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ON

Capture Based Aquaculture (CBA) – for sustainable aquaculture production

BY

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Introduction

Global production from aquaculture has grown substantially, contributing increasingly significant quantities to the world's supply of fish for human consumption. This increasing trend is projected to continue in forthcoming decades. It is envisaged that the sector will contribute more effectively to food security, poverty reduction and economic development by producing – with minimum impact on the environment and maximum benefit to society – 83 million tonnes of aquatic food by 2030.

Fishing and aquaculture are often viewed as separate activities but we now need to ask the question "where does fishing end, and aquaculture start?" The release of hatchery-reared animals into the wild for capture fisheries enhancement is aquaculture-driven and is therefore referred to as "culture-based fisheries" (FAO 1997b). Another type of activity entails the capture of animals from the wild for farming purposes. We have coined the term "capture-based aquaculture" to cover this form of overlap between fisheries and aquaculture, namely when fishing is put at the service of aquaculture and is defined as, *Capture-based aquaculture is the practice of collecting "seed" material – from early life stages to adults - from the wild, and its subsequent on-growing in captivity to marketable size, using aquaculture techniques.*

Capture-based aquaculture has developed due to the market demand for some high value species whose life cycles cannot currently be closed on a commercial scale. Capture-based aquaculture has certain advantages and disadvantages compared to aquaculture which controls the full breeding cycle of farmed species. The system does not rely on controlling the reproduction and breeding of farmed species. Thus, species of high market value or those that are readily available naturally can be farmed without the necessity to develop hatcheries or breeding programmes. The lack of domestication potential for wild-caught species is, however, a prime disadvantage as genetic improvement is not possible even in the long term. This type of aquaculture is practiced on high value marine finfish species such as tuna which require high protein diets and sturdy culture facilities. However, it is also used on low-value fish species that are sometimes farmed in small ponds or inexpensive farming systems with minimum inputs. The former provides economic opportunity, but requires substantial infrastructure and investment, whereas the latter provides food security and an additional income source to rural communities. All forms of CBA need to be evaluated in light of economic viability, the wise use of natural resources and the environmental impact as a whole. The extent and scale of CBA practices are difficult to quantify, however it is estimated that they comprise about 20 percent of marine aquaculture production, with an annual market value of US$1.7 billion. The culture of many freshwater species also relies partly or fully on fry caught from the wild because the supply from hatcheries is not adequate to meet the demand, or because the quality of hatchery-produced seed is perceived by farmers to be inferior to wild-caught seed.

Capture-based aquaculture is a worldwide aquaculture practice and has specific and peculiar characteristics for culture, depending on areas and species. An overview shows a worldwide distribution of this practice. Some examples of the species/groups harvested as wild juveniles and the various countries/regions where capture-based aquaculture is practiced is presented below:

- ✓ Shrimp (*Penaeidae*) in South America and South-East Asia;
- ✓ Milkfish (*Chanos chanos*) in the Philippines, Sri Lanka, Pacific Islands and Indonesia;
- ✓ Eels (*Anguilla* spp.) in Asia, Europe, Australia and North America, mainly in China, Japan, Taiwan Province of China, The Netherlands, Denmark and Italy;
- ✓ Yellowtails (*Seriola* spp.), mainly in Japan, Taiwan Province of China, Viet Nam, Hong Kong, Italy, Spain, Australia and New Zealand;
- ✓ Tunas (*Thunnus* spp.) in Australia, Japan, Canada, Spain, Mexico, Croatia, Italy, Malta, Morocco and Turkey; and
- ✓ Groupers (*Epinephelus* spp.), which is now widespread in Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, Hong Kong, People's Republic of China, and Viet Nam, and in other parts of the tropics, for example in southeastern USA and Caribbean. Grouper culture is also on-going in India, Sri Lanka, Saudi Arabia, Republic of Korea and Australia.

Representative species In CBA

Selected representative species for CBA from four taxonomic groups, molluscs, crustaceans, echinoderms and finfishes, Four classes of species in CBA were identified according to market demand both locally and internationally, stock condition, high predictability in time and/or location, ease of capture and accessibility. Most are higher value species rather than regular food for cheap daily consumption because these are the species on which much of CBA is focused, so economic forces are also a major factor in determining which species are selected for CBA.

- ✓ Certain valuable species are taken at a wide range of life history stages, from larvae and juveniles of various sizes to adults. Highly valued species included are spiny lobsters (*Jasus* and *Panulirus* spp.), mud crabs, sea cucumbers (*Holothuria* and *Parastichopus* spp.), Atlantic cod (*Gadus morhua*), groupers (*Epinephelus* spp.), the humphead wrasse (*Cheilinus undulatus*) and tunas (*Thunnus* spp.). As adult stocks have become overexploited, attention has turned increasingly to gaining possession of these species at an earlier life history stage and raising them to marketable sizes.

- ✓ Among certain finfishes, such as eels (*Anguilla* spp.), milkfish (*Chanos chanos*), shark catfishes (*Pangasius* spp.), mullets (*Liza* and *Mugil* spp.), temperate basses (*Dicentrarchus* and *Lateolabrax* spp.), jacks (*Seriola* spp.), rabbitfishes (*Siganus* spp.) and tunas, their early life history stages (and to some extent the adult stage) collected for CBA are highly predictable in time and/or location. These species have aggregation, migration and/or shoaling behaviours, the routes, habitats and seasons of which are well-known. Aggregation or shoaling makes such species particularly vulnerable to over-fishing because large numbers can be caught very efficiently and often easily, becoming the basis of seasonal fisheries.
- ✓ The habitats of early life history stages of certain desirable species may be very well-known or distinctive and easy to access. For example, for most molluscs spats settle in intertidal or subtidal zones of coastal waters and are easily and readily collected on artificial settlement collectors or identifiable natural substrates. For crustaceans, such as spiny lobsters and mud crabs, pueruli and megalopa (i.e. larval stage) pre-settlement occurs in large numbers near estuaries, lagoons or mangrove areas. For freshwater catfishes (*Clarias* spp.) and snakeheads (*Channa* spp.), the early life history stages are readily found in swamps, shallow waters and marshes.
- ✓ In many places, although CBA was originally a localized practice, the growing demand for seafood, declining wild stocks of some species, and improved means of international transport of live aquatic organisms, now mean that regional and global trade in wild-caught seeds is common, especially for finfishes. For example, Asian countries such as China and Japan import European glass and elver eels (*Anguilla anguilla*) to make up the short supply of the local species, Japanese eel (*Anguilla japonica*) in CBA. For the shark catfish (*Pangasius hypophthalmus*), regional transfer (mainly from Cambodia to Vietnam) is still common since the ban on wild seed collection in Viet Nam. Regional transfer within Southeast Asian countries of groupers (e.g. *Epinephelus* spp.) is common; for example, China transferred wild seeds of the Hong Kong grouper (*Epinephelus akaara*) to China Hong Kong Special Administrative Region (SAR) for CBA in the 1980s after overexploitation of adult and seed resources locally. For the Japanese amberjack (*Seriola dumerili*), China and Viet Nam have exported wild seeds to Japan since the 1980s. For the red seabream (*Pagrus major*), China Hong Kong SAR was once the major supplier of its wild seeds to Japan in the 1980s–1990s before the seed fishery dwindled.

Selected representative species of molluscs, crustaceans and echinoderms taken for CBA

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**
MOLLUSCS			
Mytilidae (mussels) *Mytilus edulis* *Mytilus galloprovincialis* *Perna canaliculus* *Perna viridis*	Spats (juveniles) after settlement with <10 mm; Sub-marketable size with <50 mm	Hard substrate of intertidal and subtidal zones of shore waters	*Global* *Asia*: China, Korea Rep., Philippines, Singapore, Thailand *Europe*: Denmark, France, Italy, Netherlands, Spain *South America* *North America* *Oceania*: Australia, New Zealand
Pteriidae (pearl oysters) *Pinctada margaritifera* *Pinctada maxima*	Spats (juveniles) after settlement	Reef habitats with 25–40 m deep, clean and pollution-free seawaters	*Regional* *Asia*: Japan, Indonesia *Oceania*: Australia, Cook Islands, French Polynesia
Pectinidae (scallops) *Argopecten purpuratus* *Chlamys opercularis* *Mizuhopecten yessoensis* *Patinopecten yessoensis* *Pecten maximus* *Placopecten magellanicus*	Spats (juveniles) after settlement with about 3–10 mm	Sandy or muddy bottoms of shore waters with fine gravels or stones	*Global* *Asia*: Japan *Europe*: Russian Federation, United Kingdom *North America*: USA *South America*: Chile *Oceania*: Australia
Ostreidae (true oysters) *Crassostrea gigas* *Crassostrea plicatula* *Crassostrea rivularis* *Crassostrea virginica* *Ostrea edulis*	Spats (juveniles) after settlement with 5–10 mm; Sub-marketable size	Estuaries waters, intertidal zones with sandy or muddy flats, or rocky substrates	*Regional* *Asia*: China, Japan, Korea Rep., Philippines, Thailand *Europe*: France, Ireland, Netherlands, Norway, Spain, Yugoslavia
Cardiidae (cockles) *Anadara granosa* *Cerastoderma edule*	Spats (juveniles) after settlement with 6–10 mm or 5–10 g	Intertidal zones with muddy or sandy bottoms	*Regional* *Asia*: China, Indonesia, Korea Rep., Malaysia, Philippines, Thailand, Viet Nam *Europe*: UK

USA = United States of America
UK = United Kingdom

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**
CRUSTACEANS			
Penaeidae (shrimps) *Metapenaeus spp.* *Penaeus japonicus* *Penaeus monodon* *Penaeus vannamei*	Post-larvae (PL) (juveniles)	Surf zones, shore waters with sandy bottoms, estuaries areas, tidal canals, mangrove areas	*Regional* *Asia*: Bangladesh, India, Indonesia, Malaysia, Philippines, Viet Nam *South America*: Ecuador
Palinuridae (spiny lobsters) *Jasus edwardsii* *Panulirus hormarus* *Panulirus ornatus* *Panulirus polyphagus*	Pueruli (larvae) between 7–8 mm and 0.25–0.35 g, and 10–15 mm and 1–9 g, at settlement and post-settlement with age of 1–2; Juveniles up to 30–80g, 100–300g	Coastal waters near estuaries, bays, gulfs and lagoons and coral reefs with sandy or muddy bottoms	*Regional* *Asia*: India, Indonesia, Malaysia, Philippines, Singapore, Taiwan PC, Thailand, Viet Nam *Oceania*: Australia, New Zealand
Portunidae (crabs) *Scylla olivacea* *Scylla paramamosain*	Megalopa (larvae); Juveniles; Sub-marketable sizes (water crabs) with <100 mm and <200 g	Tidal zones with muddy bottoms, seagrass beds and mangrove areas near estuaries and lagoons	*Regional* *Asia*: China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, Taiwan PC, Thailand, Viet Nam
ECHINODERMS (sea cucumbers)			
Holothuriidae *Holothuria scabra* Stichopodidae *Parastichopus californicus*	Juveniles with >1 g; Sub-marketable sizes with about 100 mm	Coastal shallow waters with sandy bottoms, scattered rocks, gravels and seagrass	*Regional* *Asia*: Indonesia, Japan *North America*: Canada

Taiwan Province of China abbreviated as Taiwan PC.

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**
Anguillidae (freshwater eels) *Anguilla anguilla* *Anguilla australis* *Anguilla japonica* *Anguilla rostrata*	Glass and elver eels (juveniles) with <100 mm during their migration from seas to gain assess to rivers	Estuaries and coastal waters near river mouths	*Global* *Asia*: China, Japan, Korea Rep., Taiwan PC, *Western Europe*: France, Italy, Netherlands *North America*: USA *Oceania*: Australia
Chanidae (milkfishes) *Chanos chanos*	Larvae with 10–20 mm during their migration from open sea for foods and appear seasonally in large numbers	Surf zones and shore waters with sandy beaches, river mouths, wetlands, lagoons, estuaries and mangroves swamps	*Regional* *Asia*: Indonesia, Philippines, Taiwan PC *Pacific Islands*
Clariidae (airbreathing catfishes) *Clarias batrachus* *Clarias macrocephalus*	Larvae and juveniles	Swamps, flooded lowlands	*Regional* *Asia*: Bangladesh, China, India, Indonesia, Malaysia, Philippines, Thailand
Pangasiidae (shark catfishes) *Pangasius bocourti* *Pangasius hypophthalmus*	Larvae with 13–20 mm during their migration back along down streams; Juveniles	Along Mekong River and its tributaries	*Regional* *Asia*: Cambodia, Thailand, Viet Nam
Gadidae (cods) *Gadus morhua*	Juveniles with 3–10 g; Sub-marketable sizes with 1–2 kg	Around coastal waters	*Regional* *Europe*: Iceland, Norway
Mugilidae (mullets) *Liza ramada* *Mugil cephalus*	Larvae and juveniles with 20–100 mm during their migration from open sea for foods	Around coastal shallow waters with sandy or muddy bottoms, or dense vegetation, estuaries and lagoons	*Global* *Asia*: China, Hong Kong SAR, India, Indonesia, Israel, Korea Rep., Taiwan PC *Africa*: Egypt, Nigeria, South Africa, Tunisia *Europe*: Greece, Italy, Turkey *Oceania*: Hawaii, Guam
Moronidae (temperate basses) *Dicentrarchus labrax* *Lateolabrax japonicus*	Larvae and juveniles with >20 mm length with shoaling behaviour	Around coastal shallow waters with sandy or muddy bottom and dense vegetation, estuaries, lagoons, harbours, creeks	*Global* *Asia*: China, Israel *Africa*: Egypt *Europe*: France, Italy, Spain, Turkey

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**
Serranidae (sea bases) *Cromileptes altivelis* *Epinephelus akaara* *Epinephelus awoara* *Epinephelus bleekeri* *Epinephelus coioides* *Epinephelus malabaricus* *Plectropomus leopardus*	Pre- and post-settlement stage larvae, juveniles and sub-marketable sizes with 10–250 mm and up to 200 g, most 20–100 mm	Coastal waters with seagrass beds, mangrove waters near river mouths and estuaries, lagoons, tidal pools and reef areas	*Global* *Asia*: China, Hong Kong SAR, Indonesia, Malaysia, Philippines, Saudi Arabia, Singapore, Sri Lanka, Taiwan PC, Thailand, Viet Nam *North America*: USA, Caribbean countries
Carangidae (jacks and pompanos) *Seriola dumerili* (*purpurascens*) *Seriola lalandi* *Seriola quinqueradiata*	Larvae with about 12–15 mm and 2–10 g aggregating with floating fields of seaweeds prior to their pelagic life stage; Juveniles with 25–100 mm and 25–100 g	Coastal, oceanic and offshore waters with floating fields of seaweeds	*Global* *Asia*: China, Hong Kong SAR, Japan, Korea Rep., Taiwan PC, Viet Nam *Europe*: Italy, Spain *Oceania*: Australia
Lutjanidae (snappers) *Lutjanus argentimaculatus* *Lutjanus johni* *Lutjanus lineolatus* *Lutjanus russellii*	Juveniles	Not well-known: could be around coastal waters with seagrass beds, mangrove waters near river mouths and estuaries, lagoons, tidal pools and reef areas	*Regional* *Asia*: Hong Kong SAR, Malaysia, Singapore, Thailand, Viet Nam
Sparidae (porgies) *Acanthopagrus* (*Sparus*) *latus* *Acanthopagrus schlegelii* (*Sparus macrocephalus*) *Pagrus* (*Pagrosomus*) *major* *Sparus aurata*	Larvae and juveniles with 20–100 mm and 0.2–10 g	Around coastal shallow waters with sandy or muddy bottoms and dense vegetation, estuaries and lagoons	*Global* *Asia*: China, Hong Kong SAR, Japan, Taiwan PC *Africa*: Egypt *Europe*: Turkey
Labridae (wrasses) *Cheilinus undulatus*	Juveniles and sub-marketable sizes with 200–400 mm and <300 g	Around lagoon reefs with seagrass beds, hard and soft corals, and mangrove areas	*Regional* *Asia*: Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore
Siganidae (rabbitfishes) *Siganus canaliculatus* Other *Siganus* spp.	Juveniles with shoaling behaviour and predictable seasonality	Around coastal waters with seagrass beds, mangrove areas, and offshore	*Regional* *Asia*: China, Hong Kong SAR, Indonesia, Singapore, Taiwan PC *Oceania*: Fiji
Scombridae (mackerels and tunas) *Thunnus maccoyii* *Thunnus thynnus*	Juveniles, sub-marketable sizes and adults with as small as 150–500 g, to 20–80 kg, to 80–120 kg, up to 600 kg and with shoaling behaviour	Oceanic and pelagic waters	*Global* *Asia*: Japan *Europe*: Croatia, Malta, Italy, Spain, Turkey *Africa*: Morocco, Tunisia *North America*: Canada, Mexico, USA *Oceania*: Australia
Channidae (snakeheads) *Channa* (*Ophiocephalus*) *argus* *Channa micropeltes* *Channa striata*	Larvae and juveniles with 15–100 mm	Shallow waters of lakes, swamps, marshes	*Regional* *Asia*: Cambodia, China, Hong Kong SAR, India, Korea Rep., Laos, Malaysia, Philippines, Taiwan PC, Thailand, Viet Nam

Historical perspective on capture-based aquaculture

A variety of species groups and aquaculture production systems that have evolved based on the collection of gravid females or wild-caught seed show that harvest occurs at life history stages ranging from planktonic (pre-settlement) post-larvae to large juveniles. This historical evolution is changing for many species and production systems, however, as the harvest of wild seed has often been unsustainable and unable to support higher production demands as hatchery produced seed has become more available and of higher quality and less expensive. In many cases, the technological progress in hatchery technology has displaced capture-based aquaculture as a source of seed. The following discussion highlights the historical and technological shifts occurring in the culture of many species which were once fully dependent upon wild caught seed.

In Viet Nam, before 1997, the supply of "*Tra/Basa*" fingerlings relied on wild seed. Recent successes in *Pangasius* breeding (*Pangasianodon hypophthalmus* and *Pangasius boucourti*) have led to more farmers stocking hatchery-reared catfish. About three billion fry were produced in 2004. High seasonal demand for the fry led to an insufficient supply. From the end of 2003 to the beginning of 2005, the price of fry increased two fold. There is concern that the multi-breeding of broodstock in the hatcheries has led to lower quality of fish seed (Sinh, 2005). Increasingly in the Mekong Delta, prawns are coming from hatcheries, as demand for post-larvae rises. Whether this is because of diminishing wild supply, or high demand, or a combination of both, is not known. From the limited information available, there appears to be no evidence that juvenile collection is a wasteful use of the resource, although other species are discarded in the process (Phillips, 2002).

Collection of seed, in particular shrimp seed, involved a significant bycatch of larval fish and crustaceans that was discarded, further damaging wild stocks. Larsson, Folke and Kautsky (1994) estimated that 872–2,300 km2 of mangrove was required to supply post-larvae to Colombia shrimp farms in 1990, equating to 20–50 percent of the countries mangrove forest. In response, state-run hatcheries, often supported with external assistance, were established to supply seed to emerging aquaculture sectors, however, in many cases these hatcheries were often poorly managed, producing low numbers of poor quality seed; furthermore, production cycles were often poorly matched to farmers needs and the timely distribution of seed was problematic (Bunting, 2006).

In Bangladesh, the demand for shrimp fry increased with the rapid expansion of the shrimp industry after the mid-1980s. According to the Department of Fisheries, there are 40 *Upazilas* (sub-districts) under 12 coastal districts along the 710 km long coastal area where shrimp fry are collected (DOF, 2004). The increased fishing pressure on the fry fishery has long been thought to be contributing to the gradual decline in abundance and distribution of mother shrimp causing serious damage to the productivity of coastal and marine fisheries. Moreover, a huge number of eggs, larvae and juveniles of non-target fish and shrimp harvested during shrimp fry collection are included in the bycatch. Overfishing of these fisheries has occurred to the extent that fishing in the artisanal sector is no longer remunerative. The penaeid shrimp stock in particular is over-exploited in all three fisheries, but the fry fishery in particular removes an estimated 90 percent of the *Panaeus monodon* fry stock.

Mud crab aquaculture has been practiced for many years in Southeast Asia, based primarily on capture and fattening of juvenile crabs from the wild. There is an unmet demand for mud crabs and this has led to over-exploitation in many areas. Difficulties with obtaining wild caught juveniles for farming operations, plus concerns of further over-exploitation, have led to major investment in research into hatchery techniques. Of the four species of mud crabs (*Scylla serrata, Scylla paramamosain, Scylla tranquebarica* and *Scylla olivacea*), hatchery technology is only being developed or researched for *S.serrata* and *S. paramamosain* (Allen and Fielder, 2003). In Cambodia, traditional cage culture first developed as an activity integrated with fisheries rather than agriculture, possibly more than a century ago. It subsequently spread to Thailand, Viet Nam and, more recently, to the Lao People's Democratic Republic. Older literature sometimes states that it is indigenous to Thailand but mentions Siem Riep province, previously in Siam but now in Cambodia. The traditional and intensive cage culture of the region developed in association with the "live boats"of fishers which have water-filled holds used to hold and transport the catch. Initially, it was entirely dependent upon wild fish both as seed and feed. Integration may also be at the livelihood level, as cage farmers, especially small-scale ones, may also be fishers and collect their own seed and feed (So *et al*., 2005).

The most important fish species in Cambodia's cage culture system is the strictly carnivorous giant snakehead (*Channa micropeltes*). Supply of giant snakehead seed for cage culture mainly depends on the seasonal wild seed availability in the floodplains of the Great Lake using scoop nets (So *et al.*, 2005). Pond aquaculture has developed gradually in Cambodia in the last decade. Two major fish species, the omnivorous river catfish (*Pangasaianodon hypophthalmus*) and the carnivorous hybrid clariid catfish (*Clarias batrachus* and *Clarias gariepinus*) are stocked in ponds. Wild river catfish seed are collected by both the farmers and fishers from fishing lots, bag net or *dai*, and other small-scale fishing grounds in the Great Lake, Tonle Sap, Mekong and Bassac rivers; while hatchery hybrid catfish seed is imported from Viet Nam (So *et al*., 2005).

Ahmed *et al*. (2001), reporting on the results of an assessment of milkfish fry in the Philippines state that there is a strong perception among the fry gatherers that milkfish fry production from natural stocks is declining. The reasons given for the decline are: pollution, loss or degradation of coastal habitats, overexploitation of fishery resources and a decline in the *sabalo* (fully grown milkfish) population. Data generated by the study based on a one-year catch monitoring record show a declining trend in catch during both peak and lean months when compared to the historic data for the same site. On the other hand, Ahmed *et al.* (2001) found that there are indications of a growing demand for fry in recent years. This is attributable to two factors. The first is a shift from traditional or extensive culture systems to semi-intensive and intensive or high-density culture systems. The second is the shift from prawn farming to milkfish farming. This shift is due to the collapse of the prawn farming industry. It was concluded that fry availability from the wild is highly seasonal and its abundance fluctuates over time and space. The natural supply is unable to cope with the year round demand for fry for grow-out operations, even though the producers use various mechanisms (e.g.stunting the fry in nurseries or staggering the production cycle) to even out the gaps in the supply of fry. This indicates a need to develop a framework for monitoring natural fry resources and to develop greater local participation over the management of fry gathering activities. Hatcheries are seen as an increasingly important source of supply of fry for milkfish aquaculture. While the supply from the wild is decreasing, hatcheries are improving their technology for fry and fingerling production. This could mean competition for fry gatherers. Most milkfish producers, however, place a higher value on wild caught fry relative to hatchery-bred, so there is still a good market for the fry from the wild. The live reef food fish (LRFF) trade, primarily consisting of groupers (Serranidae), wrasses (Labridae) and snappers (Lutjanidae), markets live fish for consumption in restaurants and markets, largely in Asia. Fish are supplied from capture of market sized fish, full-cycle mariculture, and grow-out from wild seed. Most live fish for the LRFF trade are currently wild-caught due to the limited supply from full-cycle mariculture. It is estimated that hundreds of millions of wild-caught seed fish are traded annually to supply grow-out operations, primarily from Thailand, Philippines and Indonesia. Only a small proportion of species desired in the LRFF trade can be hatchery-reared, with several important species still sourced exclusively from the wild. The latter include the coral trout, *Plectropomus leopardus*, the squaretailed coralgrouper, *P. areolatus*, the camouflage grouper, *Epinephelus polyphekadion*, and the humphead wrasse, *Cheilinus undulates* (Sadovy, Donaldson and Graham**,** 2003; Pomeroy, 2007).

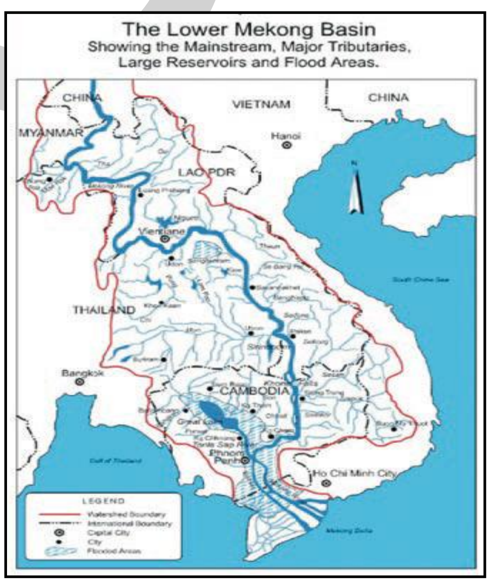
Carp-based aquaculture, which continues to dominate inland aquaculture in Asia, in the past tended to be limited to areas close to wild seed supplies. This may explain the tendency for fish seed production to be concentrated close to the rivers where hatchlings were harvested. The development and adoption of modern hatchery technologies and additional species has begun to change the nature of fish seed supply but the distribution of private sector hatchery and nursery operates often remain clustered (Edwards, Little and Demaine, 2002).

There is continued interest in developing methods for new ornamental freshwater species as well as advancing the culture of marine species. Size selectivity and sex selectivity in the marine ornamentals trade is a concern. For many species, juveniles and sub-adults are more desirable than adults due to their coloration patterns and their more suitable size for home aquaria (Job, 2005). Culture of ornamental fish and invertebrates is now recognized as a feasible alternative to a wild harvest of specimens. Many collecting localities currently limit either the number of fish or the number of species taken, or both. A long history of destructive collecting practices, combined with poor husbandry after collection, has damaged the long term health of reefs with subsequent negative impacts on the potential for harvesting animals and the associated economic benefits of this harvest. Cultivation can help sustain the ornamental fish industry, restore exploited and impacted wild populations and minimize future use conflicts. In addition, mounting pressure from conservation groups and governments restricts the collection of wild organisms which leaves aquaculture as the only means to satisfy market demand for these products (Tlusty, 2002).

CBA – Global Scenario:

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

The Mekong River Basin is probably the largest and most important inland fisheries in the world. 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.



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
- Population of 80 million people living within the Mekong basin, a large proportion of which participate in fisheries activities directly or indirectly.

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. 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

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*) 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. 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 specialized hooks.

Pangasianodon hypophthalmus

Pangasius bocourti

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*). 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. 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

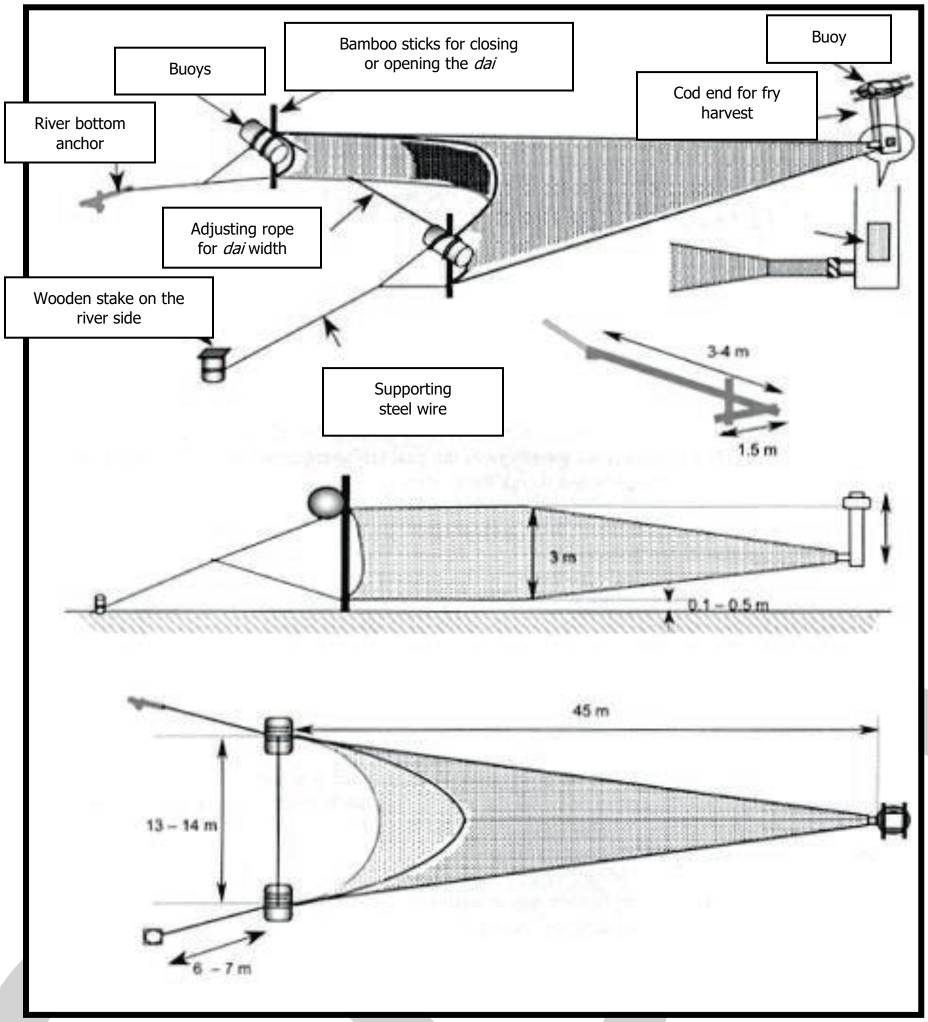
Channa striata

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.

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 occurs over 2–3 months at the beginning of the monsoon season (May–July) when the larvae drift downstream in the Mekong mainstream towards their nursery floodplain habitats. Specialized bag nets, or dais are used, designed to enable the capture of live specimens of the tiny, fragile fish larvae. The dais is typically harvested 3 times daily. Estimates from 1977 suggest that 200 to 800 million fry, 0.9–1.7 cm in length, were caught annually. 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*.



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

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

Year	Number of fry caught (million)
1977	200–800
1994	62
1995	60
1996	56
1997	48
1998	36
1999	27
2000	0.4
2006	0.1[1]

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).

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. Over time aquaculture of both snakehead and Pangasiid catfishes developed and intensified with deliberate capture of juveniles of both species for culture. 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.

Viet Nam

Pangasianodon hypophthalmus ("tra" in Vietnamese) and *Pangasius bocourti* ("basa" in Vietnamese) have been traditionally cultured for centuries in Viet Nam. 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. Presently the majority of *Pangasius bocourti* seed stocked in Vietnamese grow-out systems is from hatcheries, a small proportion is still wild caught.

Capture-based aquaculture of *clarias* catfish: case study of the santchou fishers in western cameroon

Catfishes of the genus *Clarias* (Siluroidei, Claridae) are widespread in tropical Africa and Asia (Sudarto, 2007). *Clarias gariepinus* is by far the most cultivated. However, as they do not normally reproduce spontaneously in ponds, *Clarias* catfish culture is constrained by seed availability. Induced breeding has been developed, but production systems and hatchery management techniques that make catfish seed of good quality readily available to all farmers are yet to be established in most African countries. In these conditions, seed from the wild remains an important opportunity, when available. The traditional practice of enhancing the natural entry of wild fish into flood ponds, such as the "fingerponds" in Lake Victoria wetlands (Unesco-IEH, 2005), and "whedoes" used in Benin and Togo. These traditional aquaculture facilities can be owned by individuals or communities. Due to their location in wetlands, they are often not able to be drained and are typically harvested by intensive capture fishing as water recedes at the end of the dry season, and are sometimes referred to as "amplified fisheries" rather than aquaculture.

Description of *clarias* spp. and its use in aquaculture

There are 58 species in the genus *Clarias* (Siluroidei, Clariidae) recognized in FishBase (2007), all living in freshwater, but able to tolerate salinities up to 2.2 ppt. The naked mucus-covered body is elongate, eel-like, the head is flattened, and eyes are small. *Clarias gariepinus* grows bigger (maximum size recorded 1.7 m total length, in comparison to 0.5 m for *Clarias jaensis*)

Clarias gariepinus

Clarias jaensis

According to the fishers in the Nkam Valley, *Clarias gariepinus* is the desirable and preferred aquaculture candidate, while *Clarias jaensis* is fovoured in traditional dishes and for marriages and other customary celebrations. *Clarias gariepinus*, generally considered to be the most important clariid species for aquaculture, has almost pan-African distribution, ranging from the

Nile to West Africa and from Algeria to South Africa. *Clarias jaensis*' distribution is less known. In Cameroon, this species is found in the Wouri and the Sanaga river basins. Gonadal maturation in *Clarias gariepinus* is usually associated with the rainy season. In Cameroon, reproduction begins in late March-early April with the start of the rainy season. Heavy flooding in the Nkam Valley is observed by October–November, and fingerling collection takes place a month later when the water recedes back to the river bed. Flood ponds are harvested from January to March, with production varying from 200 to 800 kilogram/100 m2 pond. The average individual fish weight is 167 grams

Wild *Clarias* fingerlings

The collection of wild *Clarias* fingerlings for aquaculture is less important than fishing for direct human consumption. In Cameroon the collection of catfish juveniles for aquaculture is specific to the Nkam River basin while it remains a marginal activity in other rivers where *Clarias* spp. are fished. The weight of fingerlings collected for aquaculture ranges between 20–120 grams.

The table shows the length-weight relationships for the most commonly marketed fingerlings in the Nkam Valley.

Clarias gariepinus					
Total length (mm)	175	180	195	200	227
Weight (g)	30	35	42	57,5	118,5
Clarias jaensis					
Total length (mm)	160	165	214	223	243
Weight (g)	30	36,5	80,9	95	132,5

Clarias are relatively robust fish and tolerant of low dissolved oxygen water levels. *Clarias jaensis* demonstrates a quieter behaviour, and is thus easier to handle compared to *Clarias gariepinus*. Nevertheless, the holding and feeding of fingerlings is problematic in Cameroon. The most common error is stocking with different sizes in the same container. As larger fish cannibalize smaller individuals, survival rates of less than 10 percent are common and can occur in less than 5 days of stocking. Another problem is artificial feeding. Uneaten feed rapidly deteriorates water quality, causing high mortalities among smaller fish and swollen bellies in larger specimens

Tilapia-*Clarias* polyculture

Nile tilapia is the most commonly farmed fish in Cameroon. In mixed-sex culture, this species produces large numbers of unwanted juveniles. Overcrowding is controlled by using predator fish. *Clarias gariepinus* is the most commonly utilized species for this. Large fingerlings of 15 grams are stocked with Nile tilapia at a 1:1 ratio and reared for 9 to 11 months.

Geographic overview of juvenile collection in the Nkam Valley

With the flooding of the Nkam and Menoua valleys numerous refuge sites for the young catfish are established in the nearby lowland farms. In addition to fishing for juvenile clariids, there is also a traditional practice of extensive fish farming of catfish in flooded ponds. The main villages concerned with the fishery for juveniles and the catfish aquaculture include Lelem, Ngang, Santchou and Fongwang. Ngang Island is particularly well known as a good fishing ground.

A collection area for *Clarias* catfish juveniles

Fishing gear and materials used for the collection of *Clarias* juveniles

Fishing materials are generally artisanal and consist of 10 to 30 litre buckets, gasoline water pumps for draining water from the fishing grounds, hand nets, seine nets, cast nets and baskets used to catch the juveniles. Materials for transporting the catch from the fishing sites to the market includes 10–40 litre plastic or aluminium containers, canoes, bicycles, and wheelbarrows.

Fishing basket (right) and a two-wheel carrier used for transporting juvenile fish (left)

Handling and holding

The distance from the fishing ground to the fisher's home, to the flood ponds and to the market varies from 0.5 to 15 kilometres. As mentioned above, juvenile *Clarias* are transported to the fish ponds by canoe, wheelbarrow or bicycle. When the destination is outside the valley, cars are used, e.g. for delivery to Kumba which is >300 kilometres away. Prior to transport, the wild seed are kept in 100 litre containers, or in earthen or concrete tanks for up to a month (Figure

5). Water is renewed 1–2 times per day. Fish are fed on corn flour, with care to avoid over-feeding and deterioration of water quality.

A typical concrete tank for holding catfish juveniles

Capture-based aquaculture of mullets in Egypt

Mullets are members of the Order Mugiliformes, Family Mugilidae. Mullets are rayfinned fish found worldwide in coastal temperate and tropical waters and, for some species, also in freshwater. Most species commonly reach about 20 cm in total length, but some (e.g. *Mugil cephalus*) may attain 80–120 cm. The head is broad and flattened dorsally in most species. The snout is short and the mouth is small. Most mullets are found in coastal marine and brackish waters. They are nektonic, usually in shallow inshore environments, such as coastal bays, reef flats, tide pools, and around harbor pilings and in brackish water estuaries, lagoons and mangroves.

Many species are euryhaline and move between marine and freshwater environments of rivers and flooded rice fields. Some species occasionally swim far up river, while a few species spend their entire adult lives in rivers. Mullets migrate in large aggregations from their feeding grounds in rivers, estuaries, lakes or lagoons to the sea for spawning in a single spawning cycle each season. Spawning seasons differ according to species and regions. Fecundity is high in all species and is estimated at 0.5–2.0 million eggs per female depending on the size of the adult. Eggs are scattered on the bottom substratum in open waters and left unguarded. The eggs develop at sea and hatching occurs about 48 hours after fertilization, releasing larvae of approximately 2.4 mm in length. When the larvae reach 16–20 mm they migrate to inshore waters and estuaries.

The grey mullets, found in coastal waters of the tropical and subtropical zones of all seas, are catadromous, frequently found in estuaries and freshwater environments. Adult mullet have been found in waters ranging from zero salinity to 75 ppt, while juveniles can only tolerate such wide salinity ranges after they reach lengths of 4–7 cm. The flathead grey mullet was the first species of mugilidae used for aquaculture. In Egypt, this species has been used for traditional aquaculture and culture-based fisheries since the late 1920s and is still of major importance today also in other Mediterranean countries and Taiwan Province of China.

The thin lip grey mullet, *Liza ramada*, although the second choice in the aquaculture of mullet constitutes the majority of the aquaculture harvest of mullet in Egypt. This species has a lower growth rate than *Mugil cephalus*, but exceeds that of all other Mediterranean mullet species. The availability and abundance of the wild fry of this species as compared to those of *Mugil cephalus* makes it the dominant aquaculture species. Thin lip grey mullet can reach a body length of up to 70 cm. in the vicinity of freshwater outflows. It feeds on minute bottom living or planktonic organisms (e.g. diatoms and amphipods) and also on suspended organic matter. *Liza ramada* is native in the Eastern Atlantic from the coasts of southern Norway to Morocco, including the Mediterranean and the Black Sea.

The bluespot mullet (*Valamugil seheli*) although it has a lower growth rate, fetches a higher market price compared to the other cultured mullet in Egypt. The fish is highly appreciated for its taste and usually consumed at an individual body weight of 120–180 grams. The bluespot mullet can reach a body length of 60 cm. The species usually swims in schools and inhabits coastal waters, but enters estuaries and rivers where it feeds on microalgae, filamentous algae, forams, diatoms,and detritus associated with sand and mud. In Egypt, the species is caught mostly from the Red Sea, Gulf of Suez, Suez Canal and the Bitter Lakes.

Flathead grey mullet, *Mugil cephalus*

Thinlip grey mullet, *Liza ramada*

Bluespot mullet, *Valamugil seheli*

Mullet aquaculture

Mullet are cultured in a large number of countries worldwide, usually in extensive and semi-intensive pond systems. Egypt has a long history of mullet aquaculture, which was traditionally practiced in the "hosha" system in the Nile Delta region for centuries. Currently, Egypt is a leading country in mullet aquaculture. Most mullet aquaculture activities rely on the use of wild seed, e.g.Egypt, Taiwan Province of China, the Philippines, Italy, Greece, Israel, Tunisia and Turkey. Reliance on collection of wild seed was a result of either insufficient supply of hatchery produced seed or its higher price. Commercial hatchery production of mullet seed is carried out in some countries. Induced spawning and production of fry has been achieved on an experimental and semi-commercial basis in the United States of America and Taiwan Province of China. In Egypt, mullet fry were first produced in a hatchery near Alexandria through a project in the early 1990s funded by the United States Agency for International Development (USAID). The hatchery production capacity was limited and was capable of producing annually 1–2 million fry of flathead grey mullet. The production cost was high and the fry sold for as much as 15 times the price of wild fry.

Wild seed fishing

Legal aspects

In Italy, the collection of wild fry is managed by the authorities that issue limited fishing licenses each year between September 16 and December 31 after an assessment of relevant environmental parameters. Each licensee is allowed a quota of fry catch. Fishing is prohibited at the outlets of rivers and in brackish lagoon channels up to 400 m from the sea. Fishers must be equipped with oxygen supplied transport tanks. In Israel, special licenses are required to collect wild mullet fry. The department of fisheries and aquaculture, which also monitors the implementation of the law by means of inspectors, issues these licenses on a yearly basis. No fishing quotas are established. Wild fry collection in Egypt is controlled by the Fisheries Law No. 124/1983.

According to this law, it is prohibited to fish, collect, handle or transport wild fish fry unless an official permit is obtained from the competent governmental authority (i.e. GAFRD). Fishing for wild fry is also allowed in limited sites supervised and managed by the governmental fry collection stations. The fry collection stations also act as the distribution and marketing sites for wild fry. Fry price is decided by the government authority and may fluctuate each year according to market demand. According to local legislation, fry and fingerlings are sold only to licensed fish farms. Each fish farm is allocated a quota of 6 250–7 500 fry/ha of flathead or thinlip grey mullet or up to 12 500 fry of bluespot mullet. This regulation has created an illegal activity of fishing and marketing of wild-caught seed by gangs of illegal fishers. The number of fry collected through this illegal activity is not recorded and is uncontrolled. The size of this illegal trade is believed to be very large and the number of collected fry may exceed those collected through the official stations.

Fishing techniques

Hatched larvae drift with surface water currents (Rossi, 1986) and then swim in large aggregations towards the shallow coastal waters to reach the rich feeding grounds in the estuaries and coastal lagoons. Mullet seed reach the estuaries and shallow coastal waters as fry that are 12–20 mm long. The gear was made from mosquito nets fitted to a rectangular metal frame with a wooden roll bar fixed to the front edge of the frame and pushed in the shallow coastal water by a team of three fishers. The reported fry catch of such gear was about 20 000 fry per hour. With the increased demand for fry in the late 1990s, shoals of fry were collected in coastal water using larger fine seine nets. The commonly used seine is 50–150 m wide and 2.25 m deep. Netting material is made of strong monofilament threads of synthetic fibers with 1 mm stretched mesh size.

Collecting mullet fry using a seine net along the Mediterranean coast

Aquaculture dependency on wild seed

Commercial aquaculture of mullet in Egypt and other producing countries relies exclusively on wild-caught fry even though hatchery techniques have been successfully developed. Fishing wild fry for aquaculture has always been a matter of debate between environmental groups, capture-fisheries communities and fish farmers. The increasing rate of seed collection in the mid-1990s was considered as a major threat to the capture fisheries. Artisanal fishing cooperatives organized extensive campaigns against wild seed collectors. Environment groups believe that wild seed collection will reduce stock recruitment even though the authority claimed that the number of collected fry will have a negligible effect to the wild mullet population. The argument is based on the fact that mullet are characterized by a very high fecundity, which means that the number of collected fry for aquaculture is a very small fraction of the seeds produced by these fish. It is also claimed that the fry losses for aquaculture are considerably less than that from natural predation.

Capture-based aquaculture of wild-caught Indian major carps in the Ganges Region of Bangladesh

Bangladesh is a riverine floodplain country with over 700 small, medium and large rivers and three major river systems (the Ganges, Brahmapura and Meghna) that originate from the Himalayan chain, cross the country and then join before emptying into the Bay of Bengal. Bangladesh has a humid climate with three broad seasons: warm summer (March to May), wet monsoon (June to October) and cooler winter (November to February). Rainfall is abundant and ranges annually from 140–400 cm,with over 80 percent received during the monsoon months. The warm temperatures and high rainfall, coupled with numerous rivers and wetlands that are rich in nutrients, have endowed the country with rich fisheries resources.

General information on the carp

The four species of carp found in the waters in Bangladesh are grouped together as Indian major carps: catla (*Catla catla*), roho labeo or rui (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and kalibaush (*Labeo calbasu*). Although the age of maturity for spawning varies by species, all require at least two years to attain sexual maturity and spawning ability; rui require at least two years, mrigel requires 2–3 years, and catla and kalibaush mature at three years.

Four species of major carp of Bangladesh with key biological and aquaculture characteristics

Major carp species	Key biological and aquaculture characteristics
 Catla: *Catla catla*	*Age of maturity:* 3–5 years *Trophic level:* Surface feeder *Growth potential:* High *Aquaculture potential:* High *Share in pond aquaculture:* 19.9 % (2004–05) *Share in Kaptai Lake*: 31 % of major carp (2004–05) *Share in annual Beel catch:* 7 % (2004–05)
 Rui: *Labeo rohita*	*Age of maturity*: 2–3 years *Trophic level:* Column feeder *Growth potential*: Medium *Aquaculture potential*: High *Share in pond aquaculture:* 23.4 % (2004–05) *Share in Kaptai Lake*: 11.9 % of major carp (2004–05) *Share in annual Beel catch:* 8.2 % (2004–05)
 Mrigel: *Cirrhinus mrigala*	*Age of maturity*: 2–3 three years *Trophic level:* Column feeder *Growth potential:* Medium *Aquaculture potential*: High *Share in pond aquaculture:* 16.2 % (2004–05) *Share in Kaptai Lake*: 6.9 % of major carp (2004–05) *Share in annual Beel catch:* 7.3 % (2004–05)
 Kalibaush: *Labeo calbasu*	*Age of maturity:* 3 three years *Trophic level:* Column feeder *Growth potential*: Medium *Aquaculture potential:* Low *Share in pond aquaculture:* 0.6 % (2004–05) *Share in Kaptai Lake*: 50.1 % of major carps (2004–05) *Share in annual Beel catch:* 2.2 % (2004–05)

The adult carp begin their spawning migration in the pre-monsoon season (March), coinciding with the gradual rise of water flow due to snow melt in the Himalayas, and the early rains and the rise in water temperatures. Spawning starts in May with the onset of southwest monsoon rains, and continues until July. Soon after spawning, the adults and fish larvae migrate downstream to the floodplains for feeding and remain there for 4–5 months. They passively migrate with the water current, and drift laterally onto the extensive productive floodplains. They then migrate back to deeper areas in the rivers and *beels* for overwintering along with the receding water during late monsoon.

Wild stock of major carp

Based on the differences in the spawning grounds, spawning seasons, and geographic distribution, the major carp in Bangladesh are often divided into four stocks named by the respective river system:

i) Brhamaputra-Jamuna stock,
ii) Upper Padma stock
iii) Upper Meghna stock, and
iv) Halda stock

Brhamaputra-Jamuna stock:

The carp in this stock possibly do not spawn within Bangladesh, as only major carp juveniles are collected from the Brhapamutra - Jamuan river systems even in the upper reaches of the river near the Indian border. The Brhamaputra-Jamuna stock travels a long distance from the lower reaches of the rivers to their spawning grounds at the southern tributaries of the upper Brahmaputra river in the Assam Hills and Letha Range, in Assam, India. The major carp in this stock spawn in the wild. Major pulses of spawn are caught in May and June, with less captured in July, coinciding with the onset of the southwest monsoon with the rise of water flow, temperatures and rainfall.

Upper Padma stock:

This stock of major carp is found in the Padma River below the Farraka Dam and its associated tributaries, canals and *beels*. In Bangladesh, fry collection in the Padma River takes place during June, July and August, suggesting that there might be a different spawning ground of major carp in the Padma River downstream of the Farraka Dam. Based on the time of availability of carp spawn in the Upper Padma, it is assumed that the spawning migration of major carp in the Padma River occurs from April to May/June,

Upper Meghna stock:

This stock remains at the upper reaches of the Meghna River from its confluence with the Old Brhamaputra River, up to the tributaries, *beels* and *haors* in Bangladesh and India. Unlike other river systems, there are no commercial carp spawn collection centers in the Upper Meghna River basin. The spawn collection centers located at the headwaters of the Surma River in Manipur province, and some in the Tripura province in India.

Halda stock:

The Halda River in the southeast of Bangladesh originates from three major tributaries that come out of the Chittagong Hill tracts, namely the Dhurang, Talpari and Sareakhal. Three species of major carp (*C. catla*, *L. rohita* and *C. mrigala*) spawn in this tidal river every year. This is the only tidal river located very close to the coastline where major carp have been naturally spawning. This spawning ground is considered as one of the richest and oldest carp spawn fisheries, and has been meeting the demand of carp fry for pond aquaculture in the immediate area as well as much of the other parts of the country.

Major carp fry fisheries

All floodplain fish species in Bangladesh spawn in the pre-monsoon to monsoon months (March–October), the exact timing depending on the climatic conditions that affect the different species. All four species of carp breed during the monsoon and rivers play a vital role in their breeding functions. Therefore, rivers not only providing habitats for the capture fishery, but also support the very important major carp grow out, spawn and fry fisheries.

Fry collection sites

Of the various river systems from which the carp spawn is collected, three rivers and their tributaries are particularly important. These are Ganges-Padma (southwest), Brahmaputra-Januma (north central) and Halda (southeast) river systems. It is estimated that there are over 90 spawn collecting centers or points in the country's three major river systems.

Species of carp by river systems

The major carp species in the collected spawn from the Halda River are catla (*C. catla*) (81.8 percent), the remainder being rui (*L. rohita*) (9.5 percentand) mrigel (*C. mrigala*)(8.7 percent), with Catla being the fastest growing Indian major carp species. The demand for Halda spawn remains very high compared to spawn from other river sites. The fry captured a month later had a different composition, with catla, rui and mrigel being 23.5, 32.8 and 43.2 percent, respectively.

The spawn of other river systems (Ganges-Padma and Brhamaputra-Jamuna) is a mix of all species of major carps, including a small percentage of minor carps (*Labeo bata* and *Cirrhinus reba*). One of the major carp species,the rui (*L. rohita*), dominated the remainder of the spawn and constituted 30.4 percent of the total catch and nearly 90 percent of the total major carp spawn. Mrigel and catla constituted a small quantity in the catch.

Trends in natural carp spawn collection:

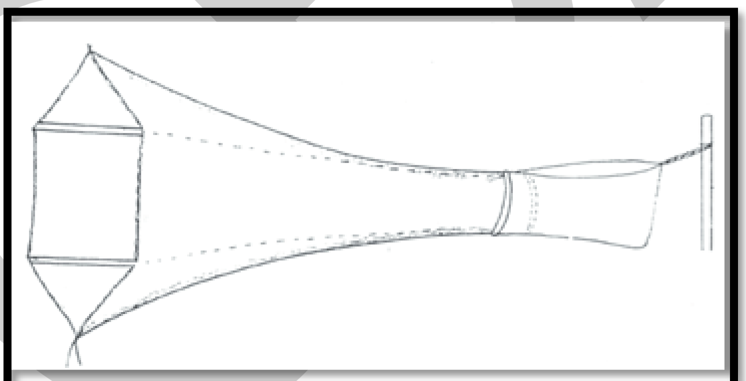
The quantity of spawn collected from river sources was previously much higher than at present. The average yearly catch has declined from 17 241 kilograms in the 1980s (mean of 6 years data), to 5 194 kilograms in the 1990s (mean of 10 years data), to only 2 255 kilograms in the 2000s (mean of 6 years data).

Degradation of natural breeding habitats

Flood Control Drainage and Irrigation (FCDI) projects have altered many important fish breeding and nursery areas in Bangladesh. The infrastructure built under FCDI projects, such as embankments, sluice gates and closures, not only reduced the wetland area but also blocked and/or obstructed the fish migration routes. As a result, migration for spawning, nursery and feeding areas has been seriously impacted, resulting in a decline in the carp fishery as a whole.

Spawn fishing gears

The major carp spawn fishing gear that has traditionally been used in the two major river systems (Ganges-Padma and Bhrhamaputra-Jamuna) is a funnel shaped fixed net, popularly called a "savar net". This is a type of set bag net specially designed to fix the net at the shallow, gently sloping shoreline of the rivers, where the depth of water is negotiable without any aid. The savar net is usually small, with a collection pocket at the tail end. The net is made of a fine mesh that traps tiny eggs or spawn that drift with the water flow during the monsoon months. A water flow in the range of 20–60 cm/sec. is desirable for spawn trapping.



Sketch of a typical savar net used in major rivers in Bangladesh for major carp spawn fishing

The savar spawn collection nets are placed in several rows near the shore, facing the current, at intervals of 2–8 m, and each row may have between 3–15 nets. The front extensions of the adjacent nets are tied together to the same bamboo pole, the poles having been set in the river at the beginning of the fishing season to mark the area of each savar site. The upper edge of the tail bag is kept about 4–5 cm above the water surface to prevent the escape of spawn.





Boats

Locally made boats of various sizes and shapes, mechanized and non-mechanized, are used for spawn collecting and transport. The most commonly used boat is small and normally carries 1–2 fishers while larger mechanized boats may carry up to 3 fishers and are usually preferred as the collected spawn can be transported quickly to the sale sites.

Handling and transportation of spawn

Usually a spawn collector operates more than one net, depending on the suitability of the sites and extent of spawn availability. Depending on silt load, water depth and spawn pulses, the operators remove, clean and reattach the nets as needed. During strong spawn pulses the spawn is scooped from the net traps every 15 to 30 minutes.

Aquaculture dependence on the wild fish seed

Over the last 15 years there has been a marked decrease in dependence on wild seed of major carp for aquaculture due to increasing capacity for producing spawn at private and government hatcheries in Bangladesh.

Adverse impact of savar fishing

The adverse impacts of savar fishing for carp spawn have been summarized as:

- ✓ Reducing the natural recruitment potential of carp (also to some extent, that of other species) and thereby gradually diminishing the natural stock.
- ✓ Reducing the shallow nursery and rearing areas in the river basin due to operation of savar fishing, thus negatively impacting natural productivity.
- ✓ Reducing the natural gene pool due to indiscriminate savar fishing.
- ✓ Affecting the natural productivity of carps in the wild due to mishandling of spawn fishery operations by inexperienced net operators, which may cause mass mortality of spawn.
- ✓ Negatively affecting overall capture fisheries production in the wild as a result of thousands of spawn of other fishes being damaged during the process of catching major carp spawn.

Capture-based aquaculture of the wild European eel (*Anguilla anguilla*)

Biological outlines

The European eel (*Anguilla anguilla*) occurs from Mauritania to the Artic Circle and the Mediterranean, and is an amphihaline and Catadromous species with a complex biological life cycle, many aspects of which are still poorly understood or undocumented. The biological cycles are often short and the stock is largely confined to coastal lagoons, particularly along the northern Africa and the French Mediterranean coasts. Exploitation is focused primarily on yellow and silver eels.

Fishing exploitation of the species

Eel is exploited at all its development stages and in various ecosystems (marine, brackish and freshwater). Fishing intensity on the different biological stages is highly variable according to the catchment areas and the geographical "groups" mentioned above. The exploitation of the glass eel ranges from 0 percent (e.g. in the Mediterranean Sea where fishing is prohibited in many river basins) to over 90 percent. Glass eel stage indicating that the exploitation has reduced the abundance of the glass eel arriving at the mouth of the rivers observed by 85 percent.

Typical glass eels caught in estuaries

For yellow eel, the data show a large fluctuation of the exploitation rate according to the hydrological parameters.

Biological stages harvested

Yellow and silver eels are generally used for human consumption as is the glass eel in Spain and in the southwestern part of France. Glass eels, elvers and, more rarely, small yellow eels, are used for aquaculture and restocking. Glass eels are the most commonly used for aquaculture purposes for several reason,

- ✓ Almost 100 percent of glass eels accept the initial food offered
- ✓ They are easier to wean on artificial food
- ✓ They have been collected for direct consumption for many decades, and the fishing industry was able to provide a good supply when aquaculture activity started
- ✓ They are easy to transport
- ✓ Compared to elvers they carry fewer pathogens, parasites, viruses or bacteria.

Difficulties in obtaining juveniles in controlled conditions

In contrast to the Japanese eel, *Anguilla japonica,* where the first glass eels were obtained in the laboratory in 2001 the success in artificial maturation of the European eel *Anguilla anguilla* has been limited until very recently (Tanaka *et al.*, 2003). The first recorded hatched larvae were described in 1983 with the prolarvae surviving only 3.5 days.

Farming techniques – a brief overview

Two rather different eel rearing techniques are in used:

1. The European intensive and
2. The Asian semi-intensive farming systems.
3. A third farming technique also exists, used mainly in northern Italy and based on extensive farming in coastal brackish waters (known as "vallicoltura"), but this technique is hardly active any longer.

European intensive farming

This technique was developed to save on energy and wastewater costs and is mainly used in northern European countries. The eels are reared at very high densities (up to 120 kg eels/m3 of water) in indoor tanks with a strong water flow to provide the necessary oxygen and removal of waste products, such as ammonia, faecal matters, carbon dioxide and food remnants. The effluent is treated and recycled in a specially designed unit with an annual output of 100 tonnes. Most operations are automatic (e.g. feeding, grading, water parameter controls, cleaning) to save manpower. In fact, only 1.5 employees are needed for an annual production of 100 tonnes.

Asian semi-intensive farming

An intensive indoor recirculated water eel farm in Europe (top) and an extensive outdoor still water eel pond in China (bottom)

As more than 50 percent of all European elvers collected since 1986 are farmed in Asia a brief description of the culture system is described below. Culture is usually carried out in still water ponds at considerably lower densities or a maximum of 20 kg/m2. Surface aerators provide the necessary oxygen and create a current which concentrates the sediment in the centre of the ponds. Approximately 20–30 persons are employed for each 100 tonnes produced. The main problems in eel farming are the following: 1) preventing escapes; 2) the significant percentage of fish refusing the artificial feeds; 3) disease problems; 4) high production costs; and 5) the slow growth in intensive farming systems once the fish has reached an average body weight of 150 grams.

Exploitation at all biological stages in various ecosystems

In these different ecosystems, the different biological stages are exploited using a large variety of fishing gear. Glass eels or elvers are caught off the coast or in the lower sections of rivers. Nearly all the juveniles for Europe come from fishing activities along the Atlantic coast and the English Channel. In the Mediterranean, the

catch of glass eel is not allowed on the French coast, but does occur in the estuaries of some Italian rivers. Harvest also occurs in Spain.

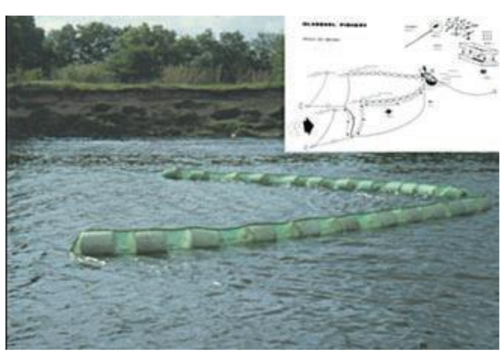
Fishing gear used

A variety of gear has been used to catch eel juveniles (e.g. dip net, scoop net, fyke net with a fine mesh – 1 mm2), but these can be grouped in gear used by hand and gear pushed by a boat. There is an important difference in the efficiency between the two fishing techniques. In Portugal, on the Minho River, a special gear is used called the “tela”. The sieves used are generally circular with a diameter around 1.20 m often fixed pole ranging between 3–10 m in length. In France non-commercial fishers are permitted to collect glass eels as long as the catch per day is 500 g.

Size and dimensions of the fishing gears used in France

Type of fishing gear	Shape	Surface of water filtration
Pushed net	Circular	2.26 m²
Large Pushed net “Pibalour”	Rectangular	8–14 m²
Pushed net	Squared	2.88 m²
Pushed net	Rectangular	3.60–4.32 m²
Handled scoop net	Oval	≈0.8 m²

Size and dimensions of the fishing gears used in France



An anchored tidal net known as “tela” used on the Minho

River, Portugal

Wild versus hatchery produced seed

Eel aquaculture is 100 percent dependant on wild seed and the supply of glass eels is decreasing. Some harvest areas seem to be declining more rapidly than others, but, as the European eel population must be considered as a whole, the overall supply is at risk. The collected seed material in Europe exceeds the needs of the aquaculture industry, and the excess supply is consumed in Spain as an expensive seafood delicacy. If artificial breeding of the European eels becomes possible, it could still take many years before the necessary quantity of seed required for farming becomes available and can be economically produced.

Capture-based aquaculture of bluefin tuna

The bluefin tuna was first described by Linnaeus in 1758 as *Scomber thynnus*. Many other denominations followed, such as *Thunnus vulgaris* and *Thunnus thynnus*. The *Thunnus thynnus* is found in Labrador, Canada and continues south to the Gulf of Mexico and the Caribbean Sea and also off the coast of Venezuela and Brazil in the Western Atlantic. In the Eastern Atlantic it occurs from the Lofoten Islands off the coast of northern Norway south to the Canary Islands and the Mediterranean Sea. There is also a population in South African waters.

Habitat and biology

Northern bluefin tuna are large pelagic marine fish. The juveniles are encountered in epipelagic waters whereas large tunas tend to be mesopelagic and are found also in deeper and cooler waters. The species has considerable thermal tolerances, as it can be found in waters as cold as 10 °C, as well as in tropical areas. Generally, the most critical environmental parameters for these large pelagic fish are sea surface temperature and the levels of dissolved oxygen and salinity.

***Thunnus thynnus* larvae (left), a school of juveniles (middle) and adults in a fattening cage (right)**

The following three growth stages can be distinguished:

1. Larvae :recently hatched individuals which are considerably different in appearance from juveniles or adults

2. Juveniles : Similar in appearance to adults, but sexually immature; and
3. Adults : Sexually mature fish

The maximum reported weight of an adult specimen has been 684 kilograms, with a total length of 458 cm. The species seems to have an average lifespan of around 15 years.

Schooling and migration

All bluefin tuna species move constantly in search for food and to maintain a constant water flow over their gills. The Atlantic bluefin (*Thunnus thynnus*), pacific Bluefin (*Thunnus orientalis*), and southern bluefin (*Thunnus maccoyii*) tunas all migrate seasonally over long distances between temperate waters, where they feed, and tropical waters, where they spawn. Spawning of all three species is generally restricted to relatively restricted areas in temperate and tropical waters.

Tuna must swim constantly to satisfy their oxygen requirements in order to stay alive. Their swimming pattern seems to be influenced by both the distribution of food and the need to return to their ancestral spawning grounds at the appropriate time. To efficiently transfer oxygen from the gills to the other body tissues, tunas have hearts that are approximately 10 times the size of those of other fish, relative to the body weight, and blood pressure and pumping rate about three times higher. Tunas have two types of muscle, white and red. The white muscles function during short bursts of activity, while the red muscles, which have a relatively large mass, allow the fish to swim at high speeds for long periods without fatigue.

Feeding

Tuna larvae live in warm surface waters and feed primarily on zooplankton, including small crustaceans and the larvae of crustaceans, fishes, molluscs and jellyfish. Tuna larvae are preyed upon by zooplankton foragers, such as larger larvae and early juveniles of other pelagic fish. Juvenile and adult tuna generally prey on fish, squid and crustaceans. The larger specimens, which feed on pelagic fishes, are positioned at the top of the trophic web and locate their prey visually.

Reproduction

The spawning of *Thunnus thynnus* has been so far detected in the Mediterranean and the Gulf of Mexico. In the Gulf of Mexico, spawning occurs from April to June when the water temperature is 25–30 °C and in the Mediterranean from May/June to August. Bluefin tuna spawn in the Levantine Sea (Eastern Mediterranean basin) with a peak in the activity in May. Sexual maturity of the Atlantic bluefin tuna is reached at the age of 5 to 8 years, while in the eastern Atlantic maturity is reached earlier, at 4–5 years. Bluefin tunas may release from 5 to 30 million eggs and spawning occurs in open water close to the surface and in areas where the survival expectations of the larvae is highest.

Capture-Based Aquaculture

Thunnus thynnus is considered a capture-based aquaculture (CBA) species, as the farming activity is entirely based on the stocking of wild caught individuals. Scientists at Kinki University, Japan, achieved the completion of the life cycle of the Pacific bluefin tuna (*Thunnus orientalis*) under controlled conditions after 32 years.

Fishing techniques, season and catching size

For farming purposes, wild tunas are caught at different life cycle stages, ranging from juveniles of less than 8 kilograms to large adult specimens. The capture system is the same for juveniles and adults, i.e. purse seines. This modern and widely used fishing technique basically creates a "purse"net to entrap the school. Juveniles at about 15 kg in weight were also caught around September-October in the Tyrrhenian Sea. There is strong cooperation among the purse seine vessels, often supported by aerial search. Small aircrafts or even helicopters are used to detect bluefin tuna schools however fish finders and sonar are largely used leaving little possibility for the fish to go undetected. A second capture system is the traditional tuna trap which are a fixed gear anchored to the sea bottom, aimed at intercepting tuna in their migration paths. While these are still in use in some countries (e.g. Italy), they are losing ground to the purse seiners, which are far more efficient in detecting and capturing the fish.

Purse seines in the process of fishing bluefin tuna

Aquaculture sites

Following the capture of wild bluefin tuna they are kept alive and carefully transferred to towing cages. The transfer action is a crucial activity as specimens may suffer severe stress that may lead to death. During the transfer process the fish are gently forced to move from the purse seine net to the towing cage usually by sewing the nets together. Once the tuna are all moved into the towing cages, tugboats are used to transport the fish from the fishing area to the on-growing or farm site. Towing speed does not usually exceed 1–1.5 knots in order to avoid excessive tuna mortality. and to allow tuna to swim easily Mortality rates during transportation are usually quite low (1–2 percent) although there have been rare cases where all the fish have died. Transportation trips that may last days, weeks or even months.

The size of the cages varies from 30–90 m in diameter, with net depths commonly ranging from 15 to 20–30 m. The industry mainly uses cages with a 50 m diameter and net depths varying according to sea location. The larger cages (i.e. 90 m in diameter) are mainly used by the Spanish operators while those in Croatia prefer smaller ones in terms of net depth, i.e. 13 m. Generally the weight of the stocked tuna is between 150–200 kilograms, however Croatian operations generally start their farming with smaller specimens weighing around 8–25 kilograms, while countries like Italy, Malta and Spain may even stock giant tunas weighing as much as 600 kilograms. there are mainly two types of cages used, those for "farming" and those for "fattening". The "farming" cages are designed to contain generally small tuna specimens for long periods of time often more than 20 months. Most countries in the region do not retain the fish for such long periods and usually only confine the tuna for periods of 1–7 months. The "fattening" season which may extend to February and generally not beyond December/January is closely linked to the market demand/opportunity.

Farming mortality

Bluefin tuna mortality rates during the fattening/farming period have been recorded at around 2 percent; however some countries (e.g. Spain and the Libyan Arab Jamahiriya) have reported higher mortalities during the first month the tuna are in cages. This is generally due to the long towing trip which stresses and weakens the fish just before they are moved into the farming cages. Bluefin tuna show great adaptiveness in captivity and so far no specific diseases have been recorded, nevertheless high mortalities may occur due to adverse environmental conditions such as strong currents or elevated water turbidity.

Feed

Bluefin tuna are fed mainly with a mixed diet composed principally of a variety of small pelagic species including sardine (*Sardinella aurita*), pilchard (*Sardina pilchardus*), round sardinella, herring (*Clupea harengus*), mackerel (*Scomber japonicus*), bogue (*Boops boops*) and squid (*Illex* sp.). Bluefin tuna are generally fed 1–3 times a day depending on the farm and country,with a mixture of defrosted bait fish. In most countries a scuba diver remains in the cage during feeding, and signals to stop the feeding when tuna are satiated. If the tuna are not fed *ad libitum* the daily feed input varies from 2–10 percent of the estimated tuna biomass. Feed conversion ratios (FCR) are generally high around 15–20:1 for large specimens and 10–15:1 for smaller fish. Bluefin tuna maintain an unusually high body temperature and their constant movement implies a high energy demand. As a result only a small fraction (5 percent) of the total energy input is used for body growth. At present only limited research studies are being carried out on artificial feeds at the farm level. The main problems related to the use of the artificial feed have still to be overcome including high production costs and opposition/resistance from the Japanese market.

Capture-based aquaculture of cod

Cod (*Gadus morhua* L.), the most important member of the Gadidae family, was formerly abundant on both sides of the Atlantic. Due to over fishing and environmental changes there has been a substantial reduction in stocks over the past decade.

Spawning, eggs, larvae and juveniles

Spawning takes place along the northern part of the Norwegian coast from February to May. The main area is Lofoten and the peak spawning period is in early April. From the age of six to seven years the cod recruit into the spawning part of the population. The females ovulate eggs every second day for five to six weeks. The spawning behaviour ends with male and female swimming belly to belly shedding eggs and sperm. The amount of eggs shed by the female equals approximately 500 000 eggs per kilograms. At 10–12 mm the larvae go through metamorphosis and become juveniles. Transported by the coastal and Atlantic current, the juveniles become demersal at 5–15 cm in length. The juvenile cod are called the "0-group" during their first year and the varying size of each year-class is mainly decided by the conditions during the first autumn.

Capelin cod

At the age of 3–5 years, immature cod follow the capelin (*Mallotus villosus*) on their spawning migration from the Barents Sea to the coast of Finnmark County. The cod feed on capelin for several weeks and are therefore referred to, during this period, as the "capelin cod".

Gear

Seine nets (such as Danish seine and Scottish seine) are by far the most important gear for cod CBA. Since 1990 major improvements have been made, both with regards to gear construction and how the fishery is performed. Normally all cod is alive when taken onboard. If the grading is done correctly, survival during transportation will be between 97 and 100 percent. Sixty percent of the cod from small coastal longline vessels will survive capture and transport.

Cages and recovery

Upon delivery from the fishing vessel, the cod is lethargic and needs to restore itself physiologically as well as refill the gas bladder. Special cages with a flat and taut bottom are used for this purpose. Normally, 50 percent of the cod will move to the bottom of the cage where they will recover and the swimming bladder will heal. Within 24 hours most of the fish become pelagic and are ready for weaning.

Weaning, feeding and growth

As for most other wild fish species caught at an adult stage, the transition to captivity for the cod can be difficult. It is, however, a species with a wide range of behavioural assets which allow it to adapt to captivity within a few weeks. CBA cod are mainly fed a diet of herring, mackerel, capelin, etc. These are wild-caught fish not suitable for human consumption, but intended for fishmeal production. All catch of these species is regulated with quotas. Depending on the state of the cod at capture, six to eight months of feeding will double the cod's weight, typically from 2.5 to 5 kilograms.

Aquaculture phase

When the fish have been transferred to holding cages, the owner can decide on the storing time. The fish can be stored short-term to exploit price variations or for quality enhancement. Long-term storage implies feeding to increase the available quantity. Harvesting of cod has always been important for people inhabiting the Norwegian coast. It is the most valuable species for the industry in terms of both revenues and employment. The traditional way of organizing the industry has been through fishing licences for professional fishermen that catch the cod in winter close to the coastal areas in the northern part of the country. Due to the seasonal migration pattern of cod, i.e. mature fish migrating to their spawning areas or immature cod hunting capelin,harvesting in winter is an efficient fishery, with high catch per unit effort (CPUE) and low costs. However, fishers lost their interest in CBA in the mid-1990s when the quota increased again opening new boundaries for cod CBA.

Capture-based aquaculture of yellowtail

The genus *Seriola* or yellowtail, a highly active fish belonging to the Carangidae family, is found in the Atlantic, Indian and Pacific oceans, with most species occurring in tropical and subtropical waters. A few species have global distribution (such as the amberjack, *Seriola dummerili*, and the Pacific yellowtail, *Seriola revoliana*) while others, such as the Japanese yellowtail, *Seriola quinqueradiata*, have a more limited regional distribution. Currently approximately 12 species of *Seriola* that have been described. Larger members of the genus which are commonly cultured (i.e. the gold-striped amberjack, *Seriola lalandi*, and *Seriola dummerili*) may reach 200 cm in length and weigh up to 50–60 kilograms. In Japan, yellowtail spawn offshore from southern Kyushu to Chugoku off the Sea of Japan and then migrate north to Hokkaido where they reach sexual maturity in 3–5 years. Following this they migrate south again to spawn. All juveniles weighing less than 50 g are called *Mojako*. Cultured yellowtail weighing <5 kg are called *Hamachi*, and those heavier than 5 kilograms are called known as *cultured-Buri* which are distinguished from the *wild-Buri.*

Collection and culture of wild seed

After the wild *Mojako* juveniles are harvested, measured and the numbers recorded by the cooperatives, they are weaned on artificial feed and weak specimens discarded. As young yellowtail and related species are sensitive to food deprivation, cannibalism may occur, particularly if the fish are kept in the holding tanks for long periods. Furthermore, if the young fish are not fed for more than three days they will usually fail to adapt to the artificial feeds.

Farming techniques

In 2004, yellowtail farming comprised 13 570 net cages and only 44 net enclosures. Most cage farms use fresh fish (524 670 tonnes) or artificial pellets (357 311 tonnes) as feed. An optimum density and proper feeding rate are essentials for an economic production of yellowtails. The optimum stocking density and feeding rate for maximum growth and feed efficiency, relative to season and fish size, can be ascertained from rearing records collected at a particular site for at least a 3-year period. The health status of the farmed fish is regularly checked by observing swimming behaviour and using underwater visual equipment to observe feeding. Observations on the swimming speed of individual fish while feeding, the swimming activity of the fish shoal as a whole, and the colour of the fish are all important parameters to determine the health status of the cultured fish.

Culture mortality

Mortality in cultured yellowtail can be caused by four main factors:

- ✓ Physical damage arising from inappropriate handling and transportation, and contact with the cage netting during storms and strong tides
- ✓ Turbid water and high levels of pollutants
- ✓ Feeding of deteriorated fresh fish and nutritionally inadequate feeds; and 4) diseases

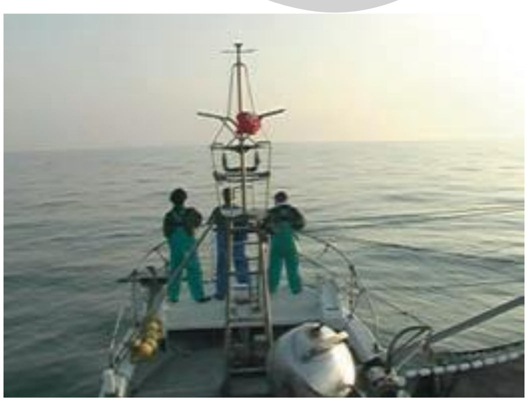
Survival rates and mortality causes in four growth stages of juvenile yellowtail from capture and the start of the farming operation

Growth stage	Weight (g)	Survival (%)	Mortality causes
Mojako (first introduction and domestication)	0.2–50	90–95	Stress Starvation
Hamachi	50–2 000	95–98	Diseases Rough handling Poor water quality
Hamachi (over-wintering)		90–95	Low temperatures Diseases
Hamachi and *Buri*	1 000–7 000	95–98	Diseases Transportation accidents
Overall survival		70–80 %	

Disease is usually not a problem during the initial phases of rearing a particular aquaculture species, however, as the number of yellowtail farms increase around Japan, disease outbreaks have become frequent. High density stocking and overfeeding make the fish more susceptible to diseases, which then can spread rapidly among the fish. The importation of wild fry, fingerlings and juvenile fish, especially from tropical waters, is also a source of disease. Environmental deterioration and nutritionally deficient feeds may aggravate the situation. The most common disease in yellowtail is caused by the bacteria, *Enterococcusseriolicida*, which is diagnosed by simply identifying gram-positive bacteria using STAN agar. Other significant problems with producing yellowtail and related species in warm waters include muscle parasites and ciguatoxin (a toxin in fish tissues that derives from dinoflagellates, and which causes poisoning in human). Among viral diseases, iridovirus is noteworthy. This virus was introduced with wild juveniles imported from tropical areas, and resulted in mortalities of juvenile yellowtail and amberjack in Japan.

Description of the fishing activity

Yellowtail spawning areas and seasons have been described by the Japan National Sea Fisheries Research Institute of the Fisheries Research Agency. In the southern parts of the East China Sea, the fish spawn from early February until April. Following spawning the young *Mojako* drift to the Pacific Ocean in association with floating seaweed. Off the west coast of Kyusyu, spawning occurs mainly from March to June and most of the *Mojako* drift through the Tsusima warm current to the Sea of Japan. Fry of yellowtail and related species seek protection in seaweeds that break off the bottom of the sea, and feed on micro-organisms and small fishes while drifting north with the current. Small *Mojako* (4–5 cm long) usually stay under or inside the floating seaweed, while larger fish swim 0.5–2 m below the surface. *Mojako* feed actively at sunrise and sunset when swarms of zooplankton can be detected; during the day they feed on small fish. After reaching 10–14 cm in length, the *Mojako* leave the floating seaweed and swim towards the shore, where they are targeted by the set nets. Wild *Mojako* juveniles for aquaculture are harvested from the floating seaweeds, by experienced crew using specifically designed fishing vessels.



Fishing vessels move to the fishing grounds

Locating floating seaweeds harbouring juvenile *Mojako*


Separating the seaweeds, *Mojako* and other aquatic organisms; Sorting *Mojako* by size and discard of bycatch

Seasonality of fishing activities

From early March, the early juveniles (*Mojako*) are collected from drifting seaweed and then raised until they reach 2 000 g, which is achieved by the end of the year. The harvest season and size are regulated by the fisheries station in each prefecture. Usually the *Mojako* season opens in May at Kagoshima Prefecture, and in June at Mie Prefecture.

Participants in the fishery and their roles

Mojako fishing is dangerous work in rough seas, and workers need experience, special knowledge and intuition. After harvest, the juvenile fish are put into small net cages (5 x 5 x 5 m), and older workers feed them with minced raw feed fish or granulated feed more than 5 times per day. The former feed type is problematic, because it quickly pollutes the water, the *Mojako* lose their appetite and may develop gill problems. The granulated feed is preferred. Larger yellowtail *Mojako* are fed extruded pellets weighing 5 g or more, twice daily. As the fish grow, they are graded and transferred into 7 x 7 x 7 to 10 x 10 x 10 metre net cages. When the fish become 200 g or more (called *Hamachi*), they are fed moist pellets

Capture-based aquaculture of groupers

Groupers are greatly valued for the quality of their flesh, and most species command high market prices. Groupers are the most intensively exploited group in the live fish trade, and the high prices paid by exporters to local fishermen mean that target species may be heavily over-fished. A large proportion of the world's groupers are caught in artisanal fisheries, and even low-level artisanal fisheries can adversely affect stocks of these highly vulnerable species. In order to alleviate the pressure on wild grouper stocks, many nations have promoted aquaculture in the hopes of producing a more sustainable grouper yield. Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible (although several important advances have been made in recent years). For this reason, about two-thirds of all grouper culture involves the capture and grow-out of wild seed. This is known as capture-based aquaculture (CBA).

There are 16 major grouper species that are cultured; the dominant species vary somewhat regionally. The most consistently abundant species that are captured for culture purposes and also reared in hatcheries are *Epinephelus coioides* and *E. malabaricus*. CBA for groupers in the western hemisphere has not been developed to any large extent, unlike in Southeast Asia. Juveniles and adults of some grouper species live in coastal or lagoonal waters and estuaries, while others prefer the cleaner waters of offshore reefs. Their eggs are single, non-adhesive, and buoyant at normal salinities. The larvae of most species spend about 30–50 days as planktonic larvae. As they become juveniles, groupers settle in shallow waters where they seek shelter in seagrass beds, mangrove prop roots, coral rubble, branching coral or branching macroalgae. Some juvenile groupers are habitat generalists, settling in any available shelter, while other species have specific nursery habitats in which their growth and survival are enhanced.

Groupers range in maximum size from only 12 cm (e.g. *Paranthias colonus*) to over 3 m (e.g. *Epinephelus lanceolatus*). Most groupers that have been studied are sexually mature within 2–6 years, but some of the larger species may take longer to mature, e.g. *Epinephelus fuscoguttatus*, which matures at about 9 years. Most serranids are protogynous hermaphrodites. As a rule, some change from female to male as they grow older; others may change only if there is a shortage of males. Groupers are some of the top predators on coral reefs, and tend to be K-strategists demonstrating slow growth, late reproduction, large size and long life-spans which make them vulnerable to overexploitation.

Trends in production of cultured grouper

Groupers are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, China Hong Kong SAR, the southeast of China and Viet Nam (Sadovy, 2000). Grouper culture is also undertaken in India, Sri Lanka, Kingdom of Saudi Arabia, Republic of Korea, Australia, the Caribbean as well as in the southeastern United States of America. Despite the huge popularity of live fish in China and Southeast Asia, only 15–20 percent of the amount consumed each year comes from aquaculture, as culture is principally constrained by limited and unreliable supplies of wild seed and the difficulties of spawning in captivity.

Grouper culture systems

There are many different systems used for the culture of groupers worldwide, although there seems to be an agreed set of stages: nursery, transition, and on-growing. Grouper seed must be nursed before being cultured to marketable size. Wild fry (2.5–7.2 cm) or fingerlings (7.5–12 cm) may initially be held in tanks or net cages or earthen ponds for a month or more (nursing period) after harvest. The density may range from 100 to 150 fish/m2, e.g. a net of 2 x 2 x 2 m would hold 400–600 fingerlings. Sorting is undertaken weekly and stock sampling every 2 weeks. Groupers are normally retained in the nursery until they reach about 16 cm, when they are thinned out and transferred to transition nets (5 x 5 x 5 m) that each hold 1 100 fish. The fish are finally transferred to production nets after 2–3 months. Floating cages are often constructed from bamboo poles and polyethylene netting material (25–50 mm mesh size). Net cages come in several sizes (3 x 3 x 2.5 m; 4 x 4 x 2.5 m;10 x 10 x 3 m); the mesh size ranges from 10 to 35 mm (Agbayani, 2002). The optimum stocking density averages 120 fish/m3. Growth to marketable size (600–800 g) takes approximately 8 months, with survival rates of 50 percent or less. Groupers can grow to 600 g in 12 months, to 1 kg within 18 months, and to 2 kg within 24 months.

Collection of grouper seed

Grouper seed is collected using several different methods, depending on location,

Overview of seed collection methods for capture-based aquaculture of groupers in Southeast Asia

Gear type	Description	Location	Fish size (cm)
Gango (fish nests)	Conical pile of waterlogged, criss-crossed wood or of rocks, sometimes in combination, together with old car tires, PVC pipe cuttings, bamboo sections, or other shelter materials. Covers 5–10 m^2, with a 2–3 m diameter or 2.5–3x2–3 m base and 0.5–1.5 m height. The largest may be 5 m diameter at the base.	Philippines	2–15 cm
Fish shelters	Formed by hanging brushes, nets or clusters of grasses, leaves or other materials. Used with or without lights.	Philippines China Thailand	1–3 cm
Fish traps	Vary in shape and size, and in mesh size. The trap frame is made of metal, wood or bamboo.	Indonesia Malaysia Philippines China Taiwan PC Viet Nam	2–25 cm
Fyke net	Big collectors, stationary nets installed in river mouths during high tides. Three mesh sizes are used: larger at the aperture, followed by medium and finer net at the end.	Philippines Thailand Viet Nam	1–15 cm
Hook and line		Indonesia Malaysia Philippines China Taiwan PC Thailand Viet Nam	>7.5 cm
Scissor net	A triangular bamboo frame of various dimensions, which may or may not have "shoes" to assist it in moving over the substrate. Fine meshed netting is attached to the frame and the bamboo poles are crossed over each other.	Philippines Thailand	2.5–15 cm
Miracle hole	Shallow holes are excavated on tidal flats. Sometimes the wall of the hole is built up with rocks.	Philippines	5–10 cm
Temarang	Artificial aggregating device (fish shelter), which consists of a bunch of twigs from wild shrubs; about 20–30 bunches of 50 cm length are tied to a 5 m rope and hung over sandy sea bottom between two poles.	Malaysia	2–2.5 cm

Mortality rates from catching to stocking

Seed quality depends on the type of fishing gears used, and there are significant differences in seed mortality rates. Mortality rates associated with fish traps are usually low. For example, the use of "*Bubu*" (fish traps used in Malaysia) cause a 5 percent mortality rate, while artificial aggregators such as *Temarang* (also used in Malaysia) cause 3 percent mortality. Other catching methods, like scissor nets and fyke nets, can generate a high mortality. "*Pompang*" (fyke net) and "*Wunron*" (push/scissor net), which are used in Thailand, are reported to cause 20–30 percent and 80 percent mortality rates, respectively.

Aquaculture dependency on wild seed

Generally, groupers spawn on offshore reefs where they form aggregations of hundreds to tens of thousands of individuals, in a few specific locations. They produce pelagic larvae that may disperse over hundreds of kilometres in the course of 30–45 days and experience high density-independent mortality. The peak grouper seed season is often associated with the relatively wet months in the year (e.g. monsoon seasons); in several areas, grouper seed collectors have claimed that their best catches were associated with strong onshore winds. Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible. For this reason, approximately 66–80 percent of all grouper culture involves the capture and grow-out of wild seed.

Fry and fingerlings are fed with mysids and small shrimp for a couple of days post-capture in tanks, to acclimatize them and check that all individuals are eating. Trash fish forms the main feed in nursery and production cages, which is minced or chopped to suit each size group; trash fish may be supplemented with vitamins and minerals. This kind of feed is gradually being replaced by moist pelleted feed.

Capture-based aquaculture of mud crabs (*Scylla* spp.)

Mud crabs are a common component of the fauna of mangrove forests, usually burrowing in mud or sandy-muds. They have a diverse diet and are omnivorous in nature, feeding on a wide range of animal and plant resources. The distribution of mud crabs extends from South Africa, along the southern coasts of middle-eastern countries, across the Indian Ocean and northerly to the southern tip of Japan, east as far as Micronesia and south to the east coast of Australia. *Scylla serrata* is the most widely distributed species, whilst Indonesia appears to be the centre of diversity for the genus, where all four species of *Scylla* are found.

Harvest products

Juvenile crabs or crablets are actively harvested throughout Southeast Asia for use as seedstock for crab farms. Sizes harvested vary from a few centimetres across the carapace to just under harvest size for sale direct to market. Crabs of close to, or at a marketable size are caught for a range of activities. Crabs which have recently moulted and have not fully grown to fill their new shells are commonly referred to as “empty” crabs. Such crabs maybe put into fattening pens, ponds or enclosures and fed until they are “full” and ready for market. Other crabs of varying sizes will be caught and put into soft shell shedding facilities. Such crabs are commonly placed in individual containers and monitored until they moult. There are a number of problems encountered by collectors and farmers, involved with using wild harvested crabs in various farming systems. Stock will often consist of a wide variety of sizes, and as mud crabs have a tendency to cannibalism, larger specimens will often predate on smaller crabs, causing significant mortalities amongst farm stock.

Farming techniques

There are a range of nursery systems used to grow mud crabs from the late zoeal stages, through megalops to settlement and metamorphosis to crablet. A variety of tanks, ponds and *hapa* nets within ponds have been successfully used. A complex 3-dimensional habitat within such systems increases the densities which can be carried by any particular system. Suitable habitats include netting, plastic mesh and artificial sea grass. An appropriate temperature and salinity range is required in nursery systems to maximize survival. The grow-out of crabs is undertaken in various systems. The two major system types

are:

1. Open : which includes ponds and mangrove enclosures where crabs are maintained at varying densities, and
2. Closed: where crabs are held in individual containers e.g.soft shell crab, or restrained in some way e.g. fattening enclosures.

Mud crab individual fattening bamboo boxes in the Philippines

Gear used to fish for juveniles

For juvenile and larger crabs, the gear used can include baited traps, lift nets or lines, together with hand held hooks, scoop nets, gillnets and fish corrals. For crab larvae and very small juvenile crabs, which are yet to settle, fine meshed push nets or drag nets can be used. In the Philippines a small meshed net is mounted on a V-shaped bamboo frame and pushed across muddy substrates to collect juveniles, whilst for larger crabs a variety of traps are used with fish baits to attract the crabs. In Viet Nam juvenile crabs are collected from canals and coastal waters using a bottom seine net.

Oyster capture-based aquaculture in the Republic of Korea

Culture techniques in the early Twentieth century were rather primitive and limited to bottom culture in intertidal areas of inner bays using rocks or wooden poles as substrates for seed collection and subsequent grow-out. In the 1960s, modern suspended culture techniques using longlines and rafts were introduced and the culture area subsequently expanded from the intertidal area to deeper waters offshore. *Crassostrea ariakensis* is an estuarine species commonly occurring in low salinity environments. Due to its fast growth rate and size, e.g. achieving 100–150 mm in shell length within 2–3 years after hatching, small-scale aquaculture has been attempted using a suspended longline system off the southwest coast. Although several species of oysters found in the country are potential candidates for the aquaculture industry, only the Pacific oyster (*Crassostrea gigas*) is extensively farmed. Most of the Korean oyster landings come from small bays on the south coast where *Crassostrea gigas* is cultured using the suspended longline system.

Annual gametogenesis

Crassostrea gigas in the Gosung Bay commences gametogenesis in February when the water temperature reaches 4–7 oC. In late May to early June, oysters become fully mature and ready to spawn. The diameter of fully mature oocytes varies from 50–70 μm. Spawning occurs as early as mid-June and can continue until the end of September when the temperature ranges from 23–26 oC. Abrupt changes in water temperature and salinity induce spawning in oysters.

OYSTER CULTURE PROCEDURES

The process of oyster aquaculture includes:

1. Seed production (collection of natural spat or artificial spat production from hatchery)
2. Hardening (i.e. stunting)
3. Growout
4. Harvest

Seed production phase

Obtaining a sufficient quantity of healthy larvae is essential to support successful oyster production. The Korean oyster industry mainly relies on the collection of natural spat. According to the Korean Oyster Longline Culture Cooperative, natural spat supply 90 percent of the national oyster seed demand, while hatchery-produced seed provide the remaining 10 percent. As shown in Figure 3, mature oysters spawn as early as mid-May and continue to do so until the end of September. Depending on key environmental parameters, such as water temperature, salinity and food availability, the larvae settle 10–20 days after fertilization. To ensure the collection of a large number of spat, the abundance and development stage of the larvae in the water column are routinely monitored by the regional marine extension services. To ensure the availability of the required volume of seed, both "early spat" collection (June–July) and "late spat" collection (August–September) are targeted by the industry.

Hardening phase

Ten days after settlement, the oysters attached to the collectors are transferred to the hardening ground, or directly to the longline culture system for grow-out. Since hardened oysters have a better survival rate, the oyster growers routinely undertake this culture phase. Hardening the seed oysters takes place in the intertidal zone where the area is exposed for 6–8 hours during the tidal cycle.

Grow-out phase

In May, the hardened seed oysters collected from the previous summer reach 1–1.5 cm in shell height. For grow-out, the hardened seed oysters attached on the clutches and suspended on the hardening racks are harvested and the seed strings are disassembled for longline culture. Using a plastic wire (o=3.8 mm) each cultch (i.e.oyster or scallop shells containing the hardened seed oysters) is strung on the wire at 20 cm intervals. The 5 m long oyster grow-out string may include 20–25 cultch.

Harvest

On the south coast, harvesting oysters from the longline begin as early as in September and the harvesting continues until the following April. The oyster strings suspended from the longline are lifted onto a work boat with the use of a winch installed on the side of the vessel. The oyster strings are then cut on the deck and dumped into plastic containers and sent to the local shucking factory

The Indian scenario

Irrespective of its vast potential, the marine/ Brackishwater culture production in India is only about 80,000-1,00,000 tonnes annually, which is almost entirely from shrimp production. Even though many Asian countries are leading in mariculture, India is yet to make an impact in this sector. Constraints are many in this line. However, it is time that India should focus on these issues and make a change in the present scenario of mariculture production. Commercial level seed production techniques are to be standardized for many species except Asian sea bass. In many non-selective gears, and shore seines juveniles of high value fish are caught which are either discarded or sold at nominal prices. If suitable measures are followed, these juveniles could be used for CBA for resource conservation as well as for increased seafood production.

Research &. Development on CBA in India

The spiny lobsters *Panulirus homarus, P. polyphagus, P.ornatus, P. pencillatus, P. longiceps* and sand lobster *Thenus oriental* is are available in India for farming or fattening. Farming/fattening of sand lobster T. orientalis has been demonstrated by CMFRI but has not been raised up to commercial level. Spiny lobster *P.polyphagus* fattening is being experimented by some NGO's in Gujarat using wild caught juveniles. CBA of lobster has potential in India because of its high value and demand in export market.

Mussel farming

Perna indica and *P. viridis* are the two mussel species suitable for farming in Indian waters. CMFRI, National Institute of Oceanography (Goa), Konkan Krishi Vidyapeeth, (Ratnagiri) and Central Agricultural Research Institute (CARl), Port Blair, have implemented research programmes on mussel farming. From early 1970s itself, CMFRI has developed grow-out structures suitable for open sea farming, seeding method and farm management measures. The first commercial mussel farm in the country was set up at Padanna, Kasaragode, Kerala in the year 2000. Mussel culture in India is entirely based on CBA

CBA seed resources

Several studies and observations by CMFRI indicated that dol nets of Gujarat and Maharshtra, shore seines of east coast, thalluvalai of southeast coast, Chinese dip nets of Kerala etc which are mostly operated between 2-10 m depth, land juveniles/seed of high value species. These mostly fetch very low price and are dried. The species include seerfish, pomfrets, mackerel, koth, shrimps etc. Also, there exists a good fishery for live juve niles of different species of lobsters but very little are used for fattening. It is estimated conservatively that about one million of seerfish juveniles of 7-10 cm and two millions of mackerel juveniles of 5-8 cm land by shore seines in the month of April alone along the stretch of Visakhapatnam, Kalingapatnam. This is only an approximation and studies are initiated by CMFRI to estimate the juvenile availability. If such a small fraction of these seed/juveniles are brought in live condition, they form very good source of CBA without affecting the ecosystem and livelihood of fishermen. It will be more lucrative for the fishermen at the same time contributing to several fold increase in mariculture production. Juvenile yellowfin tuna are available in plenty in and around Lakshadweep waters which can be used for farming in cages, for which reasonably viable cage technology is available with CMFRI. The open sea mariculture is thus having a vital role to play in the development of the fishing sector in the days to come. The motivating success in

Balasore and earlier at Visakhapatnam will inspire the stakeholders to invest in such opportunities. The seed supply is the most significant input or the component of this open sea cage farming. If we succeed in establishing a sustainable source of supply of seed, no doubt, open sea cage farming is going to rule the The open sea mariculture is thus having a vital role to play in the development of the fishing sector in the days to come. The motivating success in Balasore and earlier at Visakhapatnam will inspire the stakeholders to invest in such opportunities. The seed supply is the most significant input or the component of this open sea cage farming. If we succeed in establishing a sustainable source of supply of seed, no doubt, open sea cage farming is going to rule the mariculture industry.

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