary production and environmental impacts from intensive aquaculture practices in lakes and reservoirs. Increasingly strict regulations of the scale of cage culture, pen culture and culture-based fisheries operations in selected lakes have been gradually implemented. For example, the extent of pen culture area in East Taihu Lake has been reduced from 11,267 ha to 3,000 ha in 2009 (Wang et al., 2014). Undoubtedly, semi-intensive and intensive aquaculture practices in lakes such as for example cage culture and pen culture especially with use of feed and/or fertilisers will be further curtailed in the near future. All in all, CBF which is balanced and efficient through stock enhancement and fisheries management will be favoured, and eco-

Figure 1. Percent contribution of production for each of the freshwater environment types (left) and percent contribution of farming area for each of the freshwater environment types (right). Both are based on five year averages from 2006 to 2010 in China base on the average of five years from 2006 to 2010.



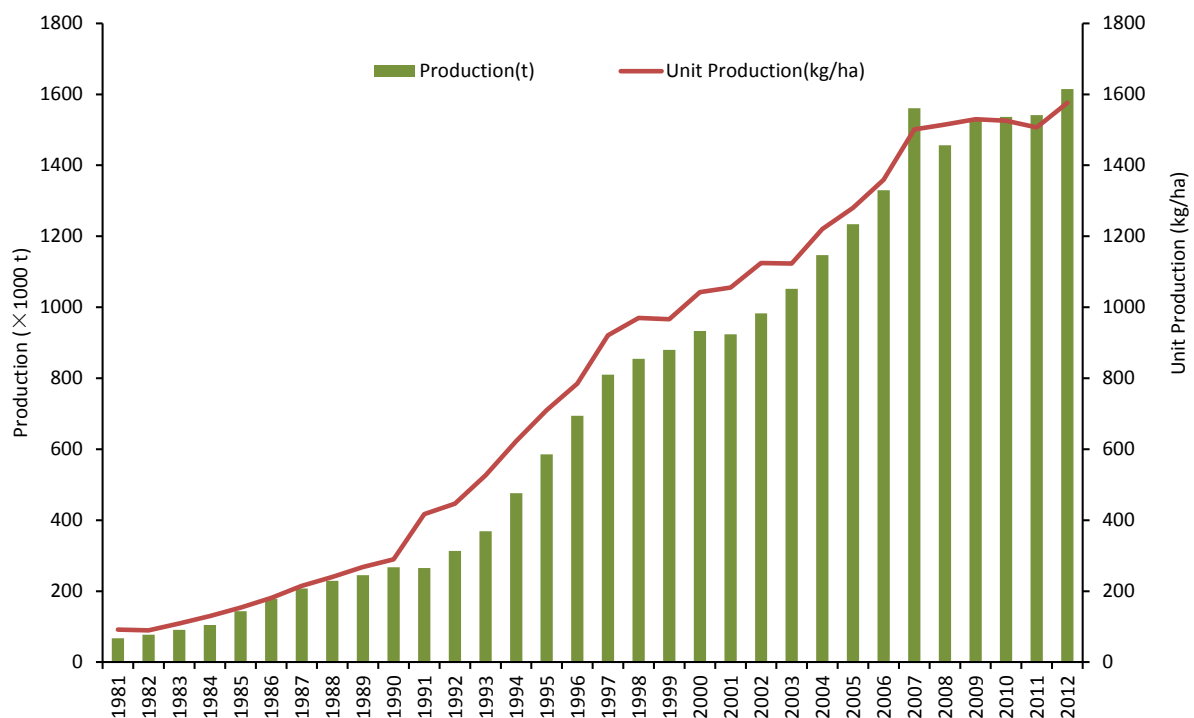
fisheries, the responsible use of natural food resources and protection of biodiversity and ecosystem health will be encouraged.

A range of CBF techniques are being implemented in China as follows:

- Introduction of new species (e.g. introduction of ice fish, *Neosalanx taihuensis* to Dianchi Lake) to exploit under-utilised fishery resources.
- Stock enhancement of four Chinese major carps, mitten crab, and mandarin fish.
- Large-scaled rotational extensive-culture of mitten crab or grass carp in lakes.
- Transplanting aquatic plants.
- Encouraging the establishment of natural food organisms (e.g. snails) for economically important species such as Chinese mitten crab.
- Removal of aquatic macrophytes with high coverage such as *Potamogeton crispus*.
- Fertilisation to maximise the productivity of water bodies enabling better growth of targeted species (e.g. silver carp and bighead carp).

- Elimination of unwanted species, especially carnivorous fishes (e.g. snakehead fish, *Channa argus* (Cantor)).
- In general, size and stocking rates of species are the two main factors influencing success of CBF. Success is mainly influenced by survival rate, size at harvesting and cost. As for stocking rates a number of models investigated some aspects of the dynamics of natural resources (e.g. zooplankton, macrophytes and zoobenthos) and bioenergetics model of stocked fish in CBF. These models derived management guidelines and served as a basis for rigorous evaluation of biological and economical effectiveness of these practices. For example:
 - › Hu (1995) documented that the monthly dynamics of zooplankton which is the natural food for bighead carp and silver carp and adopted predictive models that are related to the production/biomass ratio to estimate the production capacity of filter-feeding fish in Baoan Lake in the middle reach of Yangtze River.
 - › Cui and Li (2005) established a mathematical model based on the bioenergetics model of grass carp and the growth model of macrophytes to estimate the production capacity of grass carp stocked in macrophyte lakes.

Figure 2. Increase in total production and unit production of CBF in China over time.





Harvesting of mitten crab in a lake practicing CBF, Hubei Province.

- › Bioenergetics model related to the productivity of zoobenthos and the production/biomass ratio was also used to estimate the production capacity of fishes, such as black carp and/or common carp that feed on the zoobenthos (Liang et al., 1995).

Stock enhancement of four major Chinese carps in China

With increasing pressure on inland fisheries, increases in production or yield are being sought through the application of a range of enhancement techniques. Stock enhancement of four Chinese major carps, the most common species that were stocked in lakes is considered as one of the most efficient means to restore the fish communities and improve fish production in lakes (Zhang et al., 1997). In the 20th century, their production often accounted for 60% of the freshwater fish catch in China (Wu et al., 1992).

However, some enhancement practices and/or poor fisheries management have resulted in environmental deterioration. In this regard, perhaps stocking of grass carp in lakes in the Yangtze River basin provides an impressive lesson. Since grass carp show a rigid selection for aquatic plant species when feeding (Li, 1998; Pípalová, 2002), stocking have resulted in the exhaustion of the preferred food supply, bringing about a replacement of palatable species with unpalatable species (Liu, 1990; Xiao et al., 2010). On the other hand, stocking rates of

grass carp, depended on the biomass of macrophytes which can vary with water depth, species and climate, can rarely be accurately estimated (Killgore and Payne, 1984; Cassni et al., 1995; Pípalová, 2002). In the above context, stock enhancement of grass carp in macrophytic lakes in China has generally resulted in either complete macrophyte removal or desired/favourable macrophyte biodiversity being dominated by unpalatable species (Chen, 1989; Li, 1998).

As for stock enhancement of silver carp and big head carp in lakes, most of the lakes have reached their maximum potential under natural production regimes and the rising demand for fish is pushing many waters to maximise yields through a range of enhancement techniques. Stocking alone will result in a marginal sustainable increase of yields unless accompanied by other measures to increase the productivity of the water body (Welcomme and Bartley, 1998). In general, fertilisation is usually the first of these measures to be adopted and once a fertilisation program is initiated, it appears that it could not be withdrawn if increase productivity of waters is to be maintained. The negative impacts generated by large-scale fertilisation on water quality and structure of ecosystems have been documented previously (Yang et al., 1991; Vaux et al., 1995; Cottingham and Carpenter, 1998; Vadeboncoeur et al., 2001).

Trade-off between enhanced production from CBF and environmental protection

Undoubtedly, CBF practices in China have contributed significantly to increasing fish production and in turn to national food security and socio-economically. The constraints facing the development of CBF and the importance of overcoming such constraints, especially the increasing challenges associated with the conflicts between CBF production and environmental protection need to be emphasised. In general, although a range of unsustainable techniques such as overstocking of four major carps and/or mitten crab, using fertiliser or animal manure, using various kinds of feed and elimination of carnivorous fishes could raise the CBF production in the short-term in certain waters, these practices resulted in concerns regarding declining quality of the aquatic environments. Meanwhile, there will be increasing competition with agriculture, industry, recreation, drinking water and landscape for the use of water resources. In the future, CBF programs should benefit all stakeholders that have a claim on the respective water resources. Currently, in China the orientation of lake fisheries is

being gradually diverted from seeking fish production to protection of water quality. Fisheries capacity will be estimated according to the environmental carrying capacity of the respective waters. Therefore, aquatic environment protection oriented fisheries (or eco-fisheries) are beginning to be advocated and are gaining increasing attentions of biologists and culturists.

CBF of Chinese mitten crab and mandarin fish

Chinese mitten crab

Chinese mitten crab, is a catadromous crustacean with a life-span of about 2 years and with high nutritional and economic value in China (Pan, 2002; Jin, 2003; Chen et al., 2007). In the natural environment, it grows in freshwater until maturity and then migrates into saline water to spawn (Pan, 2002). Chen et al. (1989) reported that mitten crab from Lake Taihu fed on hydrophytes, fish, shrimp, mollusc, aquatic insects, and worms. Jin et



Mitten crab, the bulk of which is produced in CBF, is a highly priced and marketable commodity. Photo courtesy of Peter Edwards.

al. (2003) observed that mitten crab, in a natural lake in the Yangtze basin fed on macrophyte, algae, arthropods, oligochaetes, fish and detritus.

During the early 1970s to the middle 1980s, wild-caught megalopae in the Yangtze River was released into the open lakes and farmers benefitted from this stocking strategy (Chen et al., 2008). This rather primitive enhancement of Chinese mitten crab is the beginning of mitten crab farming in China and currently this farming sector has achieved remarkable success. The production of mitten crab has increased from 4,833 t corresponding to 36 million USD (1990) to 714,380 t corresponding to 4,972 million USD (2012) in China (FAO, 2014). Among all the types of aquatic environments used for mitten crab culture, lakes with high natural productivity (e.g. benthos) and macrophyte presence that favour the growth of mitten crab are favoured. In view of the above, CBF of mitten crab have been widely practised in the lakes in the middle and lower reaches of Yangtze River (Jin et al., 2000).

Seed stock

CBF practices of mitten crab are variable in regard to stocking material used. Before the 1980s, the stocking material used in CBF in lakes relied on megalopae caught in the Yangtze River. However, natural recruitment declined in the late 1980s due to over-fishing and the construction of dams. Artificial propagation of mitten crab was developed and extended at the beginning of the 1980s. Since then, an increasing number of seed of mitten crab are hatchery produced.

In general, the broodstock of major populations of mitten crab used in CBF in lakes were from the Yangtze, Liao and Ou rivers. Of these, the mitten crab from the Yangtze River enjoys good reputation for its excellent growth performances and unique taste. Mitten crab population from the Liao River is usually cultured in three provinces in the northeast China.

Until the 1980s, most of the crab seed used in CBF was megalopae. Megalopae has been gradual and increasing replaced by the coin-sized crab in practices of CBF due to the higher recovery rate of the latter.

Size of seed stock

Before or just after the Chinese Spring Festival (normally in January and February), coin-sized mitten crab ranging from 2.5 to 10 g in weight are stocked in lakes in the Yangtze basin. The two main factors that influence the size chosen were cost and survival. Apart from the above, the availability of crab seed is also a factor that influences the size chosen.

Stocking models

The deterioration of water quality and the decline of natural food resources in many lakes resulting from over-stocking of mitten crab have been dealt with (Song et al., 2010). Xu et al. (2003) found that intensive culture of mitten crab in lakes resulted in the decline of biodiversity, density and biomass of the zoobenthic community. Intensive culture in Chinese lakes also resulted in reduced submerged vegetation biomass and cover, which significantly decreased the subsequent formation of seed banks (Xiao et al., 2010). Therefore, carrying capacity estimate of mitten crab in CBF in lakes could serve as a basis for guiding stocking.

There are three steps to determine the stocking model. The first step is to select key factors affecting crab yield and driving variable of the models. In this regard, Wang et al. (2006) documented that the annual yield (CY) of mitten crab in lakes was positively correlated to biomass of submerged macrophyte (BMac), Secchi depth (ZSD), annual pH, gastropod density (DGas) and insect density (DIns), but negatively to total nitrogen (TN), chlorophyll a (Chl a), oligochaete density (Doli) and biomass (Boli). Among these, BMac is the most important factor affecting CY and can be statistically considered as the key factor affecting crab yield (Wang et al. 2006). The second step is to determine the maximal yield (kg/ha) model in lakes. It can be expressed by the equation:

$$CY_{Max} = b_0 + b_1 Z_{SD} / Z_M \text{ (Wang et al., 2005).}$$

The final step is to determine the optimal stocking model for determining the stocking rate (SROpt, ind/ha) of coin-sized mitten crab, and is expressed by the equation:

$$SR_{Opt} = (1000 CY_{Max} \times 50\%) / BW \times RR \text{ (Wang et al., 2006),}$$

where BW is the adult crab size (g/individual) and RR is the recapture rate (%).

Based on the maximal yield estimates and using 150 g/ind. for BW and 30% for RR, it is estimated that the optimal stocking rates are 700+60 ind./ha (Wang et al., 2006).

Harvesting and marketing

In general, mitten crab is harvested from October to November. Net traps of approximate 15 m length, are set in the night and hauled early next morning. All the mitten crab in a lake could be harvested in 15 to 20 days, and harvested crab will be stored in a net pen system near the lake shoreline until sold.

Aquatic product vendors often negotiated with managers of CBF in lakes based on quality tests and weight classification of mitten crab. Such as for example

the appearance (e.g. abdomen colour, cheliped loss or damage), degree of gonads maturity, degree of muscle maturity were all included in such assessments. Normally, mitten crab stocked in lakes often is thought to have better nutritional quality and tastes than that cultured in ponds and are priced higher. Wu et al. (2007) documented that the lake-stocked crab is characterised by a blue carapace, white abdomen, golden legs and yellow setae while crab cultured in ponds have a brown carapace, grey abdomen, black legs and similar yellow setae.

Mandarin fish

Mandarin fish, is a typical piscivore, that has a natural range of distribution from southern Zhujiang River through to the north in the Amur River and found to feed on live prey fish only throughout life (Liang et al., 1998; Li et al., 2013). Wild stocks of mandarin fish have been exhausted due to the damming of rivers, pollution, large-scale elimination of unwanted species in CBF since the 1970s and over-fishing driven by the increasing demand for high valued fishes in recent decades (Liang et al., 2001, Cui and Li, 2005). This aspect is best exemplified in Honghu Lake in the Yangtze basin. In 1959-1960, mandarin fish contributed 5% to the total catch, and declined to 0.2% in 1981-1982 (Song et al., 1999). Meanwhile, the rapid decline of piscivorous fish (e.g. mandarin fish) has resulted in the expansion of small fish communities in lakes adopting CBF.

There are thousands of lakes along the middle and lower reaches of the Yangtze River typically with large small sized fish resources (Xie et al., 2000; Xie et al., 2001; Ye et al., 2006; Li et al., 2010) which are natural prey fish for the mandarin fish (Xie et al., 1997; Cui and Li, 2005). Because of its high value, it has become a new species for stocking lakes. This kind of fisheries can be profitable at relatively low yields reduce the pressure of fisheries on the natural habitats (Liu et al., 1998). Studies in North American and European lakes suggested that stocking piscivorous species into lakes may improve water quality through trophic-cascading effects (Carpenter and Kitchell, 1988; Liu et al., 1998). Since the middle of the 1990s, mandarin fish stocking has been widely practised on a large scale in Yangtze lakes and resulting in the production of an increasing amount of high valued food fish and economic opportunities for livelihoods. Li et al. (2014) demonstrated that competition for food between hatchery-reared and wild mandarin fish was insignificant during the critical periods of early stocking stages and that moderate stocking of may not have a negative effect on the variability of wild *Siniperca* populations.

Stocking material

The major populations of mandarin fish are from the Yangtze, Pearl, Min, Qiangtang, Huai, Liao and Amur rivers (Li, 1991). In CBF, the population of mandarin fish from the Yangtze River which is considered to have a preferable growth performance and higher resistance to diseases is stocked in lakes in Yangtze basin. Normally, the overwhelming majority of mandarin fish fry or fingerling used in stocking in lakes are artificially propagated since 1990s.

Size at stocking

The size of stocked mandarin fish ranged from 0.5-1.0 cm (fry) to fingerling of 2.0-10.0 cm or even larger. Overall, the survival rate of fingerlings prevailed over fry, but the latter cost much less. Hence, it's also a trade-off between cost and survival rate in CBF (Table 1).

Stocking model

In order to achieve the maximum yield of mandarin fish in CBF without affecting the natural recruitment of small-sized fish estimation of the productivity of the latter could serve as a basis for guiding the stocking in certain lakes. This includes two aspects: One aspect is to estimate the growth and food demand of mandarin fish in lakes which can be estimated with a bioenergetics model, and the other is to estimate the productivity of food fishes in lakes by studying population dynamics and community ecology of food fishes in lakes (Cui and Li, 2005).

The bioenergetics model of mandarin fish includes a series of sub-models:

- Maximum food consumption sub-model: $\ln C_{max} = -4.880 + 0.597 \ln W + 0.284 T - 0.0048 T^2$, where C_{max} is the maximum food consumption (g/individual/day), W is wet weight (g) and T is water temperature.
- Specific growth rate sub-model: $\ln (SGR + 0.25) = -0.439 - 0.500 \ln W + 0.270 T - 0.046 T^2$, where SGR is the specific growth rate (%/d)
- Standard metabolism sub-model: $\ln R_s = -5.343 + 0.772 \ln W + 1.387 \ln T$, where R_s is the standard metabolism rate mg/ind/fish.
- Faecal production sub-model: $F = -0.161 + 0.077 C$, where F is faecal production (kJ/d) and C is food consumption (kJ/d).
- Excretion sub-model: $U = 0.376 + 0.047 C$, where U is excretion (kJ/d)

- Specific dynamic action sub-model: $SDA = 0.0873C$, where C is specific dynamic action (kJ/d).
- Activity metabolism sub-model: it is estimated from the energy budget equation.
- Energy of sub-model: $EW = (2.077 + 0.367R_p)W^{0.153}$, where $R_p = R_a/R_s = -0.0038 + 1.076R_p^{3.0382}$.
- Based on the macrophyte distribution, calculating food fish biomass.
- Determining the productivity of predominant food fishes in lakes and calculate P/B ratio.
- If 10% of the food fish productivity is consumed by mandarin fish, then the production potential of mandarin fish is: harvest weight \times (0.1 \times food fish productivity)/food consumption by individual mandarin fish.

Using computer programming, we can calculate any parameter in the above mentioned model and sub-models (Liu, 1998). Using the bioenergetics model, it was estimated that 1 g of mandarin fish stocked in June 1st can reach 661 g by the end of next March, consuming 2,133 g food fish (Liu, 1998).

Zhang et al. (2001) estimated the mean biomass, annual production and P/B ratio of small fish populations in Yangtze Lakes by using methods documented by Ricker (1971). Hence, productivity of small fish which could serve as potential prey for mandarin fish, can be estimated based on the monitored mean biomass of small fish in certain lakes.

In conclusion, the steps for calculating the production of mandarin fish in lakes are:

- Based on the monthly water temperature changes in lakes and the stocking time and stocking size, calculate the harvest weight of mandarin fish and the amount of food fish consumed.

Harvesting and marketing

In general, mandarin fish is harvested from October to April in lakes. The gill nets made of polyethylene and hooks are mainly used to capture mandarin fish. Electricity is also used in some areas to harvest mandarin fish.

Conclusion and future trends

Over last three decades, CBF have been practised widely in Chinese lakes, particularly in the Yangtze lakes. CBF have contributed to production of significant amounts of high quality aquatic food types, and also enabled substantial monetary gains and created large number of job opportunities. All of these have contributed to national food security, economic growth and social stability. Although in the course of development of CBF,

Table 1. Annual stocking rate, size of stocked fish and yield of mandarin fish culture-based fisheries in five lakes in the Yangtze basin from 1995 to 1999.

Year	Niushan Lake	Zhangdu Lake	Wu Lake	Taojiada Lake	Caipo Lake
Stocking rate ($\times 10^4$ individuals)					
1995	0	0	0	0	0
1996	60	11	1.6	0.5	1.2
1997	100	15	2.5	0.8	1.1
1998	110	11.5	3.8	0.7	1.3
1999	280	12.8	3.6	0.7	1.5
Size of fish (cm total length)					
1995	-	-	-	-	-
1996	0.5-1.5	3.3-3.5	3.3-3.5	3.3-3.5	3.0-3.5
1997	0.5-1.5	3.4-3.5	3.4-3.5	3.4-3.5	3.3-3.5
1998	0.5-1.5	3.3-3.6	3.3-3.6	3.3-3.6	3.0-3.5
1999	0.5-1.5	3.5-4.0	3.5-4.0	3.5-4.0	3.8-4.0
Yield (kg)					
1995	9,200	-	-	-	-
1996	17,500	27,600	1,500	1,200	1,400
1997	59,800	28,500	5,600	1,100	1,700
1998	59,200	29,400	7,600	1,400	1,600
1999	73,000	28,000	8,200	1,600	1,600

The surface area of the lakes are: Niushan Lake 4,000 ha; Zhangdu Lake 2,670 ha; Wu Lake 1,667 ha; Taojiada Lake 267 ha; Caipo Lake 100 ha. Data of Niushan Lake was cited from Cui and Li (2005), data of Zhangdu Lake, Wu Lake, Taojiada Lake and Caipo Lake were cited from He et al. (2002).

there is an increased concern with regard to intensification of aquaculture practices for varying reasons, some of which may be socio-economic and/or environmental. The situation is further exacerbated because of the increasing competition for primary resources such as land and water. The contribution of CBF in lakes could not be ignored especially in China, such a populous country.

In regard to the trends of CBF in Chinese lakes, three aspects can be expected. Firstly, it is becoming increasingly stricter to use fertilisation, various kind of feed and modification of water bodies (e.g. cut off a small and control water body from the main body by bunds, weirs or nets). Hence, it can be foreseen that the production of CBF in Chinese lakes would decrease, overall. Secondly, a growing number of fisheries communities and/or farmers will incur economic losses if they were for example to culture filter feeding fish (e.g. big head carp and silver carp). However, the gradual shift to using high valued species such as mandarin fish and mitten crab will offset economic losses even though the overall production volume is reduced. Thirdly, direct stocking is not the only answer, while habitat restoration or improvement may offer a more widely applicable means of making more resources available or improving recruitment of fish stocks.

In regard to the harvesting and marketing in CBF, most fish were harvested within a narrow time frame, normally in winter before the Chinese spring festival. This could result in decline of market price of the produce due to glut in the markets in this short period. This effect could, however, be minimised if the harvest is staggered. Such a staggered harvesting will not only have a positive influence on the market price, but will also enable the fish supplies to be maintained (De Silva, 2003).

In China, permanent water bodies are government property and have traditionally been considered a land resource under the jurisdiction of various kinds of state organisations which lease out fishing rights to the highest bidder with the sole objective of generating government revenue. Lease holders have long been among the local rich and influential people who have the political and social power to enforce their control over the resource. The leases are short-term arrangements and the leaseholders therefore try to exploit the resources to the maximum without any concern and or regard of the aquatic environments. Hence, more attention should be paid to legislation on ecological compensation mechanisms to realise payment for environmental resources usage or punishment for environmental resources damage.

References

- Cui, Y. and Li, Z. (eds.), 2005. *Fishery Resources and Conservation of Environment in Lakes of the Changjiang River Basin*, Science Press, Beijing, pp. 300-304, (in Chinese).
- Cassani, J.R., De La Vega, E. L. and Allaire, H., 1995. An assessment of triploid grass carp stocking rates in small warmwater impoundments. *North American Journal of Fisheries Management*, 15(2); 400-407.
- Chen, H., 1989. Impact of aquaculture on the ecosystem the Donghu Lake, Wuhan. *Acta Hydrobiologica Sinica*, 13(4); 359-368, (in Chinese with English abstract).
- Chen, B., Du, N. and Ye, H., 1989. Analysis on the feeding habit of the mitten crab *Eriocheir sinensis*. *Fisheries Science & Technology Information*, 16(1); 2-5, (in Chinese with English abstract).
- Chen, D., Zhang, M. and Shrestha, S., 2007. Compositional characteristics and nutritional quality of Chinese mitten crab (*Eriocheir sinensis*). *Food Chemistry*, 103; 1343-1349.
- Cheng, Y., Wu, X., Yang, X. and Hines, A.H., 2008. Current trends in hatchery techniques and stock enhancement for Chinese mitten crab, *Eriocheir japonica sinensis*. *Reviews in Fisheries Science*. 16; 377-384.
- Cottingham K.L. and Carpenter, S.R., 1998. Population, community, and ecosystem variates as ecological indicators: phytoplankton response to whole-lake enrichment. *Ecological Applications*, 8; 508-530.
- De Silva, S.S., Yu, Z. and Xiang, L., 1991. A brief review of the status and practices of the reservoir fishery in mainland China *Aquaculture and Fisheries Management*, 22; 73-84.
- De Silva, S.S., 2003. Culture-based fisheries: an underutilised opportunity in aquaculture development. *Aquaculture*, 221; 221-234.
- De Silva, S.S., Ingram, B.A, Nguyen, P.T., Bui, T.M., Gooley, G.J. and Turchini, G.M., 2010. Estimation of nitrogen and phosphorus in effluents from the striped catfish farming sector in the Mekong Delta, Vietnam. *Ambio*, 39; 504-514.
- FAO, 2014. *FishStatJ: A Tool for Fishery Statistical Analysis*. (Available: <http://www.fao.org/fishery/statistics/software/fishstatj/en>).
- Gomes, L.C., Miranda, L.E. and Agostinho, A.A., 2002. Fishery yield relative to chlorophyll-a in reservoirs of the Upper Parana River, Brazil. *Fisheries Research*, 55; 335-340.

- Hasan, M.R. and Middendorp, H.A.J., 1998. Optimizing stocking density of carp fingerlings through modelling of the carp yield in relation to average water transparency in enhanced fisheries in semi-closed water bodies in Western Bangladesh. *FAO Fisheries Technical Paper*, 374; 159-168.
- Hu, C., 1995. Ecological characteristics of zooplankton and assessment of its potential fishery production capacity in Baoan Lake. In: Liang, Y., Liu, H. (eds.), *Resources, Environment Fisheries ecology management*. Science Press, Beijing, pp. 120-133 (in Chinese).
- He, Y., Ma, J., Wan, J., Qiu, J. and Pen, G., 2002. Mandarin fish *Siniperca chuatsi* (Basilewsky) enhancement and capture technique in small and medium-sized lakes. *Reservoir Fisheries*, 22 (3); 33-35, (in Chinese).
- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2006. Culture-based fisheries in non-perennial reservoirs of Sri Lanka: influence of reservoir morphometry and stocking density on yield. *Fisheries Management and Ecology*, 13; 157-164.
- Jia, P., Zhang, W. and Liu, Q., 2013. Lake fisheries in China: Challenges and opportunities. *Fisheries Research*, 140; 66-72.
- Jin, G., Li, Z. and Xie, P., 2000. Effects of fishes on the growth and survival of Chinese mitten crab, *Eriocheir sinensis*. *Chinese Journal of Oceanology and Limnology*, 18 (4); 355-359.
- Jin, G., Xie, P. and Li, Z., 2003. Food habits of 2-year-old Chinese mitten crab (*Eriocheir sinensis*) stocked in Lake Bao'an, China. *Journal of Freshwater Ecology*, 18; 369-375.
- Killgore, K.J. and Payne, B.S., 1984. Field methods to measure aquatic plant treatment method efficacy. U.S. Army Corps of Engineers, Waterways Experiment Station, *Miscellaneous Paper A-84-3*, Vicksburg, Mississippi.
- Pushpalatha, K.B.C. and Chandrasoma, J., 2010. Culture-based fisheries in minor perennial reservoirs in Sri Lanka: variability in production, stocked species and yield implications. *Journal of Applied Ichthyology*, 26; 99-104.
- Pípalová, I., 2002. Initial impact of low stocking density of grass carp on aquatic macrophytes. *Aquatic Botany*, 73; 9-18.
- Pan, H., 2002. *Ecological culture of Chinese mitten crab*. China Agriculture Science and Technology Press, Beijing, pp. 221, (in Chinese).
- Li, S., 1991. The geographical distribution of Sinipercinae fishes in China. *Chinese Journal of Zoology*, 28 (4); 40-44 (In Chinese).
- Li, S. and Xu, S., 1995. *Culture and Capture of Fish in Chinese Reservoirs*. International Development Research Centre, and Southbound Sdn. Bhd., pp. 127.
- Li, W., 1998. Utilization of aquatic macrophytes in grass carp farming in Chinese shallow lakes. *Ecological Engineering*, 11; 61-72.
- Li, C., 2010a. China's emerging middle class: beyond economic transformation. In: Kharas, H., Gertz, G. (eds.) *The new global middle class: a cross over from west to east*. Brookings Institute Press, Washington D.C, pp. 14.
- Li, W., Zhang, T., and Li, Z., 2010b. Spatial distribution and abundance of small fishes in Xiaosihai Lake, a shallow lake along the Changjiang (Yangtze) River, China. *Chinese Journal of Oceanology and Limnology*, 28 (3); 470-477.
- Li, W., Zhang, T., Ye, S., Liu, J. and Li, Z., 2013. Feeding habits and predator-prey size relationships of mandarin fish *Siniperca chuatsi* (Basilewsky) in a shallow lake, central China. *Journal of Applied Ichthyology*, 29; 56-63.
- Li, W., Hicks, B.J., Guo, C., Li, Z., Liu, J., Zhang, T., 2014. Does hatchery-reared *Siniperca chuatsi* (Actinopterygii, Perciformes) compete significantly with two wild *Siniperca* populations for diets in a shallow lake? *Hydrobiologia*, 741; 125-138.
- Lorenzen, K., 1995. Population dynamics and management of culture-based fisheries. *Fisheries Management and Ecology*, 2; 61-73.
- Lorenzen, K. and Garaway, C.J., 1997. How predictable is the outcome of stocking? In: Petr, T., (eds.), *Inland fishery enhancements*. *FAO Fisheries Technical Paper*. No. 374. FAO, Rome, Italy.
- Liang, Y., Wu, T. and Xie, Z., 1995. A preliminary investigation of zoobenthos and its potential fishery production, in: Liang, Y., Liu, H. (eds.), *Resources Environment Fisheries Ecology Management*. Science Press, Beijing, pp. 213-217, (in Chinese).
- Liang, X., Liu, J. and Huang, B., 1998. The role of sense organs in the feeding behaviour of Chinese perch. *Journal of Fish Biology*, 52; 1058-1067.
- Liang, X., Oku, H., Ogata, H., Liu, J., He, X., 2001. Weaning Chinese perch *Siniperca chuatsi* (Basilewsky) onto artificial diets based upon its specific sensory modality in feeding. *Aquaculture Research*, 32 (Suppl. 1); 76-82.

- Liu, J., 1990. *Studies on the Ecology of Lake Donghu* (1). China Science and Technology Press, Beijing, China, pp. 390-391.
- Liu, J., Cui, Y. and Liu, J., 1998. Food consumption and growth of two piscivorous fishes, the mandarin fish and the Chinese snakehead. *Journal of Fish Biology*, 53; 1071-1083.
- Liu, J., 1998. *Growth and energy budgets in juvenile mandarin fish Siniperca chuatsi and Chinese snakehead Channa argus: a comparative study* (Doctor's degree dissertation). Graduate School of the Chinese Academy of Sciences, Beijing, China (in Chinese).
- Nguyen, S.H., Bui, A.T., Nguyen, D.Q., Truong, D.Q., Le, L.T., Abery, N.W. and De Silva, S.S., 2005. Culture-based fisheries in small reservoirs in northern Vietnam: effect of stocking density and species combinations. *Aquaculture Research*, 36; 1037-1048.
- Nguyen, S.H., Bui, A.T., Le, L.T., Nguyen, T.T.T. and De Silva, S.S., 2001. The culture-based fisheries in small, farmer-managed reservoirs in two Provinces of northern Vietnam: an evaluation based on three production cycles. *Aquaculture Research*, 32; 975-990.
- Ricker, E.D. (ed.), 1971. *Methods for assessment of fish production in fresh waters*. Oxford: Blackwell Science Publication, pp. 199-214.
- Song, X., Bing, X., Sun, L., Guo, P., Yang, C. and Gu, H., 2010. The spatial and temporal changes of nutrients of net-pen aquaculture area in Yangcheng Lake and its water quality evaluation. *Journal of Hydroecology*, 3 (6); 23-29 (in Chinese with English abstract).
- Song, T., Zhang, G., Chang, J., Miao, Z. and Deng, Z., 1999. Fish diversity in Honghu Lake. *Chinese Journal of Applied Ecology*, 10 (1); 86-90, (in Chinese with English abstract).
- Xie, S., Cui, Y., Zhang, T., Fang, R. and Li, Z., 2000. The spatial pattern of the small fish community in the Biandantang Lake- a small shallow lake along the middle reach of the Yangtze River. China. *Environmental Biology of Fishes*, 57; 179-190.
- Xie, S., Cui, Y. and Li, Z., 2001. Small fish communities in two regions of the Liangzi Lake, China, with or without submersed macrophytes. *Journal of Applied Ichthyology*, 17; 89-92.
- Xie, C., Zhu, B., Yuan, X., Wang, M. and Jin, H., 1997. The biology of mandarin fish *Siniperca chuatsi* with reference to the problem of maximum sustainable yield in Bao'an Lake. *Acta Hydrobiologica Sinica*, 21 (Suppl.); 195-207, (in Chinese with English abstract).
- Vaux, P.D., Paulson L.J., Axler, R.P. and Leavitt, S., 1995. The water quality implications of artificially fertilizing a large desert reservoir for fisheries enhancement. *Water Environment Research*, 67(2); 189-200.
- Vadeboncoeur, Y., Lodge, D.M. and Carpenter, S.R., 2001. Whole-lake fertilization effects on distribution of primary production between benthic and pelagic habitats. *Ecology*, 82(4); 1065-1077.
- Wang, H., Wang, H., Liang, X. and Cui, Y., 2006. Stocking models of Chinese mitten crab (*Eriocheir japonica sinensis*) in Yangtze lakes. *Aquaculture*, 255; 456-465.
- Wang, H., Wang, H., Liang, X., Ni, L., Liu, X. and Cui, Y., 2005. Empirical modelling of submerged macrophytes in Yangtze lakes. *Ecological Modelling*, 188; 483-491.
- Wang, Q., Cheng, L., Liu, J., Li, Z., Xie, S. and De Silva, S.S., 2014. Freshwater aquaculture in PR China: trends and prospects. *Reviews in Aquaculture*, 5; 1-20.
- Welcomme, R.L. and Bartley, D.M., 1998. Current approaches to the enhancement of fisheries. *Fisheries Management Ecology*, 5; 351-382.
- Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Athula, J.A., Pushpalatha, K.B.C. and De Silva, S.S., 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. *Fisheries Management and Ecology*, 12; 249-258.
- Wu, X., Rao, J. and He, B., 1992. The history of the Chinese freshwater fisheries, in: Liu, J., He, B. (eds), *Cultivation of the Chinese Freshwater Fishes*. Science Press, Beijing, China, pp. 5-29.
- Wu, X., Cheng, Y., Sui, L., Yang, X., Nan, T. and Wang, J., 2007. Biochemical composition of pond-reared and lake-stocked Chinese mitten crab *Eriocheir sinensis* (H. Milne-Edwards) broodstock. *Aquaculture Research*, 38; 1459-1467.
- Xu, Q., Wang, H. and Zhang, S., 2003. The impacts of overstocking of mitten crab, *Eriocheir sinensis*, on lacustrine zoobenthic community. *Acta Hydrobiologica Sinica*, 27 (1); 41-46. (in Chinese with English abstract).
- Xiao, C., Dou, W. and Liu, G., 2010. Variation in vegetation and seed banks of freshwater lakes with contrasting intensity of aquaculture along the Yangtze River, China. *Aquatic Botany*, 92; 195-199.
- Yang, P. and Xu, D., 1991. Studies on the technology and its effect of artificial fertilization in medium-sized and shallow lake. *Transactions of Oceanology and Limnology*, 3; 62-72 (in Chinese with English abstract).

Ye, S., Li, Z., Lek-Ang, S., Feng, G., Lek, S. and Cao, W., 2006. Community structure of small fishes in a shallow macrophytic lake (Niushan Lake) along the middle reach of the Yangtze River China. *Aquatic Living Resources*, 19; 349-359.

Zhang, G., Cao, W. and Chen, Y., 1997. Effects of fish stocking on lake ecosystems in China. *Acta Hydrobiologica Sinica*, 21 (3); 271-280, (in Chinese with English abstract).

Zhang, T., Cui, Y., Fang, R., Xie, S. and Li, Z., 2001. Population biology of topmouth gudgeon in the Bao'an Lake V. Production. *Acta Hydrobiologica Sinica*, 25 (4); 331-337, (in Chinese with English abstract).

PART 4.

R&D projects on culture-based fisheries supported by ACIAR over the years and publications that have resulted from these

ACIAR-supported projects on culture-based fisheries and publications arising from them

The Australian Centre for International Agricultural Research (ACIAR) has been in the forefront in supporting R&D on culture-based fisheries (CBF) in Asia. The map (overleaf) summarises the R&D projects in CBF that were supported by ACIAR in each of the countries. As most of the publications that have resulted from these endeavours will come in useful in future developments and strategies in CBF, these are enumerated and the relevant links provided.

Publications in international journals

- Nissanka, C., Amarasinghe, U.S. and De Silva, S.S., 2000. Potential yield predictive models for the Sri Lankan reservoir fishery. *Fisheries Management and Ecology*, 7; 425-436.
- De Silva, S. S., Amarasinghe, U.S., Nissanka, C., Wijesooriya, W.A.D.D. and Fernando M. J. J., 2001. Use of geographical information systems as a tool for fish yield prediction in tropical reservoirs: case study on Sri Lankan reservoirs. *Fisheries Management and Ecology* 8; 47- 60.
- Nguyen, Son H., Bui, Anh T., Le, L.T., Nguyen, Thuy T.T. and De Silva, S.S., 2001. Aspects of the culture-based fisheries in small, farmer-managed reservoirs, based on three production cycles, in two provinces of northern Vietnam. *Aquaculture Research*, 32; 975- 990.
- Amarasinghe, U. S., De Silva, S. S. and Nissanka, C., 2002. Evaluation of the robustness of predictive yield models based on catchment characteristics using GIS for reservoir fisheries in Sri Lanka. *Fisheries Management and Ecology* 9; 293- 302.
- De Silva, S. S., 2003. Culture-based fisheries: an underutilized opportunity in aquaculture. *Aquaculture*, 221; 221-243.
- Jayasinghe, U.A.D, Amarasinghe, U.S. and De Silva, S.S., 2005. Trophic classification of non-perennial reservoirs utilized for the development of culture-based fisheries, Sri Lanka. *International Reviews of Hydrobiology*, 90; 209-222.
- Jayasinghe, U.A.D, Amarasinghe, U.S. and De Silva, S.S., 2005. Limnology and culture-based fisheries in non-perennial reservoirs of Sri Lanka. *Lakes and Reservoirs: Research and Development*, 10; 157-166.
- Nguyen, H. S., Bui , A. T., Nguyen, D. Q., Truong, D. Q., Le, L. T., Abery, N.W. and De Silva, S.S., 2005. Culture-based fisheries in small reservoirs in northern Vietnam: effect of stocking density and species combinations. *Aquaculture Research*, 36; 1037-1048.
- Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Athula, J.A., Pushpalatha, K.B.C. and De Silva, S.S., 2005. Culture-based fisheries in non-perennial reservoirs in Sri Lanka: production and relative performance of stocked species. *Fisheries Management and Ecology*, 12; 249-258.
- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2006. Culture-based fisheries in non-perennial reservoirs of Sri Lanka; Influence of reservoir morphometry and stocking density on yield. *Fisheries Management and Ecology*, 13; 157-164.
- Wijeynayake, W.M.H.K., Amarasinghe, U.S. and De Silva, S.S., 2007. Performance of GIFT strain of *Oreochromis niloticus* in culture-based fisheries in non-perennial reservoirs, Sri Lanka. *Sri Lanka Journal of Aquatic Science*, 12; 1-18.
- De Silva, S.S., Nguyen, Thuy T.T., Turchini, G.M., Amarasinghe, U.S. and Abery, N.W., 2009. Alien species in aquaculture and biodiversity: a paradox in food production. *Ambio*, 38; 24-28.
- Kularatne, M. G., Amarasinghe, U.S., Wattage, P. and De Silva, S.S., 2009. Evaluation of community participation for the Development of culture-based fisheries in village Reservoirs of Sri Lanka. *Aquaculture Economics & Management*, 13; 22-38.
- Nguyen, T. T. T., 2011. Permanent genetic resources added to molecular ecology resources database 1 August 2010 - 30 September 2010. *Molecular Ecology Resources* 11; 219-222.
- Nguyen, T. T. T. and Sunnucks, P. (2012). Strong population genetic structure and its management implications in the mud carp, an indigenous freshwater species subject to aquaculture and culture-based fishery. *Journal of Fish Biology*, 80; 651-668.
- Phomsouvanh, A., Saphakdy, B. and De Silva Sena S., 2015. Production trends, monetary returns and benefit sharing protocols from the extensive aquaculture practice of culture-based fisheries in rural communities in Lao PDR. *Aquaculture*, 439; 29-38.

Conference/workshop proceedings

Gooley, G.J., De Silva S. S., Ingram, B.A., McKinnon, L.J., Gavine, F.M. and Dalton, W. 2001. Cage-culture of finfish in Australian lakes and reservoirs: a pilot scale case study of biological, environmental and economic viability. In: *Reservoir and Culture-based Fisheries: Biology and Management* (Ed. Sena S De Silva), pp. 328-346. Australian Center for International agricultural Research, Canberra, Australia.

Nissanka, C., Amarasinghe, U. S. and De Silva, S. S., 2001. Fluctuations in water level in shallow irrigation reservoirs: implications for fish yield estimates and fisheries management. In: *Reservoir and Culture-based Fisheries: Biology and Management* (Ed. Sena S De Silva), pp. 101- 109. Australian Center for International Agricultural Research, Canberra, Australia.

De Silva, S. S., Wijenayake, W.M.H.K., Gunarathe, A.B.A.K. and Amarasinghe, U.S., 2004. Use of GIS tools to develop a scale for the selection of non-perennial reservoirs for culture-based fisheries activities. In: *GIS Spatial Analysis in Fishery and Aquatic Sciences* (ed. by T. Nishida, P.J. Kailola, C.E. Hollingworth), pp. 559-571. Fishery and aquatic GIS Research Group, Saitama, Japan.

Amarasinghe, U.S., De Silva, S. S. and Nissanka, C., 2004. Fish yield prediction based on catchment features, quantified using geographical information systems, in lowland reservoirs of Sri Lanka. In: *GIS Spatial Analysis in Fishery and Aquatic Sciences* (ed. by T. Nishida, P.J. Kailola, C.E. Hollingworth), pp. 499-514. Fishery and aquatic GIS Research Group, Saitama, Japan.

Semi-technical publications

Ingram, B. A. and Lasasimma, O., 2008. Production of *Cirrhinus molitorella* and *Labeo chrysophekadion* for culture based fisheries development in Lao PDR Part I: Captive spawning. *Aquaculture Asia Magazine*, 13; pp. 21-25.

Lasasimma, O. and Ingram, B. A., 2008. Production of *Cirrhinus molitorella* and *Labeo chrysophekadion* for culture based fisheries development in Lao PDR 2: Nursery culture and grow-out. *Aquaculture Asia Magazine*, 13; pp. 23-29.

Jayasinghe, A. and Amarasinghe, U., 2007. Buffaloes in favour of culture based fisheries in Sri Lanka. *Aquaculture Asia Magazine* 12 (3); pp. 2-8.

Saphakdy, B., Phomsouvanh, A. Davy, B., Nguyen, T.T.T. and De Silva, S.S., 2009. Contrasting community management and revenue sharing practices of culture-based fisheries in Lao PDR. *Aquaculture Asia Magazine*, 14 (3); 2-6.

Anonymous, 2013. Culture based fisheries development in Lao PDR and Cambodia proceeding well. *NACA Newsletter XVIII*, No.4, October.- December. 2013.

Limsong Srun, Hort, Sary Ou, Vutha Ouch, Mohan, C.V. and De Silva Sena S., 2013. Introduction of culture based fishery practices in small water bodies in Cambodia: issues and strategies. *Aquaculture Asia Magazine*, 18 (4); 12-17.

Manuals

De Silva, S.S., 2001. *Reservoir and Culture-Based Fisheries: Biology and Management*. ACIAR Proceedings 98, ACIAR, Canberra, 384 pp.

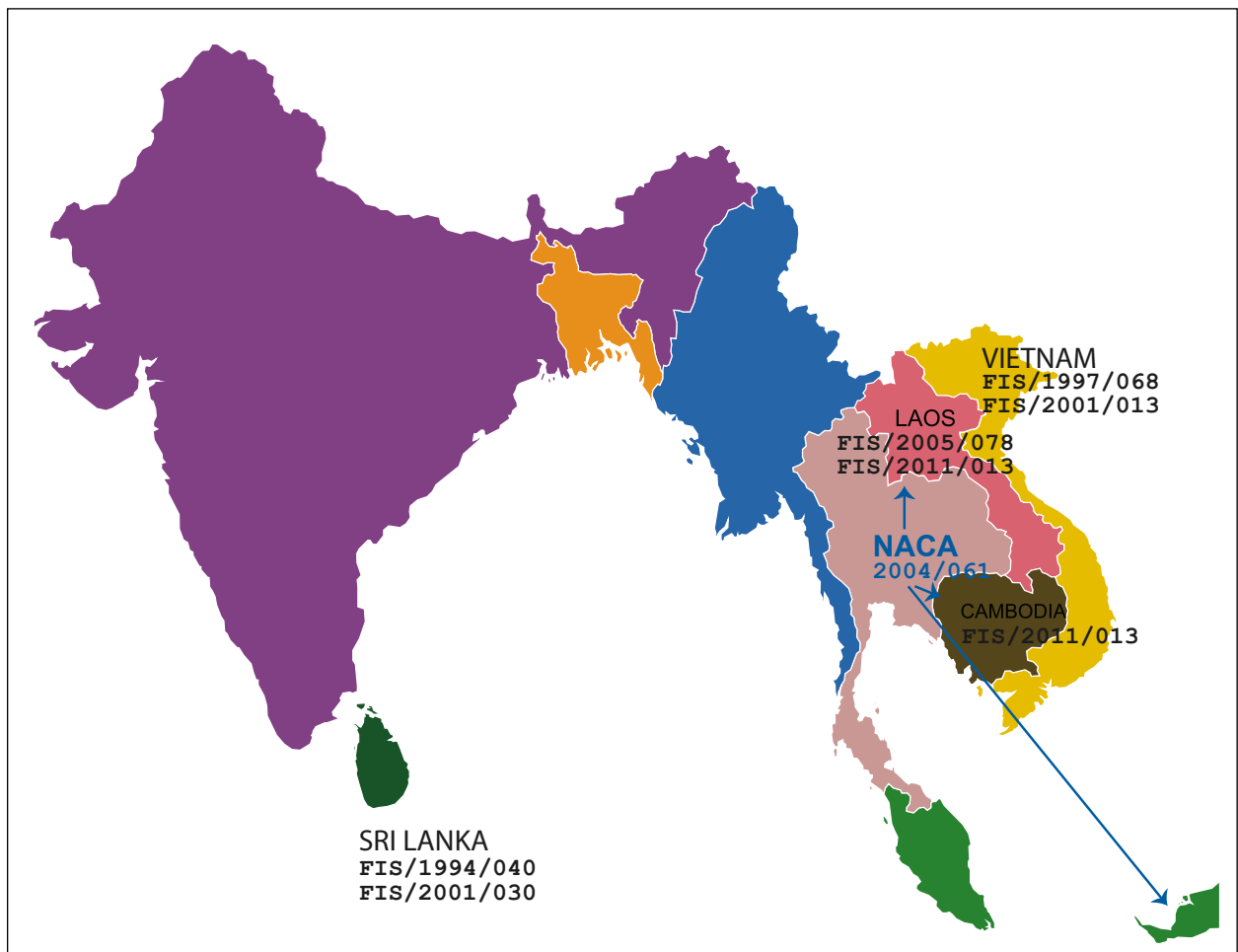
De Silva, S.S., Amarasinghe, U.S. and Nguyen, T.T.T. (Eds), 2006. *Better-practice approaches to culture-based fisheries development in Asia*. ACIAR Monograph 120, 96 pages (translated into Laotian, Sinhalese, Tamil and Vietnamese).

De Silva, S.S., 2012. *Use of 'Catchment Land Use Pattern Data', based on GIS analysis, to determine the potential stocking densities for the reservoirs in Cambodia*. Unpublished.

De Silva, S.S., 2012. *Better Management Practices for Culture-Based Fisheries*, Lao PDR. 46 pp. <http://enaca.org/publications/inland-aquaculture/better-management-practices-culture-based-fisheries-lao.pdf>.

Chanthavong, K., Nanthalath, T., Ingram, B.A. and De Silva, S.S., 2013. Guidelines for hatchery production of Pa Phia (*Labeo chrysophekadion*) fingerlings in Lao PDR (translated into Laotian by Vannaphar Tammajedy. <http://enaca.org/publications/inland-aquaculture/guidelines-hatchery-production-labeo-chrysophekadion.pdf>.

Distribution of ACIAR R&D projects on culture-based fisheries.



PART 5.

Other abstracts from the regional consultation

Objectives and aspirations of the project FIS/2011/013

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CBF is in general a community-based activity with low impacts on natural environment and ecosystem, low cost and next to zero nutrient input that contributes to sustainable intensification of food production in existing water bodies. The project: Culture-based Fisheries Development in Lao PDR and Cambodia (FIS/2011/013) was built upon previous ACIAR funded projects in Sri Lanka and Vietnam (FIS/2001/020 and FIS/2001/013 respectively) in order to optimise benefits from CBF in rural Laos and Cambodia with different geographical areas, watersheds and community organisations. This has been done through research on some selected aspects of CBF to develop better management practices, generation and streamlining of information exchange and development of marketing strategies. The overall objective of Lao component was to further consolidate the benefits gained from adoption of culture-based practices through organising community groups and ensuring the application of broodstock management plans for indigenous species, while the Cambodian component was to introduce culture-based fisheries through community management in selected water bodies in four provinces.

In Lao PDR, a suit of BMPs was developed. Three-way (farmer to farmer, resource centre and market) communication set-ups were tested and lessons learned in facilitation of knowledge and information exchange in farming communities; and a comprehensive protocol for seed production and broodstock management was developed for selected indigenous species. In Cambodia, suitability of water bodies for CBF development was investigated, suitable combinations of species and

stocking density were tested and dissemination packages on CBF was developed for furthering CBF in Cambodia. Capacity building among researchers, government officers and farmers in optimising and adopting BMPs of CBF was a major output of both project components in two countries.

CBF is undoubtedly a significant development strategy for increasing food fish production and improving rural community wellbeing by most countries in Asia and also globally to increase inland fish production. In the wake of limitation for increase of inland capture fisheries and the population increase the need to utilise inland water resources to improve more effectively food fish availability to the rural masses has become a major governmental interest and a development priority in some developing countries. NACA will continue to seek collaboration with donors and partners to extend BMPs of CBF to NACA member countries with wider geographic coverage to benefit rural communities. This will be done through: (1) formulated research to better understand hydrological and ecological process of water bodies under CBF and bionomics of CBF in order to further optimise CBF practices, (2) adaptive research and extension to establish best suitable BMPs in context of specific geographic conditions and resource settings, (3) development and application of integrated approaches to manage local resources in water-shed/catchment areas in relation to CBF and climate change, (4) capacity building for rural communities in participatory based community management, and (5) facilitation of gender integration in CBF.

Application of a multiple-criteria decision making approach for selecting suitable non-perennial reservoirs for culture-based fisheries development in Sri Lanka

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In Sri Lanka, there are about 12,000 small village reservoirs with the cumulative extent of over 39,000 ha. They are essentially irrigation reservoirs and are not traditionally used for inland fisheries production. However, there is a great potential for utilisation of these small village reservoirs for the development of culture-based fisheries (CBF). However, due to multiple uses of these water bodies, seasonal water availability, variable biological productivity and fingerling availability for stocking etc., multiple-criteria decision making (MCDM) approaches are useful for selection of suitable village reservoirs for CBF development. The MCDM approach employed in the present analysis was analytic hierarchical process (AHP). In the analysis, 3 main criteria (reservoir productivity, catchment characteristics and socio-economic factors) which influence CBF yield in 23 non-perennial reservoirs were considered. There were 2 sub-criteria under biological productivity, 5 sub-criteria under catchment characteristics and 3 sub-criteria under socio-economic factors. As most of the sub-criteria in

the analysis are essentially spatial data, it was possible to quantify the influence of each of the sub-criteria on CBF yield using geographical information systems (GIS) and remote sensing (RS) techniques, which could subsequently be assigned weighted values. Here, LANDSAT TM (24x24 m resolution) images were used to determine the reservoir area and aquatic plant cover of reservoirs. Catchment areas and their land-uses were demarcated from land-use maps of 1: 50,000 scale using the Arc GIS 9.2 software and geo-referenced map sheets were subjected to on-screen digitising. Based on the total scores obtained from the weighted linear combinations of the AHP for various sub-categories, the reservoirs were categorised in to four levels as excellent, good, fair and poor. As there was a positive significant relationship between the total AHP score and CBF yield, it was concluded that use of AHP based weighted linear combination would be a feasible approach for selection of village reservoirs for CBF development.

Broodstock management and breeding in relation to culture-based fisheries

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The aim of broodstock management and breeding plans for hatcheries supplying fish for culture-based fisheries (CBF) is to consistently provide good quality (fit and healthy) juveniles suitable for stocking. The quality of juveniles produced by hatcheries depends on a number of factors across the different production stages, from broodstock procurement to harvesting nursery ponds, and encompass factors related to the nutrition, health and genetics of stock, and good husbandry practices. The most important of these relate to broodstock management.

Poorly planned genetic management of broodstock and breeding can result in declines in the quality of stock over a number generations leading to, for example, reduced fecundity, hatch rates and growth rates, and an increase in the incidence of abnormalities and susceptibility to diseases. A major criticism of hatchery-bred fish relates to the perceived genetically inferior quality of released fish, which can interact with wild stocks leading to a shift or loss of genetic diversity and reduction in of genetic fitness. Therefore, managing genetics aspects is critical to ensuring the long term integrity and viability of a breeding program, and has important implications to the genetic integrity of receiving populations.

Genetically sound management plans will vary according to the design of the breeding program ('closed' versus 'open' breeding systems) and requires a good understanding of the genetic structure of the species being bred. Above all, broodstock management plans should

aim to prevent loss of genetic diversity and minimise inbreeding within the population. This can be achieved in each season by spawning an equal number of female and male fish (1:1 sex ratio); undertaking many spawnings; undertaking single-pair (one female and one male) matings only; retaining equal numbers of progeny from each spawning (family) as potential future broodstock; randomising broodstock choice for spawning to avoid trait selection; replacing at least 10% of the broodstock each year; and maintaining detailed and accurate breeding records.

Other relevant factors for broodstock include the source, number, size (age) appearance and health of broodstock. It is important to manage broodstock nutrition and pre-spawning conditioning, spawning and the immediate post-hatch stages (egg incubation, larviculture and post-larval husbandry). Broodstock nutrition and husbandry practices can affect gamete quality which in turn affects seedstock quality. A fish health and biosecurity plan is required to manage the health of not only broodstock, also larval and juvenile fish, which will eventually be released. Apart from diseases and parasites, this plan should also aim to manage unwanted aquatic species entering the hatchery and being released with stocked fish.

These factors determine whether the seedstock produced from hatcheries survive and grow in the waters stocked and, ultimately, their contribution to CBF.

Cambodian attempts to develop culture-based fisheries

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Cambodian people are among the highest fish eaters in the world, perhaps reflection of the relative availability, particularly of freshwater fish and other aquatic animals, at an affordable price. Fish is the most important source of animal protein for human consumption in Cambodia. On average it makes up more than 75% of animal protein and in some areas of the country aquatic resources make up 80% of the available animal protein. According to Ahmed et al. (1998) on average aquatic organisms make up more than 80% of the animal protein consumed in the country and, 90% in fishing dependent provinces such as Siem Reap. Overall, fish consumption is estimated to be around 63 kg/person/year (FiA, 2013) (whole fish equivalent) and is many times greater than the global average, reflecting the importance of the fisheries sector to the diet and culture of Cambodian people.

The application of culture-based fisheries in Cambodian waters commenced with the initiation of a project under the auspices of the Australian Centre for International Agricultural Research (ACIAR Project FIS/2011/013), coordinated by NACA. For the initial trial 16 small reservoirs located in four provinces were selected. These reservoirs differed from each other in surface area, mean depth and the catchment land use features, the latter evaluated using GIS software. In choosing the reservoirs initial consultations with the village communities responsible for the water regime management were held and their agreement obtained for monitoring and cooperating through the trial period. One common feature in all the reservoirs selected, and for that matter in all water

bodies in Cambodia, is the provision of a “conservation zone”, generally in the deeper areas of the water body, where fishing is prohibited.

Culture-based fisheries are a form of aquaculture that utilise small water bodies, both perennial and non-perennial, which cannot support a fishery through natural recruitment processes, for food fish production through a stock-recapture strategy. Culture-based fisheries are environmentally friendly as the only external input is seed stock. It also engages a co-management approach utilising the downstream farming communities in most instances already organised into functional entities for dry land agriculture as the principal beneficiaries (De Silva 2003). Culture-based fisheries are an attractive development strategy as it mobilises dry land farming communities (e.g. rice farmers) to use existing water bodies for the secondary purpose of food fish production. The strategies to optimise benefits from culture-based fisheries, however, vary in detail from country to country and across climatic regimes.

Culture-based fisheries activities were conducted over two growth cycles and in all instances the fish production increased above the levels that were obtained prior to the implementation of culture-based fisheries. In this presentation the stocking strategies and the yields obtained are presented. It is believed, however, the yields could be further enhanced by utilisation of the conservation as nursery areas which will be dealt with in a separate presentation.

Culture-based fisheries in northern Vietnam: Status and perspective

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In Vietnam, it is estimated to have about 6,000 reservoirs, of which more than 3500 are small reservoirs. Northern Vietnam has large numbers of such water bodies that are considered to be suitable for development of culture-based fisheries. Fishery activities have been ongoing, on a relatively small scale, in these water bodies for about 8-10 years. Furthermore, these are commonly referred to as farmer-managed reservoirs as these are leased to individuals or groups of individuals for fishery activities and water management by the provincial authorities.

Overall, the culture-based fisheries in northern region of Vietnam were profitable. This activity was a subsidiary income generator to the households, which is a significant contributor to rural well-being in the mountainous region of North Vietnam, where the total average household income is considerably less than in the rest of the country. It is seen that culture-based fisheries is a strategy that is relatively easily adoptable for increasing the fish food supply and generating supplementary income in rural Vietnam.

Lower Mekong basin regional perspectives on fish stock enhancement and culture-based fisheries

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MRC Fisheries Programme.

This paper presents an overall view of issues concerning fish stock enhancement and culture-based fisheries in the lower Mekong basin (LMB). The aim is to contextualise culture-based fisheries within the broader approach of fish stock enhancement which is gaining momentum in the LMB hosting one of the most productive freshwater capture fisheries in the world. Increased water development activities are putting stress on natural water bodies and fish habitats, thus impacting on natural fisheries productivity, or creating new types of water bodies such as irrigation canals and reservoirs with potentials for introducing new fisheries activities.

Fish stock enhancement, particularly seed releasing programs have been considered and carried out by the MRC Member Countries as the major measure to enhance the inland fisheries resources for decades. However, due to the knowledge gaps and weak institutional and human capacities, the enhancement practices conducted by the national institutions are far from science based and without proper pre-assessment, adequate design, good planning and execution and post evaluation. As a result, despite significant resource

inputs, the actual output of stock enhancement activities and the potential impacts on natural population have been basically unknown. Considering the interconnectivity of the regions fisheries, management measures such as culture-based fish release activities implemented in one country may potentially impact, either positively or negatively, the fisheries in the other countries of the region. Differences in fish (re-)stocking practices among riparian countries using indigenous or exotic species call for a commonly shared understanding and framework or code of practice for fish (re-)stocking.

Recognising this issue, the MRC Fisheries Programme has been exploring with its Member Countries recommended actions needed for promoting good practices of fish stock enhancement in the LMB. Hence, the paper outlines commonly agreed stepwise procedures that will be instrumental to guide the formulation of regionally meaningful stock enhancement policies, strengthen the institutional capacity of national partner line agencies, and supports the design and implementation of well targeted capacity building measures.

Community communication centres: Applications, establishment and constraints

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Network of Aquaculture Centres in Asia-Pacific.

A network of community-based communications centres were established in Lao PDR and maintained by DoLF staff to facilitate government extension services and sharing of experience between community groups participating in culture-based fisheries activities (CBF).

The network primarily operated via regular (fortnightly) face-to-face meetings at district or provincial extension offices, attended by representatives from surrounding communities. These offices and their staff served as focal points for front-line extension and also as relay points for technical queries requiring specialist input from head office or elsewhere. Initial plans to conduct face-to-face networking via Skype and similar voice-over-IP applications over 3G mobile networks were unsuccessful due to restricted 3G coverage, poor bandwidth and high signal

latency in rural areas, although some discussions and information sharing was successfully conducted using low-bandwidth applications such as Facebook and instant messaging.

DoLF staff maintained logbooks of questions and advice regarding CBF sought by participating communities. The main subjects of interest concerned procurement of quality seed, nursing of fingerlings, management of the water body and health/disease issues. We believe there is also scope to utilise the communication centres to coordinate harvesting time and marketing by nearby communities but this aspect has yet to be explored.

Culture-based fisheries in Cambodia

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MRC Fisheries Programme.

Cambodia's inland fisheries resources play a very important role in contribution to national economic, food and nutritional security. Fisheries now are under threats from inside and outside of the sector. Fisheries Administration with assistance from regional organisation try to promote an enhancement of existing small areas of water bodies such as the culture-based fisheries (CBF) development including the development of community fish refuges (CFRs) pond, both are new practices in Cambodia.

The CFRs pond is a form of natural stock enhancement or a culture-based in the rice field and can promote rice field fisheries production in wet season by a community management based approach. The site selection, the pathway connection, fish species-composition-timing stocked and management mechanism are key success of the activities. The stocking density of indigenous species varies at every site from 750-10,000 seed/ha, or 20-320 kg/ha of brood fishes will enhanced the rice field fish production that the local household can catch fish at around 348kg/ha/year, nearly 6 times more than normal catch (60kg/ha/year). Around 800 of pond site can be promoted as the CFRs pond development in Cambodia. The CBF are not the new concept but a new practice as

well as the CFRs pond, are the stocking of fish in existing small water bodies (reservoirs) in a form of enhancement for sustaining the fisheries. CBF normally is depend on species and composition stocked, size of seed and timing of releasing, active community and local authority involvement, management structure, common plan, agreement such as prohibited from fishing, sanctuary zones establishment are key success of the CBF.

The application of CBF by Fisheries Administration supported by NACA implemented in 16 reservoirs in 4 provinces in 2012 with the total stock of 1,518,000 fishes seed species and prawn, after 6 months period, when the study ended, the total fish production in the reservoirs has increased considerably. The best results in CBF are obtained when : (1) The natural productivity of the reservoirs are relatively high, (2) The predatory aquatic organisms are eliminated and or minimised, (3) Suitable species and composition is utilised at stocking (4) Seed stock is a good quality and of appropriate size, (5) The water level recedes at a suitable rate, (6) Poaching is curtailed, (7) Fish sanctuaries are established in all project areas and (7) Fishing does not take place for a five or six months period.

Review of current status of fish stock enhancement practice in Lao PDR

Sinthavong Viravong

MRC Fisheries Programme.

Fish resources from inland waters are privileged playing important role in providing food for people of Lao also income for rural people. Most fish supply has from different source water bodies such: Mekong River, tributaries, streams, manmade reservoirs (hydropower and irrigation reservoirs), natural ponds, swamps, rice fields and manmade ponds. Until recently, capture fishery production remaining predominated in rural area where people rely on fish catch resources from the

wild. The fish catch estimated from wild was about 62 percent of the country total fish production (sources DLF 2007). In parallel with growing the country population, fish marketing had led to increase fish demand. Stock enhancement in Lao PDR has been done since many decades aiming to increase inland fisheries production in the natural water. Stock enhancement process is usually done at the national fish releasing day that mentioned in the Lao Fisheries Law.

Current status of fish stock enhancement in Thailand

Suchart Ingthamjitr and Boonsong Sricharoendham

MRC Fisheries Programme.

Thai people have long been exploiting fish as cheap protein food. Fish is harvested from natural waters which is classified as; rivers and canals, swamps and lakes, large reservoirs, and small water bodies. Country development coupled with rapid population increase resulted habitats alteration and depletion of fisheries resources. Aquaculture development can produce food fish to support the increase demand to some extent. Wild capture fisheries, however, still maintain its crucial function in producing food fish to support particularly those rural poor.

Fisheries stock enhancement in Thailand is generally achieved through combined strategies; law enforcement, habitat rehabilitation and fish stocking. The latter is the most popular approach widely used for stock enhancement. Aquatic animal stocking in general has two main objectives; conservation and production enhancement. Stocking is implemented by number of agencies such as Department of Fisheries (DoF), Tambon (Local) Administration Organization, provincial agencies, Electricity Generating Authority of Thailand (EGAT) and other private sector and government agencies.

DoF is the fisheries competent authority, responsible for fisheries production enhancement, adequately supply the local consumption demand and export for income earning. Fisheries Act B.E. 2490 (1947) is the important tool use to manage sustainable fisheries production. Alongside with law enforcement, aquatic animal stocking is implemented under stock enhancement projects; 1) Village Fisheries Project, 2) School Fisheries Project, 3) Bamrung Phan Pla Pracha-arsa Project (Participatory Voluntary Fish Stock Enhancement Project), 4) Small Water Bodies Rehabilitation for Fisheries Project, 5) Large Water Bodies Fisheries Development Project, and 6) Seed Production for Stocking.

Stocking has been more intensified when fisheries stations capable in producing more fish seed. The annual stocking of DoF is more than billions fingerlings for years. In 2013, the total stocking number was 1,333 million fingerlings of 59 aquatic animal species. Out of the total 59 stocking species, 53 species are freshwater fish, 6 species of frog, turtle and freshwater giant prawn. The DoF has followed up and assessed the impact of stocking programs since 1985. Positive impact was apparently found with freshwater giant prawn stocking. Recapture rate of the species is found at 3% with more than 6 folds rate of investment return. Recapture rate of those stocked fish ranges 5-10% with total production of 20,000 tonnes and valued about 30 million USD.

Stock enhancement can be achieved through number of approaches depend on conditions of each particular water. Law enforcement on illegal fishing is an important lesson learnt at the Yom river basin, stock large number of freshwater giant prawn is successful at Pak Mun reservoir while community fisheries base management is effective at Ubol Ratana reservoir. These are important stock enhancement lessons learnt of Thailand. Co-management by local communities is increasing its role in fisheries management in recent years.

Fisheries production particularly inland capture production varies depending on many challenges including habitat alteration, overfishing, genetic alteration, outdated fisheries act and climate change. Alteration of inland capture production will definitely adversely impact on livelihood of those rural poor who entirely rely on the resource. Stock enhancement by various approaches will be effective only when all challenges concern are taken into account and properly managed.

Review of current status of fish stock enhancement in Viet Nam

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As of 2008, there were about 1,055 reservoirs of total area about 332,190 ha with potential for aquaculture in Vietnam. After impoundment, most reservoirs in Vietnam were stocked with fingerlings but only a few have had a good recovery. The return rate of stocking was from 2-10% of total stocked fingerlings. Nowadays, aquaculture is implemented more than 40% of the total reservoir area, mainly in small and median sizes of 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, the fisheries reservoir management systems in Vietnam fall under three main types: state controlled management, community management, and privately owned reservoirs. The major gear used includes gill-nets, lift-nets, lighted lift-nets, integrated nets, cast-nets, long-lines, and seines. Reported yields from reservoir range from 20 – 700 kg/ha/year.

In Vietnam, “The national plan for reservoir fisheries towards 2020” was approved last year, included the stock enhancement strategy for reservoirs. However, the official guideline for stock enhancement has not been published yet. Some policies for reservoir fisheries have been applied but the results have been less than expected. In recent years, the central government has not invested much in reservoir fisheries, so it tends to be underdeveloped. However, some particular reservoirs have had successful stock enhancement, including Ajun Ha (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). The lessons learned from these reservoirs are presented in this report.

Farmer managed systems in Thailand - is this CBF?

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The answer to the question of whether culture-based fisheries (CBF) are farmer-managed aquatic systems (FAMS) in Thailand or elsewhere is dependent upon way of aquaculture and fisheries systems classification.

Aquaculture is defined as the cultivation of aquatic organisms in fresh, brackish and marine waters. The principles of cultivation of aquatic plants are similar to agricultural crop production and culture of aquatic animals is somewhat similar to that of animal husbandry. Aquaculture differs from the fisheries on the degree of human intervention. While aquaculture industry is production oriented and the fisheries are “hunting” oriented. Hence, aquaculture has control over the production process and fisheries have control over capturing process.

The degree of human intervention and control in aquaculture is governed by the production intensity. The extensive aquaculture systems, which are entirely

dependent on the natural feed supply, have a minimal human control and similar to stock enhancement processes of inland fisheries. In aquaculture, humans mostly, with a few exceptions, control reproductive processes, stocking sizes and densities, water and feed use and harvesting strategies that match market demand.

The concept of FAMS captures the diversity of aquatic resource systems at the interface of aquaculture and wild capture fisheries. In aquaculture, aquatic animals are reared usually, not necessarily, in private ownership. FAMS include aquatic systems such as rice field and farmer-owned (or rented) farmer-managed pond systems.

In CBF, the harvesting of stocked fish held in a water body of common or community ownership. If this activity is considered as extensive aquaculture, CBF can be considered as a part of FAMS, not vice versa.

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