PAPER 2: Alternative strategies for enhancement of fish stocks

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

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1 INTRODUCTION

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

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

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

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

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

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

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

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

1.1 What is stocking and what is its purpose?

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

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

[1] Hasan and Taklukder (2004)

1.1.1 Occasional stocking of fish to restore or develop a fishery

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

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

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

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

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

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

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

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

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

1.2 Does stocking necessarily mean more fish production?

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

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

[2] Mustafa and Brooks (2009)

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

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

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

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

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

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

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

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

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

1.4 Stocking to supplement existing wild stocks to increase productivity

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.5 Stocking of waterbodies that are recruitment-limited

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

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

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

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

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

2 POTENTIAL ENVIRONMENTAL IMPACTS OF STOCKING

2.1 Effects of stocking on wild, native fish stocks

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

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

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

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

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

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

2.2 Conflicts between fisheries for stocked fish and wild fish

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

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

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

[10] Mustafa and Mamun (2005)

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

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

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

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

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

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

3 USE OF ENVIRONMENTAL INTERVENTIONS TO ACHIEVE MANAGEMENT OBJECTIVES

3.1 The four main purposes of environmental interventions

Environmental interventions are implemented to achieve four principle objectives:

- Protection
- Restoration/rehabilitation
- Mitigation
- Intensification.

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

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

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

[11] Mamun and Haque (2008)

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

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

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

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

3.2 Maintaining the habitat and hydrological function of rivers and floodplains

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

Rivers comprise two main components:

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

[12] FAO-NACA (2003)

3.3 River channels

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

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

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

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

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

3.3.1 Restoring or improving connectivity in main channels of rivers

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

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

3.3.2 Maintaining water flows and quantity in rivers

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

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

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

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

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

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

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

3.4 Floodplains

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

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

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

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

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

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

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

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

3.4.1 Connectivity in floodplains

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

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

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

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

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

3.5 Rice fields

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

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

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

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

3.6 Improving habitats and water management of man-made waterbodies

3.6.1 Small natural lakes, artificial waterbodies

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

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

3.6.2 Large reservoirs

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

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

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

3.6.3 Enhancing the suitability of reservoirs

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

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

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

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

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

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

3.6.4 Discharge control and conservation of water in dams

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

3.6.5 Discharge controls

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

4 CONCLUSIONS

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

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

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