PART 2

SPECIES PAPERS

Capture-based aquaculture of Pangasiid catfishes and snakeheads in the Mekong River Basin

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Poulsen, A.; Griffiths, D.; Nam, S.; Nguyen, T.T. 2008. Capture-based aquaculture of Pangasiid catfishes and snakeheads in the Mekong River Basin. In A. Lovatelli and P.F. Holthus (eds). Capture-based aquaculture. Global overview. *FAO Fisheries Technical Paper*. No. 508. Rome, FAO. pp. 69–91.

INTRODUCTION

The Mekong River Basin is probably the largest and most important inland fisheries in the world (Figure 1). The annual yield from capture fisheries in the lower Mekong basin (encompassing the Lao People's Democratic Republic, Thailand, Cambodia and Viet Nam) is estimated at between 2.5 to 3 million tonnes, accounting for 2 percent of the total annual global fisheries yield including both marine and inland fisheries. This in turn represents a direct monetary value of approximately US$2 000 million annually (Barlow, 2006). The main foundations for this important fishery are:

- the extreme fish diversity of the Mekong (second only to the Amazon River);
- the ecological functioning of the riverine ecosystem, including large areas of extremely productive floodplain habitats, and conservation of connectivity between habitats; and
- a population of 80 million people living within the Mekong basin, a large proportion of which participate in fisheries activities directly or indirectly.

FIGURE 1
The Mekong River Basin

An important feature of Mekong fisheries are their extreme seasonality. The bulk of the catch is taken during the flood season from August to December, when the water level rises and large inundated floodplains are formed in the lower sections of the basin, particularly in Cambodia and Viet Nam. This seasonal cycle means that there is a large surplus of fish during the monsoon season, whereas in the dry season, yields are comparatively low.

Local people and communities have adapted to the seasonal fluctuations in fish supply. They have for instance developed many ways to process and preserve catches during the monsoon, so that the surplus can be kept and used during the "lean" season.

Aquaculture also originally developed as a way to convert the large bulk of low-value yields from the monsoon season into high-value products that can be harvested, marketed and/or consumed at other times of the year. Throughout the basin, specialised "juvenile" fisheries have emerged, capturing various juvenile stages of high-value species during the monsoon season for later grow-out in ponds and cages.

Traditionally, aquaculture enterprises in the Mekong Basin were capture-based. Only with the introduction of exotic aquaculture species during the second half of the twentieth century did the more conventional aquaculture operations, based on hatchery inputs, take over. As research capacities developed within the region, hatchery techniques for indigenous species such as Pangasiid catfishes were eventually developed, setting the scene for the further development of the aquaculture industry into what are now large-scale, export-oriented enterprises.

Although capture-based aquaculture of Pangasiid catfishes has developed into an important export industry and is now largely based on hatchery produced seed, many other capture-based aquaculture activities using wild seed (such as snakehead aquaculture) are still practiced as a way to alleviate fish shortages during lean seasons and/or converting seasonally abundant, low-value excess fish into a high-value harvest. Sustainability and management issues for Pangasiid catfish and snakehead fisheries and culture in the Mekong basin are very different.

The main management issues currently facing Mekong capture fisheries are habitat conversion and overfishing. The high levels of exploitation throughout the basin leave little room for expansion of the fisheries and the main challenges will therefore be to sustain current output levels. Any future increases in fisheries yields from the Mekong will thus have to come from aquaculture. However, if increased aquaculture outputs are achieved at the expense of capture fisheries outputs, they do not represent net increases and may in some cases be counter-productive from a poverty alleviation point of view (e.g. when a resource that is important for the poor is converted to a high-value resource targeted at wealthier households).

The capture-based aquaculture systems that exist in the Mekong each have different characteristics, and management solutions will differ accordingly. Each fisheries/culture system will thus have to be assessed on a case by case basis. If appropriate management measures are taken based on valid data and information, and with the aim of ensuring sustainability, some may offer good opportunities for increased production. Sustainable catch levels may be identified (again, based on solid research information) and maintained to support the traditional ways of transferring bulk monsoon catches to off-season marketing and consumption.

This paper describes capture-based aquaculture practices of two groups of taxa in the Mekong basin, the Pangasiid catfishes and the snakeheads (Channidae). Pangasiid catfish juveniles are used throughout the lower Mekong basin but are particularly important in the Mekong delta in Viet Nam, where their culture has shifted from a traditional small-scale activity into a million-dollar export business, largely based on hatchery seed. Snakehead juveniles from the wild are used in grow-out cages, ponds and pens throughout the basin as a way to convert low-value catches from the peak monsoon season into high-value harvest in the off-season.

The two species groups thus represent two different development scenarios for capture-based aquaculture in the Mekong basin. In one group (the catfishes), the traditional wild seed-based aquaculture practice triggered the development of hatchery technology, allowing the aquaculture practice to shift from wild seed-based to the current hatchery-based practice. In the other group (the snakeheads), the practice has largely remained wild-seed based.

DESCRIPTION OF THE SPECIES

Pangasiid catfishes

There are 16 species of Pangasiid catfishes in the Mekong, belonging to four genera (*Helicophagus*, *Pangasianodon, Pangasius* and *Pteropangasius*) (Gustiano, 2003). The group include one of the largest and most conspicuous freshwater species in the world, the Mekong giant catfish (*Pangasianodon gigas*).

Only two species are currently used in significant numbers in capture-based aquaculture: the river catfish (or Sutchi catfish) (*Pangasianodon hypophthalmus*) (Figure 2) and Bocourt's catfish (*Pangasius bocourti*). Some of the others, particularly *Pangasius conchophilus, Pangasius krempfi* and *Pangasius larnaudiei* are also used (Trong, Hao and Griffiths, 2002), but at much smaller scales.

FIGURE 2
A specimen of *Pangasianodon hypophthalmus*

COURTESY OF PHAM VAN KHANH

The traditional development of capture-based aquaculture was based on Sutchi or river catfish, *Pangasianodon hypophthalmus*, probably because it is a prolific spawner, which produces a relatively large number of larvae that are easily harvested from the flowing river. *Pangasius bocourti* on the contrary, lays far fewer eggs and thus it is harder to collect significant numbers of drifting wild fry. They are instead captured when they are older and bigger (i.e. at a total length of around 5 cm) using specialised hooks (Van Zalinge *et al.*, 2002).

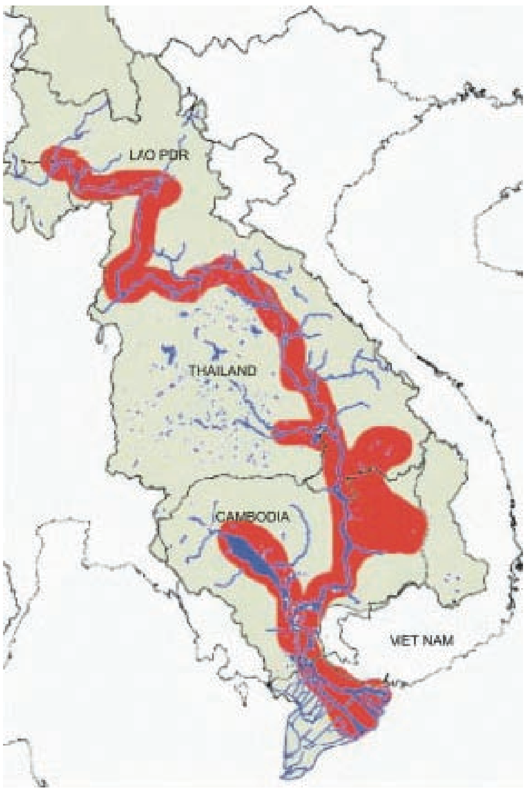
All of the Pangasiid species are migratory. Some of them carry out spectacular long distance migrations between feeding habitats, refuge habitats and spawning habitats. The two key species above, for instance, both migrate several hundred kilometres between upstream refuge/spawning habitats and downstream feeding and nursery habitats.

Research programmes are currently working on the domestication and artificial breeding of several species of the group, including *Pangasius krempfi* and *Pangasius larnaudiei*, and these may become important aquaculture species in the future. However, since *Pangasianodon hypophthalmus* and *Pangasius bocourti* are the main cultured Pangasiid species in the Mekong, they are the main focus of this paper.

Life cycle of *Pangasianodon hypophthalmus*

The river catfish, *Pangasianodon hypophthalmus*, occurs throughout the lower Mekong Basin, from the upper reaches along the border between Thailand and Lao People's Democratic Republic, through Cambodia, to the Mekong delta in Viet Nam (Figure 3). It is however extremely rare in the upper reaches. It has been suggested that there are two or more separate populations, i.e. a small "upper Mekong" population (mainly covering Thailand and Lao People's Democratic Republic) and one or more "lower Mekong" population(s), mainly covering southern Lao People's Democratic Republic, Cambodia and Viet Nam, which is by far the largest population (Poulsen *et al.*, 2004), a hypothesis subsequently supported by recent genetic studies (So, Maes and Volckaert, 2006a; So, Maes and Volckaert, 2006b).

FIGURE 3
Distribution map for *Pangasianodon hypophthalmus* in the Mekong River Basin



Source: Poulsen *et al.*, 2004.

As with all other fishes of the Mekong, the life cycle of *Pangasianodon hypophthalmus* is intimately synchronized with the annual flood cycle caused by the monsoon. Spawning mainly takes place at the beginning of the monsoon in May-June. For the southern population, the main spawning grounds are believed to be located in the mainstream Mekong in northern Cambodia along a stretch between the two river towns of Kratie and Stung Treng (So, 2005). This stretch of the river is particularly rich in rapids and deep pools and is generally considered a key area for a large proportion of Mekong fishes particularly for spawning, and as a dry season refuge, including most of the Pangasiid species.

The eggs are sticky and are believed to be deposited on roots of certain types of vegetation (Touch, 2000; Van Zalinge *et al.*, 2002). A 10 kilogram individual can produce more than one million eggs (Van Zalinge *et al.*, 2002).

When hatched, the larvae enter the Mekong water column and join a large number of other

Mekong fish species in a spectacular, multi-species larval drift downstream towards the Mekong delta, where they enter their nursing grounds on the vast floodplains of the delta and Tonle Sap/Great Lake system. Studies of this larval drift in Viet Nam have identified at least 153 species of fish belonging to 32 families and 10 orders within a period of three months from May to August (Nguyen *et al.*, 2001). Subtle differences in drift patterns probably represent ecological differences between species. For instance, *Pangasianodon hypophthalmus* is the only species to mainly drift in the surface waters, which makes them easier to capture in large numbers, whereas all other species mainly occur in deeper waters (Hortle *et al.*, 2005).

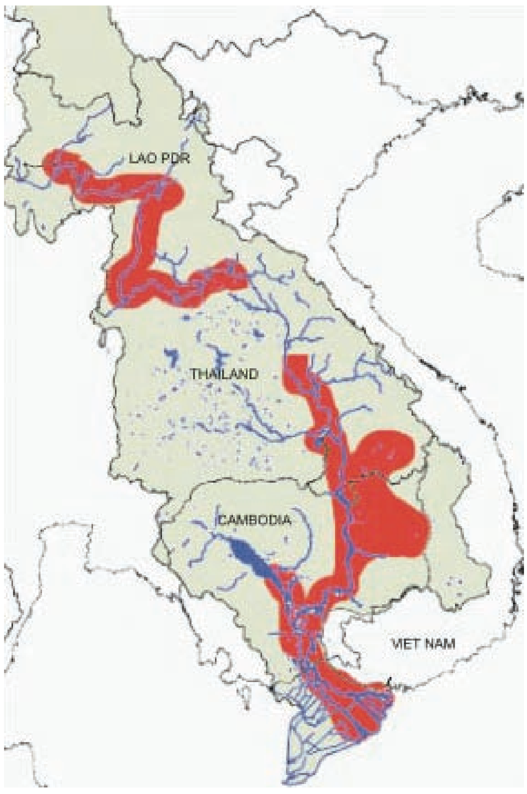
Pangasianodon hypophthalmus feeds on a variety of items including algae, higher plants, zooplankton and insects. Larger river catfish also eat fruits, crustaceans and fish (Van Zalinge *et al.*, 2002).

Recent genetic studies of *Pangasianodon hypophthalmus* in Cambodia have indicated that the relatively limited extent of spawning habitats compared with the feeding habitats may have triggered the evolution of up to five "cryptic" (sympatric) populations (So, Maes and Volckaert, 2006b). These populations are believed to use the same spawning habitats, but at separate times (separate spawning "runs") – whereas at the feeding grounds the populations are mixed (So, Maes and Volckaert, 2006b). In other words, spawning habitats may be the main bottleneck for the populations of *Pangasianodon hypophthalmus* and are therefore also of critical importance for sustaining the diversity and size of populations.

Life cycle of *Pangasius bocourti*

Pangasius bocourti has a similar distribution range to *Pangasianodon hypophthalmus*, and occurs in the Mekong mainstream and larger tributaries throughout the lower Mekong basin (Poulsen *et al.*, 2004). It also appears to consist of geographically separated and genetically distinct populations, i.e. an upstream population (in northern Thailand and Lao People's Democratic Republic) and one or more populations downstream in southern Lao People's Democratic Republic, Cambodia and the Mekong Delta in Viet Nam (Figure 4).

FIGURE 4
Distribution map for *Pangasius bocourti* in the Mekong River Basin



Source: Poulsen *et al.*, 2004.

Genetic studies have recently indicated that several distinct sub-populations may exist in the lower Mekong reaches, in Cambodia and Viet Nam, i.e. similar to *Pangasianodon hypophthalmus* (So, Maes and Volckaert, 2006a; So, Maes and Volckaert, 2006b). Since it has not yet been possible to sample the earliest larval stages of *Pangasius bocourti*, genetic sub-structures are much more difficult to detect.

Little is known about the detailed ecology of the species, including its spawning behaviour and migration patterns. It is believed to spawn in the same river stretch in northern Cambodia and have similar migration patterns to *Pangasianodon hypophthalmus* (Poulsen *et al.*, 2004; So, Volckaert and Srun, 2006). As mentioned above, *Pangasius bocourti* is less fecund than *Pangasianodon hypophthalmus*. The main spawning season is also believed to be at the beginning of the monsoon season in May-July, but there are probably subtle, yet unidentified differences between the timing and habitat requirements of *Pangasius bocourti* and *Pangasianodon hypophthalmus*.

Thus, as with *Pangasianodon hypophthalmus*, the life cycle of *Pangasius bocourti* is determined by the annual hydrological cycle of the monsoon.

The fact that *Pangasius bocourti* is much less commonly found in catches from the floodplain habitats of the Tonle Sap and the Mekong delta, suggests that the species is less dependent on floodplain habitats for nursing and feeding and is probably more confined to the river channel habitats than *Pangasianodon hypophthalmus*.

SNAKEHEADS (CHANNIDAE)

Eight species of snakehead occur in the Mekong basin, all belonging to the genus *Channa*. Only two of these are currently used in significant numbers for aquaculture namely the giant snakehead (*Channa micropeltes*) and the Chevron snakehead (*Channa striata*).

Life cycle of snakeheads

Snakeheads generally live in still or slow-flowing waters throughout the Mekong basin. Contrary to the Pangasiid catfishes described above, they do not undertake long distance migrations, but instead make shorter lateral migrations between rivers and nearby floodplains, following the hydrological cycle of the monsoonal, floodplain river ecosystem.

Snakeheads are opportunistic breeders that can spawn whenever conditions are right. In the wild they normally spawn during the monsoon season, i.e. from May to September. They lay a small amount of floating eggs in a small nest made of vegetation. The male guards the nest, and later the fry – a behaviour that is used by experienced fishers to collect the fry for stocking in grow-out cages.

Chevron snakehead, *Channa striata*

The Chevron snakehead, *Channa striata*, is one of the most common fish in the lower Mekong basin (Figure 5). It is air-breathing and is able to live in very shallow waters and is therefore particularly well adapted to life in rice farming landscapes and ecosystems (Amilhat and Lorenzen, 2005). It moves seasonally between open-water, perennial habitats (lakes, swamps, rivers) and seasonal floodplain and rice field habitats, where spawning, nursing and feeding takes place during the monsoon period from May to October.

The long association with man-made habitats have in some places resulted in the emergence of habitat management interventions by rice farmers aimed at increasing the yield from Chevron snakehead fisheries, e.g. by making small perennial "trap ponds" within the rice farming ecosystem (Amilhat and Lorenzen, 2005).

FIGURE 5
A specimen of *Channa striata*

COURTESY OF ERIK KEUS

Giant snakehead, *Channa micropeltes*

The giant snakehead has a similar life cycle to the Chevron snakehead and is also distributed throughout the lower Mekong basin. It moves seasonally between perennial refuge habitats and floodplain spawning and feeding habitats.

It is particularly common in areas, where natural floodplain habitats and their connectivity to river habitats are extensive and intact. In the Mekong, the Great Lake and Tonle Sap River floodplain systems are particularly important for the giant snakehead – and this ecosystem consequently harbours the most important fishery, including capture-based aquaculture practices, for this species.

Other areas with maintained river/floodplain ecosystems include several tributary systems in Lao People's Democratic Republic and Cambodia. In Thailand, the Songkhram River is one of the last tributary systems with maintained floodplain systems – and the giant snakehead is therefore common in both adult and juvenile fisheries.

DESCRIPTION OF CAPTURE FISHERIES

General fisheries

Most of the Pangasiid catfishes are important species in capture fisheries of the Mekong basin, generally as elements of a diverse range of multi-species fisheries throughout the basin.

Pangasianodon hypophthalmus is particularly important in the fisheries of the Tonle Sap River and the Great Lake of Cambodia, for instance in the bagnet, or dai fisheries in the Tonle Sap River targeting a range of migratory fishes at the beginning of the dry season. They are also important in floodplain fisheries of the lower basin, in southern Cambodia and the Mekong delta in Viet Nam.

Larger specimens are caught sporadically in the Mekong mainstream and in the Sesan-Srepok-Sekong river systems in northern Cambodia. In the spectacular Khone Falls fisheries, targeting migratory species crossing the falls, the species is rarely encountered and is only caught extremely infrequently above the falls in Lao People's Democratic Republic and Thailand.

Pangasius bocourti are captured throughout the lower Mekong basin. In Cambodia and Viet Nam, it is much less frequently caught than *Pangasianodon hypophthalmus*. However, upstream in Lao People's Democratic Republic and Thailand, it is caught in large numbers in gillnet fisheries on the Mekong mainstream and larger tributaries, particularly during their upstream migrations at the beginning of the monsoon season.

During the same period, significant numbers of *Pangasius bocourti* are also captured at the Khone Falls trap fisheries on the border between Lao People's Democratic Republic and Cambodia, when the species take part in spectacular, multispecies migrations through the falls (e.g. Baird, 1998).

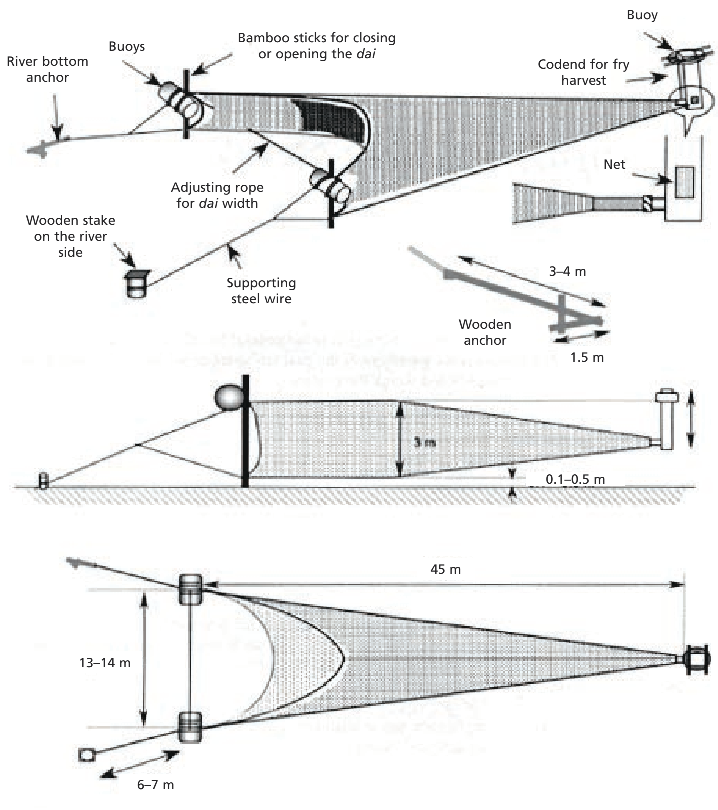
Both snakehead species are extremely important in capture fisheries throughout the basin. *Channa striata* is one of the most important species in the Mekong and is mainly captured in floodplain and rice field habitats. *Channa micropeltes* is most commonly captured in sections of the river basins with maintained, natural floodplain habitats, such as the Tonle Sap River and Great Lake ecosystem and the Songkhram River in Thailand.

Capture of juvenile Pangasiid catfishes

Large numbers of river catfish larvae (*Pangasianodon hypophthalmus*) were, until recently, caught in the upper Mekong delta near the border between Viet Nam and Cambodia. The fishery was concentrated in Chao Doc and Tan Chau districts of An Giang Provinces in Viet Nam, and in Kandal province of Cambodia.

The fishery occurs over 2–3 months at the beginning of the monsoon season (May–July) when the larvae drift downstream in the Mekong mainstream towards

FIGURE 6
The design of the Bagnets, or dai, for capturing larvae Pangasiid catfishes



Source: Tung *et al.*, 2000.

their nursery floodplain habitats. The spawning sites are believed to be far upstream in the Cambodian Mekong near the border with Lao People's Democratic Republic, approximately 500 kilometres from where the larvae are caught. Specialised bagnets, or dais are used, designed to enable the capture of live specimens of the tiny, fragile fish larvae (Figure 6). The dais are typically harvested 3 times daily.

Limited quantitative data are available on this fishery. Estimates from 1977 suggest that 200 to 800 million fry, 0.9–1.7 cm in length, were caught annually (based on data from An Giang Department of Agriculture, cited in Trong, Hao and Griffiths, 2002). A small amount of other Pangasiid larvae are caught in this fishery and used for grow-out, particularly *Pangasius bocourti*, *Pangasius conchophilus* and *Pangasius larnaudiei*.

In 1977, Dong Thap and An Giang province had a total of 1 974 stationary dais for the collection of river catfish larvae, of which 204 were state-owned, while 1 770 were owned by private individuals. The mean daily yield from each stationary dai was 13 100 larvae, with a total estimate of 763 million river catfish larvae being harvested in 1977 (Huy and Liem, 1977). Tung *et al.* (2000) reported a total production of 200 million river catfish larvae in 1996.

From the 1950–1980s, approximately 2 000 farmers in Hong Ngu, and Tan Chau districts of An Giang province and Chau Doc district of Dong Thap province raised wild river catfish larvae to fingerlings. The annual production of river catfish fingerlings was 50–100 million.

In the wild fishery, non-Pangasiid catfishes were either thrown back or used as fish feed (Bun 1999; Van Zalinge *et al.*, 2002). Only an estimated 5–15 percent of the larvae harvest was river catfish and an estimated 5–10 kilogram of other fish species were killed for each kilogram of river catfish fry caught (Phuong, 1998). Bycatch of non-target larvae was higher in Viet Nam than Cambodia probably because there were lower numbers of larvae within Vietnamese waters (Van Zalinge *et al.*, 2002).

Pangasius bocourti larvae that were 10–20 days old were also taken as a bycatch by the stationary dai fishery for river catfish. There is also a small, but specific hook and line fishery for *Pangasius bocourti* fingerlings of 12–15 cm length in Viet Nam between August–October. These fingerlings typically sell for VND 3 000–4 000 (approximately US$0.19–0.25) each for use as cage aquaculture seed.

The dai fishery for catfish larvae was banned in both An Giang and Dong Thap provinces in March 2000, due to its perceived negative impacts on the wild stock of both target and non-target species (Ish and Doctor, 2005). Before the ban, the provincial authorities auctioned the fishery annually to the highest bidder.

TABLE 1
Estimated numbers of *Pangasianodon hypophthalmus* caught in the An Giang province dai fishery, Viet Nam

Year	Number of fry caught (million)	References
1977	200–800	Khanh, 1996
1994	62	Tung *et al.*, 2001b
1995	60	Tung *et al.*, 2001b
1996	56	Tung *et al.*, 2001b
1997	48	Tung *et al.*, 2001b
1998	36	Tung *et al.*, 2001b
1999	27	Tung *et al.*, 2001b
2000	0.4	Tung *et al.*, 2001b
2006	0.1[1]	Phuong (Personal communication)

[1] Mainly in Dong Thap province

The fishery for juveniles in Cambodia was outlawed in 1994 but collection was still reported in 1998 (Edwards, Tuan and Allen, 2004). So and Haing (2006) estimated that in 2004, a total of 20 million fingerlings from a range of different species were caught from rivers for aquaculture purposes. Approximately 18 percent of these were Pangasiid catfishes, including *Pangasianodon hypophthalmus* (1.1 million), *Pangasius conchophilus* (900 000), *Pangasius bocourti* (600 000) and *Pangasius larnaudiei* (400 000) (Data based on official statistics of the Department of Fisheries, Cambodia, published in So and Haing, 2006).

Table 1 shows that there has been a massive decrease of wild-caught Pangasiid fry in An Giang province since 1977 to almost zero today following enforcement of the ban.

Unlike *Pangasianodon hypophthalmus*, *Pangasius bocourti* larvae cannot be caught in significant numbers in larvae dai nets. Larger juveniles are instead caught by specialised hooks, particularly in Cambodia.

CAPTURE OF JUVENILE SNAKEHEAD

The spawning habits of snakeheads make them relatively easy targets for fishers, who can visually identify parents guarding their offspring in the shallows of rice fields and floodplains, and then simply "scoop up" the fry with small nets. This is the main method for obtaining snakehead fry from the wild throughout the lower Mekong.

However, juvenile snakeheads are also caught in a variety of fisheries during the monsoon season. Examples include:

- River dai fisheries in Viet Nam and Cambodia;
- Floodplain fisheries using various traps, cast-nets and lift-nets in Viet Nam and Cambodia;
- Large lift-nets (operated from boats) in upper tributaries such as the Songkhram River, Thailand, and Nam Ngum, Lao People's Democratic Republic;
- Great Lake fisheries, including various traps, seine nets, cast-nets (mainly for *Channa micropeltes*); and
- Rice field fisheries throughout the lower basin (mainly for *Channa striata*).

These are all multispecies fisheries that do not target any single species. The catches are sorted immediately after capture and snakehead juveniles kept and sold to cage culture operators (often through middlemen). Other large and high-value species are also taken for retail marketing, whereas the bulk of the catch of low-value fish is used for processing (e.g. fish sauce), livestock or aquaculture feed (including for snakehead culture).

In Cambodia, snakehead fingerlings are the most common species in juvenile fisheries. According to the 2004 official statistics from the Department of Fisheries (DOF), more than 15 million fingerlings of *Channa micropeltes* were caught in

Cambodian waters, constituting 77 percent of all captured fingerlings (So and Haing, 2006). By comparison, the number of captured *Channa striata* was insignificant (approximately 18 000).

In Thailand and Lao People's Democratic Republic, snakehead farming is also important, but no quantitative data are available on the capture of wild seed. *Channa striata* is produced in hatcheries, whereas *Channa micropeltes* is captured from wild stocks on a seasonal basis (Simon Funge-Smith, personal communication).

AQUACULTURE DEPENDENCY ON THE WILD SEED

Pangasiid catfishes

Cambodia

In Cambodia records show that aquaculture of snakeheads and Pangasiid catfishes in cages and pens developed in the tenth century when wild fish captured in the peak fishery season were held over until later in the year when fish were less abundant and prices were higher. Fish species like "trey riel" (*Cirrhinus siamensis*), mixed with rice bran were/are the main feed ingredients used to fatten snakeheads and Pangasiid catfishes. Over time aquaculture of both snakehead and Pangasiid catfishes developed and intensified with deliberate capture of juveniles of both species for culture.

Today over 80 percent of aquaculture production in Cambodia comes from cages and pens in the Great Lake and Tonle Sap, and along the Mekong and Bassac rivers. River catfish *Pangasianodon hypophthalmus* is the main fish species cultured in earthen ponds, while snakehead *Channa micropeltes* is the main cultured species in floating cages. Intensive *Pangasianodon hypophthalmus* culture, is also conducted around Phnom Penh and in Kandal province because of its close vicinity to the urban markets of Phnom Penh (Phillips, 2002).

In 2004, 26 percent of the total number of fish seed used for aquaculture in Cambodia was wild caught. Of these, *Channa micropeltes* accounted for almost 78 percent (15 million fingerlings), *Pangasianodon hypophthalmus* for 4.7 percent (1 million) and *Pangasius bocourti* for 2.3 percent (600 000). Approximately 56 percent of aquaculture seed was imported (mainly from Viet Nam), while domestic hatcheries supplied only 18 percent (So and Haing, 2006).

There are a total of 14 government hatcheries in Cambodia, though not all function well because of poor water supply systems, limited staff capacity, funding and broodstock resources (So and Haing, 2006). The 5 largest freshwater fish seed hatcheries in Cambodia are the 4 government hatcheries (Bati Fish Seed Production and Research Centre in Prey Veng province, the Chrang Chamres Fisheries Research Station, the Toul Krasang Fish Seed Production Station in Kandal province, and the Chak Ang Rae Fish Seed Production Station in Phnom Penh) and the NGO SAO-Scale hatchery in Kandal Province, near Phnom Penh.

Viet Nam

Pangasianodon hypophthalmus ("tra" in Vietnamese) and *Pangasius bocourti* ("basa" in Vietnamese) have been traditionally cultured for centuries in Viet Nam (Peignen 1993, cited by Cacot, 1999; Lazard and Cacot, 1997). Today river catfish and *Pangasius bocourti* are the two main cultured freshwater fish species in Viet Nam in terms of both quantity and export value. Like Cambodia, the Vietnamese Pangasiid aquaculture industry developed from holding fish over to sell later when supply was lower and prices were higher. Culture of *Pangasiid* catfishes prior to 1980 was totally dependant on stocking of wild caught seed.

Pangasianodon hypophthalmus were first artificially propagated in Thailand in 1959, and the technology has since spread throughout southeast Asia (Trong, Hao and Griffiths, 2002). The doctoral thesis (in Vietnamese) "Induced spawning of the

TABLE 2
Pangasiid larvae and fry/fingerling production (millions) by province in the Mekong Delta region of Viet Nam, 2000–2005

Province	2000		2001		2002		2003		2004		2005	
	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry
An Giang	36	2	45	2	228	17	240	24	375	27	715	66
Dong Thap	430	30	416	36	572	47	624	52	4 250	935	4 681	1 744
Can Tho		–	–	19	–	9	–	4	–	3	–	3
Vinh Long				6	–	7	–	10	–	8	–	6
Tien Giang				–	–	–	–	2	–	2	–	1
Long An												
Hau Giang												
Bac Lieu												
Kien Giang												
Soc Trang												
Ca Mau												
Tra Vinh												
Ben Tre												
An Giang												
Total	**466**	**32**	**461**	**63**	**800**	**80**	**864**	**92**	**4 625**	**975**	**5 396**	**1 820**

Source: Provincial DOFI and DARD annual progress reports.

river catfish *Pangasius hypophthalmus* in the Mekong Delta" (Khanh, 1996) details the development, beginning in 1978, of artificial propagation techniques for the river catfish (*Pangasianodon hypophthalmus*) in Viet Nam. Prior to 1996, there was no hatchery production of Pangasiid catfishes in Viet Nam.

Table 2 shows the rapid rise in the hatchery production of river catfish seed in the Mekong Delta of Viet Nam, with larvae and fry/fingerling production increasing 11 and nearly 57 fold respectively, between 2000 and 2005.

In 2006 the 130 hatcheries (An Giang 15; Can Tho 5; Tien Giang 4; Vinh Long 3; and Dong Thap 103) in the Mekong Delta region of Viet Nam produced 10 billion river catfish larvae and the production of *Pangasianodon hypophthalmus* fingerlings reached 1 billion (Table 3).

Today there are a myriad of small-scale hatcheries and nurseries (<1 ha in area) supplying Pangasiid seed in Viet Nam and the price of larvae is down to as low as VND 2–3 each. Vietnamese hatcheries and nurseries produce more than sufficient for local demand, with excess river catfish larvae and fingerlings being exported to Cambodia (Edwards, Tuan and Allen, 2004). However Government Decree 15/2006/QD-BTS will prohibit the export of live Pangasiid larvae and fingerlings from September 2007 onwards.

In stark contrast, Cambodian hatcheries only produced a total of 883 840 river catfish fingerlings in 2004 (So and Haing, 2006).

The first "basa" (*Pangasius bocourti*) hatchery in the Mekong Delta of Viet Nam began operation in 1996. Ten hatcheries (2 in An Giang; 2 in Tien Giang and 6 in Dong Thap provinces) produced an estimated 15–20 million *Pangasius bocourti* larvae in 2006, selling at VND 100 (approximately US$0.006) each. *Pangasius bocourti* broodstock, which are held in cages, typically at stocking densities of 1.5–3 kg/m^3, mature between February and June. *Pangasius bocourti* larvae are first fed on *Artemia* nauplii and later commercial pellets. Survival of *Pangasius bocourti* larvae nursed to fingerlings at 90 days is approximately 70 percent.

While the majority of *Pangasius bocourti* seed stocked in Vietnamese grow-out systems is from hatcheries, a small proportion is still wild-caught. Private and government hatcheries produced an estimated 15 billion river catfish and 3 billion *Pangasius bocourti* seed in 2004 (MOFI, 2005).

TABLE 3
River catfish larvae and fingerling production, 2004–2006

Years	Larvae (billion)	Fingerlings (billion)
2004	6	0.4
2005	8	0.7
2006	10	1

Source: Annual 2006 progress reports from the Provincial Extension Centres of An Giang, Dong Thap, Tien Giang, Vinh Long, and Can Tho provinces.

BOX 1
From wild seed fisher to hatchery owner

Hong My Hatchery, Hong Ngu district, Dong Thap
Mr My began catching and trading wild Pangasiid seed (*Pangasianodon hypophthalmus, Pangasius bocourti* and *Pangasius krempfi*) 38 years ago. Following training on spawning from the provincial Department of Agriculture and Rural Development (DARD) in the 1990s, Mr My established his Pangasiid hatchery in Hong Ngu district, Dong Thap province, close to the border with Cambodia.

Today the hatchery holds 25 tonnes of "tra" (*Pangasianodon hypophthalmus*) of about 6 kg each, 6.5 tonnes of "basa" (*Pangasius bocourti*) of about 8 kg each and 1.5 tonnes of *Pangasius conchophilus* of about 1.8 kg each, all of which were obtained from wild stocks. Most of the broodstock are held in floating cages on the nearby river. The broodstock are used for 5–6 years before being replaced.

Mr My has a total of 6 ha of ponds, 3.5 ha of which he owns and the remainder are leased. Hong My hatchery sells 90 percent of its production as 1-day old larvae, while 10 percent is sold as fingerlings after 45 days of pond nursing. The hatchery is run by 5 family members and 15 hired labourers. The hatchery's main operating costs are feed for broodstock and spawning chemicals. Its main constraints were reported to be disease occurrence and the low fecundity of "basa" (*Pangasius bocourti*). Hong My hatchery sells mainly to Vietnamese nursery farmers and also to Cambodian wholesalers.

Culture systems for "tra" (*Pangasianodon hypophthalmus*) and "basa" (*Pangasius bocourti*) catfish in Viet Nam

River catfish is the major freshwater finfish produced in the Mekong Delta region of Viet Nam (Phillips, 2002) because it is hardier, grows faster, is less expensive to produce and has a fecundity up to ten times higher than *Pangasius bocourti* (Edwards, Tuan and Allen, 2004). In addition river catfish also has a higher dress out weight than *Pangasius bocourti*, with 3.1 and 3.7–3.8 kg fish, respectively, required to produce 1 kilogram of fillet (Edwards, Tuan and Allen, 2004). While tra is the major exported freshwater finfish from Viet Nam, *Pangasius bocourti* is still preferred for local consumption and sells for one third more than river catfish.

Pangasius bocourti are cultured almost exclusively in cages on tributaries of the Mekong River. From 1995 to 1999 there were approximately 3 000 *Pangasius bocourti* cages in the Mekong Delta of Viet Nam, producing 30 000 tonnes annually, most of which was destined for the domestic market (Nguyen Tuan, 2000). With increasing focus by producers on river catfish for export, there has been a significant recent decline in *Pangasius bocourti* production, with 800 cages producing an estimated 12 000 tonnes in 2006.

In Viet Nam, river catfish (*Pangasianodon hypophthalmus*) are cultured in monoculture in cages and net pens along the edges of rivers, intensively in ponds and in polyculture systems in small-scale ponds (Hung *et al.*, 2003). An Giang and Dong Thap provinces have the greatest number of Pangasiid cages. Cage sizes in the Mekong Delta range from 50 to 1 600 m^3, with larger cages commonly including living quarters on top and the submerged cage portion below (Phillips, 2002). Intensive pond culture of river catfish (*Pangasianodon hypophthalmus*) is concentrated in Can Tho, An Giang, Dong Thap, and Vinh Long provinces. Despite the higher risks (caused by high stocking densities and poor water flow) of characteristics unfavourable to export markets (e.g. yellow flesh), 50 percent of total Pangasiid culture is from ponds (Cacot, 2004). Small-scale pond culture of river catfish including in VAC systems (Vietnamese acronym for garden, pond, and livestock quarters) is also found throughout the Mekong Delta

(Edwards, Tuan and Allen, 2004). Recently river catfish and *Pangasius bocourti* have also been 'exported' to the northern and central regions of Viet Nam, and pilot culture has been conducted (Khanh 2004, cited in Hao, Hung and Trọng, 2005). However to date, the majority of Pangasiid culture in Viet Nam is from the Mekong Delta.

River catfish can tolerate dissolved oxygen as low as 0.05–0.10 mg l^{-1} (Browman and Kramer, 1985, cited by Cacot, 1999; Khanh, 1996), highly polluted water (chemical oxygen demand = 25), and being obligate air breathers, can be stocked at densities as high as 120 fish m^{-2}. River catfish reach 1–1.5 kg after 8 months of culture and being omnivorous adapt to different kinds of feed (Khanh, 1996). The feed conversion ratio of river catfish is typically 1.9–2.0 on commercial pellets.

Ponds are usually stocked at 60–80 fish m^{-2}, though some grow-out farmers may stock as high as 120 fish m^{-2}. Grow-out cages are typically stocked at 100–150 fish m^{-3}. Yields reach 300–400 and exceptionally 500 tonnes ha^{-1} $crop^{-1}$ in ponds, and 100–120 kilograms m^{-3} $crop^{-1}$ in cages. Yields as high as 500 tonnes ha^{-1} $crop^{-1}$ have been reported from pen systems. Grow-out producers, have traditionally used home-made feed, but are increasingly moving to commercial pelleted feeds, which today supply an estimated 80 percent of feed inputs. Producers are aerating ponds and regularly exchanging pond water to reduce muddy off flavours and to produce whiter fleshed fish.

With increased culture area and intensity of Pangasiid production disease outbreaks like Bacillary Necrosis of *Pangasius* (BNP) are becoming more frequent. Outbreaks typically occur at the start of the rainy season (April–May) and the end of the flood season (October–November) (Crumlish and Dung, 2006). Although banned by the Ministry of Agriculture and Rural Development (MARD), many producers still treat diseases with antibiotics, plus disinfection agents. This has resulted in rejection of export shipments in Japan, the European Union and the United States of America. This is a priority issue for the government and the industry.

Production costs for pond and cage reared river catfish are relatively stable at approximately VND 7 000 kg^{-1} (US$0.43) and VND 9 000 kg^{-1} (US$0.56), respectively. River catfish and *Pangasius bocourti* products are exported to Europe (approximately 60 percent), Asian countries, Mexico, Australia (30 percent), the United States of America (<10 percent), and the Middle East. New markets like Russia are emerging.

In 2004 Pangasiid production reached 300 000 tonnes (MOFI, 2004). In 2005, a pond culture area of 4 912 hectares and 340 800 m^3 of cages produced 416 908 tonnes of Pangasiid catfishes, with a total value of US$2 393 million. Of this, pond culture of river catfish, cage culture of river catfish and cage culture of *Pangasius bocourti* were 89 percent, 10.5 percent and 0.5 percent respectively. Mean productivity of river catfish in ponds in 2005 was 75.6 tonnes $hectare^{-1}$ $year^{-1}$, while mean productivity of river catfish and *Pangasius bocourti* in cages was 140 and 67 kilogram m^{-3} $year^{-1}$, respectively (Southern Sub-Institute for Fisheries Planning, 2006). Estimated production of Pangasiid catfishes in 2006 was 842 000 metric tonnes, comprising 830 000 and 12 000 tonnes of river catfish and *Pangasius bocourti*, respectively. Viet Nam exported 286 600 tonnes of Pangasiid catfishes, valued at US$736 million in 2006 (Source: Viet Nam General Department of Customs). Viet Nam's 2010 target production of river catfish and *Pangasius bocourti* is 1 million tonnes, with exports valued at US$800 million[1] (Hao, Hung and Trong, 2005).

Culture systems for snakehead

Wild-seed based snakehead culture has been and still is practiced throughout the lower Mekong Basin, but is particularly important in Cambodia and Viet Nam.

Until the early 1990s, an estimated 15–20 million wild snakehead seed weighing 0.3–0.5 g were collected annually between March and May, using lift scoop nets in the Mekong Delta area of Viet Nam. From 1999 onwards hatchery produced snakehead

[1] Viet Nam surpassed 1 millon tonnes of Pangasiid production in 2007.

met Viet Nam's demand for seed for stocking in grow-out systems. Today there are over 200 snakehead hatcheries in Viet Nam, with most located in Hong Ngu and Tam Nong districts of Dong Thap province. Broodstock are fed predominantly trash fish, and are held in small ponds, typically 200–500 m^2 in area. When broodstock reach maturity, farmers make net spawning enclosures in which the snakehead naturally lay and fertilize their eggs. Presently hatcheries in the Mekong Delta area of Viet Nam produce about 20 million snakehead larvae annually.

Larvae are typically nursed in a blue nylon hapa measuring 3 x 4 x 1.5 m, holding 500 larvae, and fed on trash fish and/or fishmeal and fine rice bran, with 20–30 percent survival. Annual production of snakehead fingerlings, from hatcheries and wild collection, is estimated to be 15–18 million.

In the Mekong delta in Viet Nam, giant snakehead (*Channa micropeltes*) are cultured in cages together with Pangasiid species. It is estimated that they contribute 5 percent of the total output from cages (Trong, Hao and Griffiths, 2002). The Research Institute for Aquaculture No. 2 (RIA 2), in the south of Viet Nam has been spawning giant snakehead at Cai Be in Tien Giang province for several years and their staff have been disseminating spawning, nursing and grow-out technologies throughout the country (Khanh, personal communication). However since monoculture of snakehead is dependent on locally available cheap trash fish, which is in short supply, it is unlikely that giant snakehead culture will be anything other than a small-scale activity throughout Viet Nam for the foreseeable future.

In 1998, 954 farmers cultured snakehead in ponds and cages in Dong Thap province. Stocking at 25–50 fingerlings m^{-2}, feeding low value freshwater trash fish, yields were 70–120 tonnes $hectare^{-1}$ $year^{-1}$ and total production was 4 641 tonnes. With the easy availability of hatchery produced snakehead seed, snakehead culture has expanded rapidly. Today stocking densities are typically 30–40 fish m^{-2}, and yields 100–150 tonnes $hectare^{-1}$ $year^{-1}$ of market sized, 500–700 gram fish.

Cage culture of snakehead is popular in An Giang province, where yields range from 42.5–116 kg/m^3. In 2003, An Giang province produced 5 294 tonnes of giant snakehead (*Channa micropeltes*).

In 2006 total production of snakehead (*Channa micropeltes* and *Channa striata*) in Viet Nam was an estimated 25 000–32 000 tonnes (Phuong, personal communication).

In Cambodia, cage culture of snakehead (*Channa micropeltes* and *Channa striata*) has been practiced for over a century (Chevey and Le Poulain, 1940), but recently increased dramatically because they are high-value fish that can be marketed alive. Furthermore, they can be fed low value freshwater fish that are seasonally abundant in the country, thereby providing an efficient way of attenuating the seasonal peak fish harvest (Khay and Hortle, 2005). Cambodian snakehead culture (both cage and pen culture) is thus in a transition between capture and culture fisheries. The following examples illustrate this transition (Phillips, 2002):

- farmers who use the cages solely for transporting captured fish;
- farmers who hold and fatten fish for a few months, subsequently marketing them when price and demand are higher than at the time of capture; and
- farmers who stock wild-captured juveniles into cages and/or pens for feeding and grow-out to market size.

In 2004, there were 4 492 cages in Cambodia on the Tonle Sap Great Lake, and the Tonle Sap, the Mekong and Bassac Rivers (So and Haing, 2006), all of which at the time were entirely dependant on wild fish as seed, and feed (So *et al.*, 2005). An estimated 20 million wild seed were collected for cage culture in 2004 (So *et al.*, 2005), including 15.4 million giant snakehead seed, 1.1 million river catfish, 0.94 million *Pangasius conchophilus* and 0.62 million *Pangasius bocourti*. So *et al.* (2005) also estimate that 6.6 million wild river catfish fingerlings were stocked in ponds in Cambodia in 2004.

While Cambodia exported billions of river catfish fingerlings and tens of millions of *Pangasius bocourti* fingerlings in the 1980s, the trend reversed with the development of Pangasiid hatcheries in the Mekong Delta region of Viet Nam, with Cambodia importing 60 million fish fingerlings for cage and pond aquaculture in 2004, including 1.5 million river catfish. Viet Nam and thereafter Thailand became the major suppliers of seed to Cambodia.

While total hatchery production of fish seed in Cambodia expanded 33 fold from 560 000 in 1987 to 18.5 million in 2004 (So and Haing, 2006), Cambodian hatcheries supplied only 18 percent of the country's total aquaculture seed requirement in 2004.

Cage culture of snakehead was banned in Cambodia in 2005, because of its reliance on small wild fish as feed. This resulted in a partial shift to cage culture of hybrid catfish (*Clarias gariepinus* x *Clarias batrachus*) in Cambodia.

In Lao People's Democratic Republic, cage culture of snakehead based on wild-captured seed is commonly practiced in the Nam Ngum Reservoir. Seed appear to be a limiting factor as prices have been increasing (Hambrey, 2002). There may therefore be an opportunity for Viet Nam to export giant snakehead seed to Lao People's Democratic Republic.

FISH FEED

Since capture-based aquaculture was traditionally developed to even out the surplus from capture fisheries during the monsoon season, locally captured, low value fish constituted the basis for aquaculture feed, sometimes mixed with other on-farm products including rice bran.

The large yields of "trey riel" (*Cirrhinus siamensis*) and other low value species, constitute the basic feed for culture of both Pangasiid catfishes and snakeheads in Cambodia (Ngor, Aun and Hortle, 2005).

In the Nam Ngum Reservoir in Lao People's Democratic Republic, the locally available small freshwater clupeid "Pa Keo" (*Clupeichthys aesarnensis*) is the main feed ingredient for the cage culture of snakehead (Hambrey, 2002).

Until recently, 95–97 percent of Vietnamese Pangasiid cage culture systems used home-made feeds (Phu and Hein, 2003). Food safety concerns, fluctuating quality, rising trash fish costs and the establishment and expansion of the fish food production industry in Viet Nam have encouraged farmers to increasingly use commercial pelleted feeds for monoculture grow-out of Pangasiid catfishes in cages and ponds. At present the division between home-made and manufactured feed is approximately 20:80. Pangasiid catfishes are also produced in small-scale integrated grow-out systems in polyculture with other species and fed with small marine and/or freshwater fish species which are either bycatch or targeted low-value species, as a supplementary feed (Edwards, Tuan and Allen, 2004).

Factoring in levels of trash fish in home-made diets and fishmeal content in pelleted feeds for Pangasiid catfishes, moisture content and FCR, Edwards, Tuan and Allen (2004) estimated that a minimum of 64 800 to a maximum of 180 000 tonnes of trash fish were used to produce the 180 000 tonnes of Pangasiid catfishes that Viet Nam produced in 2002.

ENVIRONMENTAL IMPACTS OF CAPTURE-BASED AQUACULTURE

Impact of juvenile and fry fisheries

Pangasiid catfishes

The capture of Pangasiid catfish juveniles has largely been replaced by hatchery-reared fry for the main catfish industry in the Mekong Delta of Viet Nam. However, operations in Cambodia, Lao People's Democratic Republic and, to a lesser extent Thailand, still use wild-captured juveniles as seeds for cage and pond culture.

The collection of Pangasiid larvae from the Mekong delta has generally been perceived as unsustainable and detrimental to the target species as well as to the many other species caught as bycatch in the fisheries. For instance, Trong, Hao and Griffiths (2002) cited information from Donh Thap Province that the capture of Pangasiid larvae had declined tenfold during the past decade, “due to over-fishing”.

The bycatch from the fishery is significant. Phuong, 1998 (cited in Trong, Hao and Griffiths, 2002) estimated the bycatch at between 5 to 10 times (by weight) the catch of the targeted Pangasiid larvae. Trong, Hao and Griffiths (2002) concluded that the fishery for catfish fry was “highly destructive” for both the catfish populations themselves as well as for other species caught as bycatch.

Although it is easy to draw the conclusion that the catch and bycatch levels are and were detrimental, no data exist to support this claim. In general, most fish species of the Mekong are adapted to high larvae and juvenile mortalities as a result of living in the versatile, but productive floodplain habitats.

The Mekong River Commission (MRC) has facilitated several studies over the past 6–7 years on larvae and juvenile drift in the lower Mekong in both Viet Nam and Cambodia. Data from these surveys do not indicate any reductions in numbers of larvae in recent years.

Genetic studies of *Pangasianodon hypophthalmus* do not suggest any recent declines in genetic diversity and/or population sizes (So, Volckaert and Srun, 2006). They attribute the high genetic diversity of *Pangasianodon hypophthalmus* to the large and productive feeding habitats associated with the Mekong floodplains.

Although existing information is inconclusive, fisheries catch data (e.g. Tonle Sap Dai fisheries, described in Lieng, Yim and Van Zalinge, 1995), larvae sampling and recent genetic studies suggest that *Pangasianodon hypophthalmus* and *Pangasius bocourti* have not suffered recent population size declines. Any negative impacts of juvenile fishing seem to be negligible and the annual recruitment appears to have been able to absorb the fishing pressures on all life stages of the species.

However, there may be some impacts of these fisheries at the sub-species population level. Although such impacts are currently little understood, genetic studies on the larval drift of *Pangasianodon hypophthalmus* have revealed that up to five sub-populations exist, which are temporally separated in the drift and therefore probably represent distinct spawning populations of the species. Two of those populations were not found downstream of Phnom Penh and in the Mekong delta, where three relatively common populations were identified. Interestingly, studies on the larval drift in the Mekong delta in Viet Nam also identified three temporally separated peaks of *Pangasianodon hypophthalmus* larvae, corresponding to these three genetically distinct populations (Nguyen *et al.*, 2006).

The two other populations appear to be rare and could potentially be impacted negatively by juvenile fisheries at certain times and/or places. The reason why two out of five populations appear to be comparatively rare is not currently understood. Further studies, combining ecological and genetic methods, will be needed to shed light on this issue and possibly suggest management implications (So *et al.*, 2006b).

Population genetics of migrating Pangasiid catfishes in the Mekong is extremely complex and genetic research is only just beginning to reveal some of these subtle characteristics that nevertheless may have important management implications. For instance, one interesting observation coming out of recent genetic population studies is that one of the ecological drivers of the high number of sympatric intra-species populations may be the disproportionate availability of productive nursery and feeding habitats compared to spawning habitats (So, Maes and Volckaert, 2006). Different populations use the same spawning sites, but at different times of the spawning season, and all the off-spring are subsequently mixed and distributed throughout the vast nursery areas on the floodplains. As a consequence, the management priority for sustaining these species and populations should be the conservation of their spawning sites.

Potential genetic impact of hatchery-reared fry on wild populations is another issue related to genetics that is little understood and not documented for the Pangasiid catfishes. Such impacts may occur if hatchery-reared fish escape to the natural environment and interbreed with wild populations. If broodstock are taken from the local environment, as is generally the case for the catfish industry in the Mekong delta in Viet Nam, such impacts would be minimal.

However, if broodstock are transferred to other areas, particularly if those are in different river basins, such impacts could be significant. For instance, broodstock used in the aquaculture industry in the upper Mekong in Thailand probably originate from the Chao Phraya River basin and are genetically different from the wild populations of the Mekong basin. Chao Phraya broodstock have also been imported to Cambodia for use in aquaculture. This practice was subsequently stopped, because of concern that fish might escape and breed with the wild populations (So and Haing, 2006).

In Viet Nam, broodstock from wild populations of *Pangasianodon hypophthalmus* are taken in on a regular basis to maintain genetic diversity of aquaculture broodstock – a practice that effectively ensures that the genetic integrity of the wild populations will not be compromised by hatchery-reared material.

Ish and Doctor (2005) ranked the risk to wild Pangasiid stocks from escaping cultured Pangasiid catfishes as “low” because most cage structures are floating and sited in relatively sheltered areas. In addition, because most Pangasiid broodstock are from wild populations, and to date there has been minimal selection and improved breeding programme work conducted the genetic diversity and make-up of hatchery and wild Pangasiid fish populations are essentially the same. Hybridization of *Pangasius bocourti* and *Pangasianodon hypophthalmus*, while possible, has been banned by MOFI and the ban is being enforced.

Snakeheads

As with the Pangasiid catfishes, there is no data to suggest that juvenile snakehead fisheries have negative impacts on the species. Again, the large annual recruitments appear to be able to counteract any potential negative impacts.

Channa striata is one of the most common species of the lower Mekong basin and one of the most frequently encountered fish at markets throughout the basin. It is well adapted to living in rice-field habitats and therefore, may in fact have benefited from anthropogenic impacts, including the conversion of natural habitats to paddy fields.

Due to its conspicuous spawning behaviour including parental care of the larvae, adults and juveniles are easily captured by fishers. Parents guarding snakehead seed are easily identified in shallow waters and can simply be scooped up by net together with the entire larvae shoal. Therefore, the potential impact on populations of other species appears to be minimal, although no data exist to confirm this.

Aquaculture feed

Since the culture of both catfishes and snakeheads is based on the use of low value and/or trash fish, concerns have been raised about the environmental impact of the practice. For instance, earlier estimates suggested that up to 300 000 tonnes of trash fish are used as fish feed for the river catfish and *Pangasius bocourti* industry in Viet Nam annually (Sverdrup-Jensen, 2002). This figure must now be significantly higher due to the recent increase in Pangasiid catfish production from this area.

When the production of cultured fish was based on the traditional capture-based system (i.e. the use of a seasonally abundant, low value fish resource to produce a high-value product that could be marketed outside the peak season) the practice could probably be carried out in a sustainable manner. However, as the Pangasiid industry, in particular, has developed into a large export industry, the demand for trash fish has exceeded local supply. As a result, marine trash fish are now also used as a feed for the culture of Pangasiid catfishes and snakeheads. This raises environmental concerns, not only locally, but for the marine environment and fisheries that supply the trash fish.

The use of wild-caught trash fish for aquaculture feed is also practiced for other capture-based aquaculture activities in the Mekong basin. Large quantities of the indigenous cyprinids *Cirrhinus siamensis* and *Cirrhinus lobatus* are used throughout the basin, but particularly in Cambodia. An unknown (but significant) amount of the Cambodian catch of *Cirrhinus* sp. is transported across the border to Viet Nam to satisfy the need of the expanding Pangasiid catfish culture industry.

Feed for snakehead culture in Lao People's Democratic Republic and Thailand is mainly based on the capture of the small freshwater clupeid *Clupeichthys aersarnensis*, from reservoirs (e.g. Nam Ngum Reservoir in Lao People's Democratic Republic). In Thailand, slaughter-house waste, particularly from chicken processing, is also used as a feed supplement for snakehead culture (Simon Funge-Smith, personal communication).

The use of wild fisheries resources for feed is the main environmental sustainability challenge that currently faces the Pangasiid catfish industry in the Mekong Delta of Viet Nam. Research efforts aiming at reducing the use of feeds based on trash fish are on-going.

OTHER ENVIRONMENTAL ISSUES

Disease

Crumlish *et al.* (2002) identified the bacteria *Edwardsiella ictaluri*, a disease native to North America and *Ictalurid* catfish, in farmed river catfish cultured in the Mekong River Delta. This was the first time this disease was recorded in Pangasiid catfishes. As yet it is not known whether the bacteria was indigenous but previously unknown, or if it was introduced from overseas. There are no data as yet to show that wild stocks have been affected by this disease. Additionally there is no evidence to suggest that wild Pangasiid stocks are suffering more disease as an impact of contact with cultured Pangasiid catfishes, particularly those in cages.

Effluent

Monoculture of Pangasiid catfishes in cages which are open net containers, and ponds which are drained into canals and rivers, impact on the natural water environment by increasing nutrient and suspended sediment loads and increasing Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The high water temperatures in the Mekong Delta region of Viet Nam allow primary consumers to proliferate which rapidly break down ammonia, nitrates, and organic matter released in faecal wastes from Pangasiid cages and ponds. However despite this, anoxic conditions can occur in localised areas where there are more cages and ponds than the carrying capacity of the area can sustain.

Other issues

Diseases and water quality issues pose serious threats to the future of the industry. Export markets will in the future increasingly demand that products live up to both product quality standards as well as social and environmental sustainability standards. If Viet Nam's current level of export is to be maintained (and, according to official targets, even increased) standards will have to be developed and implemented for the industry. The Sustainable Aquaculture Group of Viet Nam is proposing to commence a study on the Pangasiid production carrying capacity of the Mekong Delta region of Viet Nam in 2008.

SOCIAL AND ECONOMIC IMPACTS

No studies exist on the social and economic impacts of the wild-capture fisheries for aquaculture seed in the lower Mekong basin. The development of the Pangasiid catfish industry in Viet Nam has had tremendous economic impacts both at national and local levels. The entire industry, including the research activities and subsequent hatchery development that has rendered the wild seed fisheries for Pangasiid catfish seed obsolete, was initially triggered by the traditional capture of Pangasiid catfish seed.

The capture of wild seed is generally carried out by relatively poor fishers in the Mekong basin and the captured juveniles provide much needed additional seasonal income. The banning of the fisheries may therefore have had significant local-level socio-economic impacts which were not assessed prior to the introduction of bans. In some cases, the bans resulted in fishing gear confiscation, causing additional economic loss to fishers.

As Box 1 shows, some Pangasiid catfish juvenile fishers were able to take advantage of the subsequent hatchery development and become seed producers after the capture seed fishery was banned.

There do not appear to be any data or information on the socio-economic importance of the juvenile fisheries for Pangasiid catfishes and snakehead in the Mekong basin, including the socio-economic impacts that bans on certain fisheries (such as the dai fisheries for Pangasiid larvae) have had on local fisher communities.

MANAGEMENT

Often the capture of juvenile fishes is seen as a wasteful practice. Conventional wisdom tells us that juveniles should be left to grow to their full potential before being harvested. This conventional wisdom has also taken hold in the Mekong basin, where the capture of juvenile fishes for use in either culture or consumption has generally been banned.

In Cambodia, the bag net (dai) fisheries targeting Pangasiid larvae were banned in 1994. However, in spite of the ban, the number of bag net units in operation increased to 948 in 1998, up from 650 units in 1981 (Van Zalinge *et at.*, 2002). Since then however, enforcement has been strengthened. The "New Fisheries Law" calls for the protection of aquatic biodiversity and the environment (So and Haing, 2006).

In Viet Nam, the "New Fisheries Law" came into force in 2003. This is a legislative framework within which specific directives will be developed to accommodate the legal aspects of specific fisheries issues, such as capture fisheries management, aquaculture and habitat/species conservation.

In relation to the capture of wild seed for aquaculture, the New Fisheries Law states that the exploitation of fish smaller than regulated size is prohibited, except for permitted aquaculture purposes.

The provincial authorities in Viet Nam have some legislative powers for specific management regulations of provincial level fisheries, including juvenile fisheries. In both An Giang and Dong Thap provinces, for instance, the use of dais to capture *Pangasianodon hypophthalmus* larvae was banned in 2000. The timing of this ban coincides well with the emergence of increased hatchery seed production that was subsequently able to meet the Pangasiid seed demand of the area.

Regulations for snakehead juvenile fisheries, include some size restrictions, e.g. in An Giang Province the capture of snakeheads below 10 cm in length is illegal. From 1 May to 1 June each year, fishing for juvenile snakeheads is completely banned to reduce fishing pressure during the peak spawning season of snakeheads (Sjorslev, 2001). However, enforcement of these regulations appears to be extremely weak.

Most existing legislation related to the capture of juveniles and their use in aquaculture, is generally based on weak and unreliable data.

With the massive recruitment occurring within the Mekong ecosystem, for at least three of the four species covered in this paper, and with the extreme seasonality of the fisheries, the capture of juveniles may actually be a sustainable resource exploitation approach. The key management issue for the sustainability of the capture-based aquaculture practice is whether the use of trash fish-based feeds is sustainable, and if not, whether these feed inputs can be replaced by other protein sources.

In the extremely complex and multi-species setting of the Mekong basin fisheries, it is important that all management issues are seen within the larger, ecosystem context. Experiences from past decades suggest that if essential habitats for the targeted species are protected and maintained (in terms of quality as well as quantity), juvenile fisheries can continue to be conducted in a sustainable manner.

CONCLUSIONS

- Aquaculture traditionally developed in the lower Mekong basin as an integrated element of capture fisheries to transfer a low value, seasonal surplus into high-value fishes (such as Pangasiid catfishes and snakeheads) that could be marketed all year round.
- Wild seed is used in cage and pond culture (Pangasiid catfishes) and cage and pen culture (snakehead) throughout the basin, particularly in Cambodia and Viet Nam.
- Traditionally, these culture systems relied on wild-caught, low-value "trash fish" from the Mekong (e.g. the small cyprinid genus *Cirrhinus*) as feed. This is still the case in most places. Today marine trash fish are also being utilized as a feed input to accommodate the increasing demand in the Mekong Delta of Viet Nam. Trash fish, however, is increasingly being replaced by commercial pelleted feeds, particularly in Viet Nam.
- For Pangasiid catfishes, traditional capture-based aquaculture systems triggered the development of hatchery technology which today meets the demand for seed within Viet Nam and Thailand, with surplus seed exported to Cambodia and Lao People's Democratic Republic.
- Snakehead culture continues as a capture-based aquaculture system in most parts of the basin, except in Thailand. The large recruitment from natural ecosystems and their relatively easy capture means that large-scale hatchery production of snakehead seed (particularly the giant snakehead, *Channa micropeltes*) is financially unattractive.
- Current data and information suggests no significant negative impacts of juvenile fisheries on wild populations of Pangasiid catfishes and snakeheads. Both species groups have maintained healthy and extremely productive wild populations in spite of juvenile fishing pressure.
- For the two main Pangasiid species, recent genetic studies indicate that the bottleneck for sustainable management of both species is the protection of their spawning habitats.
- When wild capture of aquaculture seed is increasingly replaced by hatchery-reared seed (as has happened with Pangasiid aquaculture in the Mekong delta of Viet Nam), it is important to introduce sound genetic management practices. These include using broodstock of local origin and/or periodically replacing broodstock with newly captured wild broodstock from local sources.
- The use of low-value/trash fish from within the Mekong basin as well as from marine sources poses the biggest challenge to the industry in terms of ecological and environmental sustainability.
- The socio-economic importance of past and present juvenile fisheries in the Mekong basin, and their subsequent banning in some areas, has not been adequately assessed.

- Capture-based aquaculture, including the practices of capturing juveniles and using wild-captured resources for feed, should be assessed and managed within a larger-scale ecosystem approach.

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