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; an increase of 37.5 million tonnes above the 2004 level.

Aquaculture is a diverse sector using many strategies for fish production. The harvesting of wild individuals, either as broodstock whose eggs will hatch and develop under culture in ponds or cages, or as early life-history stages for on-growing under confined and controlled conditions is one of these strategies. This system of aquaculture production has been termed by the Food and Agriculture Organization of the United Nations (FAO) as *capture-based aquaculture* (CBA) and is practiced worldwide on a variety of marine and freshwater species, with important environmental, social and economic implications.

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. The main concern related to CBA is whether the seed fishery has a negative impact on wild stocks of the targeted species as well as non-targeted species. Although there is generally little data on this issue, some countries have tried to ban or somewhat restrict such fisheries.

There are environmental concerns which need to be addressed regarding the harvesting of wild resources for CBA. Many fishery management regulations have minimum size limits for harvested species, and often there are restrictions on the harvest of spawning adults. The targeted individuals in wild-caught farming are early life history stages and adults ready to spawn which may not be adequately covered by existing legislation. The impacts on natural populations that are "targeted" for this type of aquaculture, and impacts on the associated non-targeted species and the surrounding ecosystem, need to be addressed to determine the sustainability of CBA.

These sustainability issues in aquaculture development have been recognized by many scientists, government experts, aquaculture producers and suppliers, traders of aquaculture products, and social and environmental advocacy or stakeholder groups. Numerous national as well as international and intergovernmental meetings have concluded that there is a significant need to address and resolve those issues which constrain the sustainable development of aquaculture at the local, national, regional and global levels.

FAO and the Committee on Fisheries (COFI) have repeatedly discussed aquaculture and the need for international collaboration for the promotion of its sustainable development, and its potential contribution to development in many rural areas. The 1999 FAO Ministerial Meeting as well as the first and second Sessions of the COFI Sub-Committee on Aquaculture also reiterated strongly the need for enhanced efforts by the international aquaculture community to work towards more sustainable and responsible aquaculture production practices.

The project "*Towards sustainable aquaculture – selected issues and guidelines*" implemented by the FAO and funded by the Government of Japan, through a Trust Fund arrangement, has provided the means to address selected key issues of sustainability in global aquaculture practices and development. With due recognition to the recommendations of the FAO Committee on Fisheries/Sub-Committee on Aquaculture during its first two sessions, the thematic area on the "*use of wild fish and fishery resources for aquaculture production*" has been identified as a priority for targeted action.

Furthermore, the project has focused on collating and synthesizing available information on the aforementioned and other thematic areas and based on the information analysed provided possible management regimes and options for targeted response measures in relation to the specific issue of concern including constraints and problems, and with due consideration of feasibility and affordability of possible implementation of identified measures. The outputs generated by the project will assist FAO Member countries in the promotion and implementation of the provisions of the Code of Conduct for Responsible Fisheries (CCRF).

The specific objective of the previously mentioned project sub-component is to contribute to improved and effective fish farming and conservation of natural aquatic populations at the global level, with minimum disruption to responsible fisheries and livelihoods through the successful implementation of ecosystem approaches in fisheries. In order to achieve such an objective the FAO organized an international workshop in Hanoi, Viet Nam, in October 2007, to initiate the production of a set of technical guidelines on the responsible use of wild fish and fisheries resources for aquaculture production (see Annexes for workshop agenda, list of participants, expert profiles and group photograph). These technical guidelines, once available, aim at assisting policy-makers in developing policies and regulations that take account of both the use and conservation of aquatic resources.

In preparation of the Hanoi workshop, two main thematic reviews were prepared covering environmental and biodiversity and socio-economic issues related to CBA along with eleven species specific review papers that covered both marine and freshwater examples from around the world and the ecological, socio-economic and livelihood impacts associated with CBA. The commercial species and related geographical coverage included: mullet (Egypt); bluefin tuna (Europe); European eel (France/Europe); cod (Norway); mud crab (Asia-Pacific); grouper (Southeast Asia); yellowtail (Japan); snakehead and pangasiid catfish (Mekong region); Indian major carps (Bangladesh); *Clarias* catfish (Cameroon); and oyster (Republic of Korea). The two thematic reviews and species papers are included in this FAO Fisheries Technical Paper.

PART 1

REVIEW PAPERS

Environmental and biodiversity impacts of capture-based aquaculture

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SUMMARY

The project "*Towards sustainable aquaculture: selected issues and guidelines*", implemented by the Food and Agriculture Organization of the United Nations (FAO), seeks to address selected key issues of sustainability in relation to current global aquaculture practices and developments. The specific thematic area, *use of wild fish and fishery resources for aquaculture production*, is identified, an important component of which is aquaculture production systems based on *capture-based aquaculture* (CBA). Around this thematic area, two review papers, one covering social and economic aspects, the other environmental and biodiversity issues of wild resource use, and ten background papers on selected marine and freshwater species used for CBA, have been compiled.

The thematic review on environmental and biodiversity issues, reported on herein, covers a wide range of representative marine and freshwater, vertebrate and invertebrate species used for CBA, selected from the four major taxonomic groups of cultured organisms, molluscs, crustaceans, echinoderms and finfishes with the following objectives:

- to summarize the life history stage(s) and habitat(s) of seeds collected from the wild, the regions and countries where CBA is taking place, why and how they are being used, capture method(s) and volumes with associated bycatch and discards;
- to diagnose and discuss the current and/or potential impacts of CBA practice on the environment and wild stocks;
- to review current agreements and legislation for ensuring sustainability of wild seed fisheries and trade for CBA, methods to reduce bycatch and their implementation, and to discuss potential management measures at national and international levels;
- to discuss the fundamental relationships between life history stages being exploited and impacts on wild stocks; and
- to provide recommendations for sustainable wild seed and capture fisheries and CBA practices.

The review concludes that major representative species from the four different taxonomic groups share characteristics of high market demand, and high predictability in time or location leading to ease of capture and accessibility. Most CBA species are high value, luxury, species, rather than regular food fish or invertebrate species used for cheap daily consumption.

Although issues of disease, environment and biodiversity are also relevant to hatchery-based aquaculture (HBA), there are certain considerations specifically or indirectly pertinent to CBA practices and matters relevant to both CBA and HBA. With the extensive practice and development of CBA-related fisheries (seed fisheries), international transport and growing trade of wild seed both regionally and globally, problems of disease and genetic pollution associated with transfers and escapes of wild seeds may be a matter for concern. Moreover, the non-selective use of many gears associated with CBA, wasteful bycatch associated with the capture of certain species, high post-capture mortality of target species, and extensive use of fish feed (sourced from wild fish and hence a further pressure on wild populations) for grow-out, could mean that certain seed fisheries are not sustainable and have a negative impact on other fishery sectors of the same, or different, species.

Current and recent management measures, as well as those being developed that are applicable to various aspects of wild seed fisheries associated with CBA, are summarized and discussed. Management measures need to respond to problems noted in various fisheries, including declining catches, control of fishing gears, bycatch and damage to substrate. Wild seed fisheries for CBA are typically not managed or controlled effectively and most management measures are relatively recent, developed or adopted after the seed fishery has declined substantially.

CBA is an economic activity that is anticipated to expand in the short term, and is very likely to continue into the long term for many species. CBA is practised because it has become necessary or desirable as a livelihood, as an alternative means of controlling access to fishery resources, to meet market demand and, if practised properly, to enhance yield. It does not necessarily, as is often assumed, or even desirably, lead to HBA, does not demonstrably take pressure off wild stocks, and is typically practised with high value species, often for export or luxury markets, rather than inexpensive food alternatives for local use. Recommendations are provided that include the need to apply the precautionary principle, refer to the FAO Code of Conduct for Responsible Fisheries (CCRF), seek measures to reduce mortality of captured animals and to minimize bycatch of non-target species. For CBA activities, it is important to develop management approaches, especially where different life history phases of a stock are exploited by different fishing sectors, develop clear objectives and definitions in each case and consider culture practices that reduce dependence on carnivorous species and seek cheaper alternatives to provide affordable food for local use.

INTRODUCTION

Given growing shortages in many fishery resources, aquaculture is widely considered to be important for food provision and for reducing pressure on fisheries in both developing and industrialized countries. Aquaculture production has developed since the 1970s at an average annual increase rate of 8.8 percent with growth accelerating in recent years (FAO, 2007). Among the 200 or so species of mollusc, crustacean and finfish cultured, many are based on "grow-out" or "fattening" of wild-caught "seeds" (see "Definitions" below), the seeds ranging from very early in life to adults. In all cases these "seeds" are held for varying time in captivity and/or fed and/or protected from predators until they reach marketable size (FAO, 1997a, 2006; Ottolenghi *et al*., 2004). This practice, the "growing-out" or "fattening" of wild-caught "seeds", is referred to as "capture-based aquaculture" (CBA), and involves a range of marine and freshwater, vertebrate and invertebrate species. The fish production from such growing-out or fattening practices is estimated to be at least 20 percent of the total annual fish aquaculture production with a value of US$1.7 billion (FAO, 2004; Ottolenghi *et al*., 2004). Although CBA has been practised for decades, it was not until 2004 that the descriptive term, CBA, was introduced to clearly define this practice and to distinguish it from hatchery-based aquaculture (HBA) on the one hand, and capture fisheries on the other hand (Ottolenghi *et al*., 2004). In reality, CBA is a hybrid of these two practices but differs in important ways from both as a means of food production and in relation to fishing pressure on wild populations.

CBA has several widely assumed advantages resulting from its history and its apparent practical simplicity. For example, it is widely considered that the economic cost of seed taken directly from the wild is lower compared to seed reared in hatcheries for many species. It is also commonly believed that CBA is conducted on animals caught locally to culture operations and, therefore, that the risks of exotic disease transfer and genetic pollution to the environment and wild stocks are low to non-existent (Munro and Bell, 1997). These perspectives largely stem from the early practice of what has come to be known as CBA in some species of keeping alive in captivity animals taken in the local fishery to maintain them fresh for short periods of time until the market price improved or they were needed. Over time these practices expanded considerably to include trading of species both regionally (defined as within the geographical range of the species) and globally (defined as out of the geographical range of the species) or for extended maintenance in captivity for grow-out (Islam *et al*., 1996; Mohan Joseph, 1998; Bagarinao, 1999; Jeffs *et al*., 1999; Sadovy, 2000; Ottolenghi *et al*., 2004).

One other factor that makes CBA appealing is the belief that taking fishes or invertebrates when they are small and young and placing them into captivity for feeding and protection from predators reduces their natural mortality. In this way, the practice is widely assumed to increase productivity by enhancing survivorship relative to natural levels at a given size or age. This may or may not be true and depends on many factors, most importantly on the life history stage(s) at which animals are removed from the wild and the volumes involved. While this subject is covered in more detail below, for those species in which natural mortality levels become very low within a few weeks or months of settlement, their capture before sexual maturation but after this early high natural mortality period could substantially affect the sustainability of natural populations. Moreover, the degree of bycatch and discards and the mortalities of wild seeds during and after capture (i.e. from capture and during culture) can be extremely high, factors rarely considered when examining the culture of such species. Combined, these factors mean that the costs, both economic and environmental/biodiversity, of CBA are substantially higher for some species than previously thought and the impacts of CBA on natural stocks generally not considered (Naylor *et al*., 2000; Sadovy, 2000; Sadovy and Vincent, 2002; Ottolenghi *et al*., 2004). Nonetheless, as demand for seafood grows and over-fishing and competition for fishery resources increase, CBA is inevitable and must be addressed directly to ensure sustainable practices especially when it is not considered, or has proven unlikely, to be a stepping stone to HBA.

As a combination of aquaculture and capture fisheries, CBA exhibits characteristics of both practices. For example, captive grow-out for CBA uses the same systems (e.g. extensive and intensive; ponds, cages and tanks), consumes the same natural resources (e.g. land, water and labour), and utilizes the same feeds (e.g. formulated/pellet feed or fresh feed that contain mainly small fishes and shellfish) as HBA. CBA also encounters some of the same problems, such as production of wastes and resultant contamination of the environment, diseases and their treatment and transfer. On the other hand, wild seed collection of many species for CBA has many similarities to typical capture fisheries, in terms of capture methods (including some that are destructive) and seasons, catch sizes, catch per unit effort (CPUE), bycatch and discards, stock assessment and fishery management. In more extreme cases, CBA is little more than a capture fishery of juveniles, almost always unmanaged, and hence a clear and additional threat to the long term sustainability of targeted species.

CBA poses unique challenges to resource managers at a time when aquaculture is increasingly viewed as essential for future food production and for reducing over-fishing. The extent to which CBA contributes to both is, based on current practices for many species, far from clear. On the positive side, CBA is often a step towards HBA, a transition phase which allows much to be learned about rearing species before the challenges of hatchery production can be met. Conversely, some species used for CBA are also taken as part of traditional capture fisheries in fishing sectors that focus on adult fish, rather than seeds, and the removal of different life history stages by separate fishing sectors can lead to conflicts and problems of equity. Removing too many larvae and juveniles (i.e. immature individuals) for CBA, for example, could compromise stock persistence in the adult capture fishery sector because insufficient juveniles persist to maintain reproductive output, or *vice versa*. In addition, the option of CBA in over-fished stocks has resulted in the transfer of fishing effort from dwindling adults to juveniles possibly compromising stocks (Naylor *et al*., 2000; Sadovy, 2000; Sadovy *et al*., 2003; FAO, 2004; Ottolenghi *et al*., 2004). In such cases, the apparent increased food production from CBA can come at the cost of reduced fishery captures leading to questions of equity and efficiency of use of limited fishery resources.

Notwithstanding concerns over CBA, it continues to be extensively practised despite limitations noted in the supply of wild seed in some cases and where there are no moves towards HBA. There are growing concerns, therefore, that the practice itself may be one more cause of reductions in seed availability and the adult fisheries that these support. Given these concerns and the ever-growing interest and focus on aquaculture in general, there has emerged a need for both developing and industrialized countries to create and implement a comprehensive framework of regulations and market mechanisms to ensure that the practice of CBA is conducted in a sustainable manner, and to understand more about CBA practices in general.

To achieve sustainable CBA there is a need for gathering data on the biology, practices and seed collection (seed fisheries) of CBA species. A wide range of representative marine and freshwater, vertebrate and invertebrate species used in CBA practices selected from four major groups, molluscs, crustaceans, echinoderms and finfishes are examined in this review. There are five objectives in relation to the selected species: (1) to summarize the life history stage(s) and habitat(s) of seeds collected from the wild, and the regions and countries where CBA is taking place and to indicate why and how they are being used; (2) to gather data on capture method(s), volumes, and associated bycatch and discards (when information is available); (3) to diagnose and discuss the current and/or potential impacts of CBA practices on the environment and wild stocks, based on the findings of (1) and (2); (4) to discuss current/recent and/or potential impacts in relation to transfer of wild-caught seeds in relation to diseases, genetic pollution, etc., providing examples, as appropriate; and (5) to review current agreements and legislation for ensuring sustainability of wild seed fisheries and trade for CBA, methods to reduce bycatch and their implementation, and to discuss potential management measures at national and international levels. The theoretical relationship between life history stages of certain species, their exploitation and its impacts on wild stocks, especially in relation to management decisions, are discussed. Finally, recommendations are given, based on information gathered in the present review for sustainable wild seed and capture fisheries and CBA practices.

DEFINITIONS

Aquaculture

The term is defined by FAO for statistical purposes (FAO, 1997b), "Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their period contribute to aquaculture". In this definition, the sources of the aquatic organisms farmed are not defined clearly; they can be either from the wild through capture and collection or from hatcheries through manipulation of broodstock maturation and reproduction, and larval and juvenile rearing.

Fisheries

"It is a practice of capturing aquatic organisms by the public as a common property resource, with or without appropriate licences" (FAO, 1997b). According to this definition, wild seed collection is a type of fisheries. The significant difference between capture fisheries and seed fisheries is that the caught aquatic organisms go to market directly in the former case, and to culture operations before entering markets in the latter.

Capture-based aquaculture (CBA)

It is a practice of collecting "seeds" (see below) from the wild from early life history stages to adults and subsequent growing-out them in captivity to marketable size, using aquaculture techniques (Ottolenghi *et al*., 2004). This definition can clearly distinguish CBA from HBA, which is a practice of producing and using "seeds" from hatcheries through manipulation of adult maturation and reproduction and larval and juvenile rearing.

Seeds

"Seeds" are the aquatic organisms used to farm in captivity for varying times; these organisms can be captured and collected from the wild (e.g. for CBA) or hatched in hatcheries (e.g. for HBA). These organisms cover a wide range of life history stages, from larvae to juveniles to adults, defined on the basis of morphology, including size, and sexual maturation stage. Larvae are the stage prior to metamorphosis; they can be pre-settlement or early post-settlement and differ in form and appearance from the adults. Juveniles are the stage from after metamorphosis to prior to sexual maturation; they can be late post-settlement and are often similar in form and appearance to the adults. Adults are the stage after sexual maturation. Wild seeds collected for CBA are not only from early life history stages (larvae and juveniles) but also from adult stages depending on the species and market demands. We use "larvae", "juveniles" or "adults" instead of "seeds" in this report whenever they can be distinguished clearly or where the distinction is relevant. Sub-adults refer to late stage juveniles that will soon reach sexual maturation.

Some words are also commonly used to describe early life history stages of aquatic organisms, such as "fry" and "fingerling". "Fry" can be applied to larval stage in finfish, or post-larvae (i.e. after metamorphosis) in shrimps, and "fingerling" can be applied to small juveniles in finfish.

Grow-out and fattening

"Grow-out" in CBA is the process of farming the aquatic organisms captured and collected from the wild till they reach marketable size. The grow-out period varies on the basis of the life history stages of the farmed organisms at the start and the market demand for each species and circumstance. If the organisms started from larval and small juvenile stages, they usually need to be kept in captivity for a considerably longer period to reach marketable size, unless there is sale between grow-out phases for economic reasons; if the organisms are at sub-marketable size (e.g. large juvenile and adult stages), they need relatively short period to reach marketable size. "Fattening" is a type of grow-out activity, which particularly focuses on sub-marketable or even marketable size individuals aiming to increase the fat content (e.g. tunas *Thunnus* spp.) or the gonad maturation (e.g. female mud crabs *Scylla* spp.) through a short culture period for a better price, usually accompanied with high feed input. The differences between "grow-out" and "fattening" are the relative length of the culture period, and the life history stage being cultured in some cases, although in practice the difference between the two is often unclear, such as "grow-out" of sub-adult grouper and "fattening" of sub-adult or adult tuna.

REPRESENTATIVE SPECIES IN CBA

Selected representative species for CBA from four taxonomic groups, molluscs, crustaceans, echinoderms and finfishes, are summarized, with a focus on understanding their life history stage(s) and habitat(s) captured and collected as seeds, the regions and countries where CBA is taking place (Tables 1 and 2). 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.

TABLE 1

Selected representative species of molluscs, crustaceans and echinoderms taken for CBA with a summary of the life history stage(s) and habitat(s) of wild seeds collected, and the regions and countries where CBA is taking place. *, see Definitions; **, not an exhaustive country list

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**	References
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	Lutz, 1980; Lovatelli, 1988a; Delmendo, 1989; Hickman, 1992; Chou and Lee, 1997; Mohan Joseph, 1998; Jeffs *et al*., 1999; TAFA, 1999-2004; Smaal and Lucas, 2000; Burton, MacMillan and Learmouth, 2001; Jia and Chen, 2001
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	Gervis and Sims, 1992; Ellis and Haws, 1999; Ponia *et al*., 2000; Tisdell and Poirine, 2000
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	Lovatelli, 1987; TAFA, 1999-2004; Burton, MacMillan and Learmouth, 2001; Ivin *et al*., 2006; Kosaka and Ito, 2006; Norman, Román and Strand, 2006; Parsons and Robinson, 2006; von Brand *et al*., 2006
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	Korringa, 1976a; Ling, 1977; Lovatelli, 1988a, b; Park *et al*., 1988; Delmendo, 1989; Smaal and Lucas, 2000; Burton, MacMillan and Learmouth, 2001
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	Lovatelli, 1988a; Tiensongrusmee and Pontjoprawiro, 1988a; Delmendo, 1989; Burton, MacMillan and Learmouth, 2001; Minh, Yakupitiyage and Macintosh, 2001

USA = United States of America
UK = United Kingdom

TABLE 1
Continued

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**	References
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	Ling, 1977; Ungson, 1990; Phillips, Lin and Beveridge, 1993; Islam *et al*., 1996; De Silva, 1998; Naylor *et al*., 2000; Petersson, 2002; SAPB, 2002; Ottolenghi *et al*., 2004; M.L. Cobo personal communication, 2007
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	Chou and Lee, 1997; TAFA, 1999-2004; Phillips *et al*., 2003; Arcenal, 2004; Bell, 2004; Juinio-Memez and Gotanco, 2004; Thuy and Ngoc, 2004; Gardner *et al*., 2006
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	Ling, 1977; Angell, 1992; Chou and Lee, 1997; De Silva, 1998; Keenan and Blackshaw, 1999; Le Vay, 2001; Minh, Yakupitiyage and Macintosh, 2001
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	Tiensongrusmee and Pontjoprawiro, 1988b; Tanaka, 1992; Conand and Tuwo, 1996; Sutherland, 1996; Lovatelli *et al*., 2004; Tuwo, 2004

Taiwan Province of China abbreviated as Taiwan PC.

TABLE 2

Selected representative finfishes taken for CBA with a summary of the life history stage(s) and habitat(s) of wild seeds collected, and the regions and countries where CBA is taking place. *, see Definitions; **, not an exhaustive country list. Classifications follow those of Nelson 2006 with species names accessed 2007 from http://www.fishbase.org

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**	References
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	Korringa, 1976b; Ling, 1977; Tzeng, 1997; Ringuet, Muto and Raymarkers, 2002; Ottolenghi *et al*., 2004; Sugiyama, Staples and Funge-Smith, 2004
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*	Korringa, 1976b; Ling, 1977; Uwate *et al*., 1984; Bagarinao *et al*., 1986; Uwate, 1988; Hickman, 1989; Ungson, 1990; Pullin, 1993; Bagarinao, 1994, 1999; Ahmed *et al*., 2001; Ottolenghi *et al*., 2004; Rimmer, 2006
Clariidae (airbreathing catfishes) *Clarias batrachus* *Clarias macrocephalus*	Larvae and juveniles	Swamps, flooded lowlands	*Regional* *Asia*: Bangladesh, China, India, Indonesia, Malaysia, Philippines, Thailand	Ling, 1977; Tripathi, 1996
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	Ling, 1977; Edwards, Little and Yakupitiyage, 1997; Trong, Nguyan and Griffiths, 2002; Van Zalinge *et al*., 2002; Lieng and Hortle, 2005
Gadidae (cods) *Gadus morhua*	Juveniles with 3–10 g; Sub-marketable sizes with 1–2 kg	Around coastal waters	*Regional* *Europe*: Iceland, Norway	Björnsson, Hugason and Gunnarsson, 2005
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	Korringa, 1976b; Major, 1978; MEDRAP/TR, 1985; Costa-Pierce, 1987; Hickman, 1989; Allen, 1991; Chandrasekaran and Natarajan, 1993; Nlewadim and Deekae, 1997; De Silva, 1998; Sadek, 2000; Sadek and Mires, 2000; Tamaru *et al*., 2001
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	Pickett and Pawson, 1994; Zheng, 1994; Sadek, 2000; Sadek and Mires, 2000

TABLE 2
Continued

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**	References
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	Glude, 1982; Tseng, 1983; Heemstra and Randall, 1993; Chou and Lee, 1997; Tseng and Ho, 1988; Huang, 1998; Sadovy, 2000; Tuan, Nho and Hambrey, 2001; Ottolenghi *et al*., 2004; H.S. Wang personal communication, 2006
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	Korringa, 1976b; Wilson, 1997; Tuan, Nho and Hambrey, 2000; Ottolenghi *et al*., 2004
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	Wilson, 1997; Chou and Lee, 1997; Huang, 1998
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	Korringa, 1976b; Tseng, 1983; MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000
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	Chou and Lee, 1997; Huang, 1998; Sadovy *et al*., 2003
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	Glude, 1982; Tseng, 1983; Uwate *et al*., 1984; Hickman, 1989; Chou and Lee, 1997
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	Ottolenghi *et al*., 2004; UNEP/MAP, 2004; Vita and Marin, 2007
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	Ling, 1977; Wee, 1981; Boonyaratpalin, McCoy and Chittapalapong, 1985; Edwards, Little and Yakupitiyage, 1997

- 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 (Ottolenghi *et al*., 2004; J.B. Liu personal communication, 2007). For the shark catfish (*Pangasius hypophthalmus*), regional transfer (mainly from Cambodia to Viet Nam) is still common since the ban on wild seed collection in Viet Nam (Trong, Nguyan and Griffiths, 2002; Van Zalinge *et al*., 2002). 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 (Tseng and Ho, 1988; Wilson, 1997; Sadovy, 2000). For the Japanese amberjack (*Seriola dumerili*), China and Viet Nam have exported wild seeds to Japan since the 1980s (Dao, 1999; Ottolenghi *et al*., 2004). 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 (Wilson, 1997).

CAPTURE METHODS, VOLUMES AND IMPACTS ASSOCIATED WITH WILD SEED COLLECTION FOR CBA

The capture methods and associated bycatch and discards with wild seed collection for CBA, and their impacts on the environment and wild stocks are summarized for selected representative species from four major taxonomic groups, molluscs, crustaceans, echinoderms and finfishes; mortality from capture and during culture is indicated (when information is available) (Tables 3 and 4). Estimated catch volumes of wild seeds for CBA are given, when data are available (Table 5). The actual and potential problems of bycatch and sustainability in relation to catch volumes and associated mortalities are highlighted using illustrative examples. Such information is essential for identifying management issues and needs for planning future developmental directions for aquaculture. Examples are provided from each of the four groups of species.

- CBA in molluscs typically involves the collection of spats. Spats settle on specially designed "collectors" or on natural substrates, often during well-known settlement seasons and in specific collection areas. Although this approach is thought to be associated with a low level of bycatch due to the methods used, there are possible but unknown potential impact(s) from over-collection of the wild spats. Moreover, when settlement areas are modified or habitat dredged to install artificial settlement collectors, potential impact(s) on wild stocks of target or other species is (are) possible. Little is known of the early mortality rates in molluscs that would allow for management of this activity for CBA and there have been declines noted in both adults and spat supplies in areas where a wild seed collection exists for CBA for a number of species (Tables 3 and 5). Although the cause(s) for the declines is (are) unknown, given that spat catch volumes can involve tens to hundreds of tonnes (e.g. the Greenshell® Mussel *Perna canaliculus*), or tens of thousands to millions of spats, it is feasible that adult stocks are ultimately affected, especially if much of the annual settlement is concentrated in specific areas, or during specific seasons. It is quite possible that highly targeted collection of large numbers of spats could significantly affect population regeneration if a high proportion of settlers are removed for CBA each year.

TABLE 3

Selected representative species of molluscs, crustaceans and echinoderms taken for CBA with a summary of capture methods and bycatch and discards associated with the process of wild seed collection, and the impacts of CBA practice on environment and wild stocks. *, mortality from capture to harvest is indicated if information available

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Mytilidae (mussels) *Mytilus edulis* *Mytilus galloprovincialis* *Perna canaliculus* *Perna viridis*	Natural settlement substrates (e.g. macroalgae, hard substrates); Artificial spat collectors such as longlines with fibrous ropes hang down <10 m below the water surface; By hand or divers; Dredging settlement beds	Low due to well-known settlement season and area	High through dredging, which leads to habitat disturbance or loss, change of benthic species composition, reduction of mussel growth; Wild adults and spats have shown declines	Delmendo, 1989; Hickman, 1992; Mohan Joseph, 1998; Scott and Tai, 1998; Jeffs *et al*., 1999; Smaal and Lucas, 2000; Dolmer *et al*., 2001
Pteriidae (pearl oysters) *Pinctada margaritifera* *Pinctada maxima*	Artificial spat collectors such as longlines with black polyethylene shade cloth, mesh bags or tree branches hang down <5 m below the water surface; By divers; Dredging settlement beds	Low due to well-known settlement season and area	Impact through dredging is unknown, but could be the same as mussels and oysters; Wild adults and spats have shown declines; Available supply of hatchery-reared spats reduces impact on wild stocks	Gervis and Sims, 1992; Southgate and Beer, 1997; Ellis and Haws, 1999; Ponia *et al*., 2000; Tisdell and Poirine, 2000
Pectinidae (scallops) *Argopecten purpuratus* *Chlamys opercularis* *Mizuhopecten yessoensis* *Pactinopecten yessoensis* *Pecten maximus* *Placopecten magellanicus*	Artificial spat collectors such as longlines with polyethylene mesh bags inserted substrates (e.g. cedar leaves) or empty shells hang down below the water surface; By hand or divers	Low due to well-known settlement season and area	Wild adults and spats have shown declines; Available supply of hatchery-reared spats reduces impact on wild stocks	Lovatelli, 1987; Masuda and Tsukamoto, 1998; Ivin *et al*., 2006; Kosaka and Ito, 2006
Ostreidae (true oysters) *Crassostrea gigas* *Crassostrea plicatula* *Crassostrea rivularis* *Crassostrea virginica* *Ostrea edulis*	Natural settlement substrates; Artificial spat collectors such as bamboo sticks, cement bars, limed-coated roofing tiles, polyethylene ropes hang down below the water surface; Empty shells or tree branches; By hand or divers; Dredging settlement beds	Low due to well-known settlement season and area	High through dredging, which lead to change of benthic species composition; Wild adults and spats have shown declines; Disease (e.g., parasite *Bonamia* and *Marteilia* spp.) caused wild stock extinction in some areas; Disease through spat collectors of empty shells (e.g. *Cardium edule*)	Korringa, 1976a; Ling, 1977; Lovatelli, 1988a, b; Delmendo, 1989; Smaal and Lucas, 2000; Virvilis and Angelidis, 2006
Cardiidae (cockles) *Anadara granosa* *Cerastoderma edule*	Trawling sea beds with a wire basket-shaped device	Low due to well-known settlement season and area	Impact through dredging sea beds is unknown, but could be the same as mussels and oysters; Wild adults have shown declines; Limited supply of wild spats may due to the declines of wild stocks and natural low recruitment; Habitat loss may have further impact on wild stocks	Lovatelli, 1988a; Tiensongrusmee and Pontjoprawiro, 1988a; Delmendo, 1989; Burton, MacMillan and Learmouth, 2001

TABLE 3
Continued

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Penaeidae (shrimps) *Metapenaeus* spp. *Penaeus japonicus* *Penaeus monodon* *Penaeus vannamei*	Nets (with fine mesh size) such as hand nets, push nets, dragged seine nets, bag nets, tow nets, long nets, scoop nets; Sieves; Trawls	Bycatch can be 80–99.9% and includes larvae and juveniles of commercial fishes, other crustaceans, molluscs and cnidarians; Most PL of Penaeid spp. are used for CBA, but discards are high for other groups; Mortality at capture and transportation is low (<10%) in *Penaeus monodon* to high mortality (60–70%) in hatchery-reared PL	Wild adults and PL have shown declines; Available supply of hatchery-reared PL reduces impact on wild PL but may increase impact on wild female stocks for hatchery purpose; Threat to wild stocks of other species due to high bycatch and discards	Ling, 1977; Ungson, 1990; Islam *et al*., 1996; Bagarinao, 1999; Rosenberry, 2000, Peterssen, 2002; SAPB, 2002
Palinuridae **(spiny lobsters)** *Jasus edwardsii* *Panulirus hormarus* *Panulirus ornatus* *Panulirus polyphagus*	Artificial substrates; Nets such as seine nets, gillnets; By snorkeling divers; Traps; Cyanide	Low with high selectivity	Wild adults and pueruli have shown declines; Average size of fished lobsters has shown a decline; Unavailable supply of hatchery-reared pueruli and increase of pueruli demand have negative impacts on wild stocks; Habitat loss may have further impact on wild stocks; Fish and shellfish (lizard fish *Saurida* spp., red big-eye *Priacanthus* spp., pomfret, snails, mussels, oysters and cockles) are fed with poor food conversion ratio (10:1) and water pollution	Arcenal, 2004; Juinio-Menez and Gotanco, 2004; Thuy and Ngoc, 2004
Portunidae (crabs) *Scylla olivacea* *Scylla paramamosain*	Nets such as seine nets, dilly nets; Baited traps/pots; By shovels and hooks	Low with high selectivity	Increase of megalopa demand have negative impacts on wild stocks; Limited supply of hatchery-reared megalopa is not able to reduce impact on wild stocks; Habitat loss may have further impact on wild stocks	Angell, 1992; Le Vay, 2001
Holothuriidae *Holothuria scabra* **Stichopodidae** *Parastichopus californicus*	Artificial seed collectors such as longlines with oyster shells and cedar leaves hang down below the water surface; By hand	Low with high selectivity	Wild adults have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Tiensongrusmee and Pontjoprawiro, 1988b; Tanaka, 1992; Conand and Tuwo, 1996; Sutherland, 1996; Lovatelli *et al*., 2004; Tuwo, 2004; Wang and Cheng, 2004

TABLE 4

Selected representative finfishes taken for CBA with a summary of capture methods and bycatch and discards associated with the process of wild seed collection, and the impacts of CBA practice on environment and wild stocks. *, mortality from capture to harvest is indicated if information available

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Anguillidae (freshwater eels) *Anguilla anguilla* *Anguilla australis* *Anguilla japonica* *Anguilla rostrata*	Nets such as stow nets, fixed nets, lift nets, plankton nets, dip nets, flow traps, scoop nets, hand nets, sieves; Small trawlers	Unknown	Both wild adults and juveniles have shown marked declines; Unavailable supply of hatchery-reared glass and elver eels and high demand for them have negative impacts on wild stocks; Climate changes, oceanic current changes, water pollution, diseases, parasites and habitat loss and juveniles consumption directly have further impacts on wild stocks	FAO, 2002; Ringuet, Muto and Raymarkers, 2002; Knights, 2003; Ottolenghi *et al*., 2004; The Fisheries Secretariat, 2005; Chen *et al*., 2006
Chanidae (milkfishes) *Chanos chanos*	Nets such as push nets, dragged seine nets, fixed nets, hand nets, scoop nets, bag nets, fry sweeper; Longlines attached with bundles of palm leaves; Traps	High bycatch with many other commercial fish and shrimp larvae and juveniles; High discards; Mortality at capture was <10% from most capture methods but up to 20% by fry sweepers; Mortality during storage and transportation was <10%; Mortality during grow-out period was about 50–60%	Wild stocks of adults and larvae have shown marked declines; Available supply of hatchery-reared larvae is far below compared to larvae demand and is not able to reduce impact on wild stocks; High demand of larvae due to the shifts of extensive (traditional) to intensive culture system, and use of prawn ponds as well as international market growth; Habitat degeneration and loss, over-fishing, water pollution and lack of effective regulation on stocks have negative impacts on wild stocks; Smuggling of wild larvae has been a major problem	Korringa, 1976b; Ling, 1977; Kumagai, Bagarinao and Unggui, 1980; Ungson, 1990; Pullin, 1993; Bagarinao, 1998, 1999; Ahmed *et al*., 2001; Liao, Su and Chang, 2001; Hong and Zhang, 2003; Rimmer, 2006
Clariidae (airbreathing catfishes) *Clarias gariepinus* *Clarias macrocephalus*	Nets such as hand nets, scoop nets	Low with high selectivity	Impact of wild larvae and juvenile collection on wild stocks is unknown; Available supply of hatchery-reared larvae and juveniles reduces impact on wild stocks; Habitat loss may have negative impact on wild stocks	Ling, 1977
Pangasiidae (shark catfishes) *Pangasius bocourti* *Pangasius hypophthalmus*	Fine-mesh "*dai*" nets (stationary trawls or fixed bag nets), especially for *Pangasius hypophthalmus*; Hooks (*santouch kontrey pra*) with baits (red ant eggs, worms), especially for *Pangasius bocourti*	High bycatch using "*dai*" with most cyprinids (e.g. 75–90%); 10–30% bycatch using hooks with most other catfishes (*Pangasius*, *Mystus* and *Arius* spp.); High discards or consume by humans; 40–50% of mortality while larvae are transported to farms	Wild adults and larvae have shown marked declines; Limited supply of hatchery-reared larvae is not able to reduce impact on wild stocks; High demand of larvae and habitat loss have negative impact on wild stocks; Smuggling of wild larvae in Cambodia	Trong, Nguyan and Griffiths, 2002; Van Zalinge *et al*., 2002; Lieng and Hortle, 2005
Gadidae (cods) *Gadus morhua*	Seine nets; Traps; Shrimp trawlers; Longlines	Unknown	Wild adults have shown marked declines; Wild juvenile collection quota for CBA reduce impact on wild stocks; Available supply of hatchery-reared juveniles reduces impact on wild stocks but culture techniques need improvement	Björnsson, Hugason and Gunnarsson, 2005
Mugilidae (mullets) *Liza ramada* *Mugil cephalus*	Nets such as shallow-bagged drag nets, beach seine nets, scoop nets, hand nets	High bycatch with about 90% catches were mullets, temperate basses and porgies, and most used for CBA	Wild adults, juveniles and larvae have shown declines; Limited supply of hatchery-reared juveniles and larvae is not able to reduce impact on wild stocks; Low numbers of wild juveniles and larvae may have genetic threaten on wild stocks	Korringa, 1976b; Major, 1978; MEDRAP/TR, 1985; Chandrasekaran and Natarajan, 1993; Sadek, 2000; Sadek and Mires, 2000; Liao, Su and Chang, 2001; MEGAPESCA, 2001; Hong and Zhang, 2003

TABLE 4
Continued

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Moronidae (temperate basses) *Dicentrarchus labrax* *Lateolabrax japonicus*	Nets such as shallow-bagged drag nets, beach seine nets, scoop nets; Traps; Trawlers	Unknown	Wild adults have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Pickett and Pawson, 1994; Zheng, 1994; Sadek, 2000; Sadek and Mires, 2000
Serranidae (sea bases) *Cromileptes altivelis* *Epinephelus akaara* *Epinephelus awoara* *Epinephelus bleekeri* *Epinephelus coioides* *Epinephelus malabaricus* *Plectropomus leopardus*	Nets such as bag (=fyke) nets, fixed nets, scoop nets, push nets; Artificial reefs/shelters (=gangos); Hook-and-line; Traps; Cyanide; A wide range of methods particularly designed for early settlement stage (small juveniles) such as branches and twigs bundles and floating attractant units	High bycatch from most capture methods with high discards or consume by humans; Method of sorting leaves bycatch stranded prior to release associated with very high mortalities for some gears, such as nets and gangos; Often very high mortalities of target grouper from capture to entering culture operations for grow-out to harvest	Wild adults, juveniles and larvae have shown declines in multiple places in Southeast Asia; Some capture methods (e.g. traps and cyanide) damage habitats (e.g. corals) directly; Limited supply of hatchery-reared juveniles is not able to reduce impact on wild stocks; Habitat loss has negative impact on wild stocks	Tseng, 1983; Wilson, 1997; Tseng and Ho, 1988; Sadovy, 2000; Liao, Su and Chang, 2001; Tuan, Nho and Hambrey, 2001; Sadovy and Vincent, 2002; Estudillo and Duray, 2003; Hong and Zhang, 2003; Ottolenghi *et al*., 2004; Mous *et al*., 2006
Carangidae (jacks and pompanos) *Seriola dumerili* (*purpurascens*) *Seriola lalandi* *Seriola quinqueradiata*	Purse seine nets; Pair trawlers; Traps; Artificial floating substrates made from leaves and branches	Low with floating plant substrates where fish aggregation	Wild juveniles and larvae have shown declines; Limit supply of hatchery-reared juveniles and larvae is not able to reduce impact on wild stocks	Korringa, 1976b; Wilson, 1997; Ottolenghi *et al*., 2004
Lutjanidae (snappers) *Lutjanus argentimaculatus* *Lutjanus johni* *Lutjanus lineolatus* *Lutjanus russellii*	Nets such as push nets, gillnets; Trawlers; Traps	High bycatch with many commercial pelagic and demersal fishes	Wild adults and juveniles have shown declines; Available supply hatchery-reared juveniles reduces impact on wild stocks	Wilson, 1997; Huang, 1998
Sparidae (porgies) *Acanthopagrus* (*Sparus*) *latus* *Acanthopagrus schlegelii* (*Sparus macrocephalus*) *Pagrus* (*Pagrosomus*) *major* *Sparus aurata*	Nets such as shallow-bagged drag nets, beach seine nets, scoop nets, seine nets; Trawlers; Traps	High bycatch with many commercial pelagic and demersal fishes	Wild juveniles and larvae have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Korringa, 1976b; MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000
Labridae (wrasses) *Cheilinus undulatus*	Hook-and-line; Gillnets; Traps; Cyanide	Unknown bycatch although cyanide likely to kill off non-target fish affected; 0–80% mortality from capture to harvest	Wild adults and juveniles have shown declines; Unavailable supply of hatchery-reared juveniles and high demand of wild adults and juveniles have negative impacts on wild stocks	Sadovy *et al*., 2003; Sadovy *et al*., 2007
Siganidae (rabbitfishes) *Siganus canaliculatus* Other *Siganus* spp.	Artificial substrates with floating grass	Low	Impact of wild juveniles collection on wild stocks is unknown	Uwate *et al*., 1984
Scombridae (mackerels and tunas) *Thunnus maccoyii* *Thunnus thynnus*	Purse seine nets; Tuna traps; Mid-water trawls	Low	Impacts on environment are high through high feeding levels (5–8%) and poor food conversion ratio (10–20:1); Frozen commercial fishes and squids as feeds; Wild adults have shown declines; Unavailable supply of hatchery-reared juveniles and increase of juvenile demand have negative impacts on wild stocks; Hydrological changes have negative impacts on wild stocks	Ottolenghi *et al*., 2004; Vita and Marin, 2007
Channidae (snakeheads) *Channa (Ophiocephalus) argus* *Channa micropeltes* *Channa striata*	Nets such as dip nets, scoop nets; Traps	Low	Impact of wild juvenile and larvae collection on wild stocks is unknown; Available supply of hatchery-reared juveniles and larvae reduces impact on wild stocks	Ling, 1977; Wee, 1981; Boonyaratpalin, McCoy and Chittapalapong, 1985

TABLE 5

Estimated, observed or inferred catch volumes of wild seeds from selected representative species taken for CBA

Representative species	Catch volume	References
Mytilidae (mussels) *Perna canaliculus*	In the Ninety Mile Beach (New Zealand), about 40–170 tonnes of spats were collected annually, with an increase trend	Jeffs *et al*., 1999
Pteriidae (pearl oysters) *Pinctada margaritifera*	In the Manihiki Atoll (Cook Islands), 3.5 and 1 million of spats were collected in 1996 and 1999, respectively, with a decrease trend	Ponia *et al*., 2000
Penaeidae (shrimps) *Penaeus monodon*	In the Godavari estuary (India), about 1 000–5 000 post-larvae (PL) were collected per person per day in the peak season with a decrease trend in catch (e.g. 4 000–5 000 PL in 1995 and 1 000–2 000 PL in 1999) and at least 500 000 PL per day; In Bangladesh, an estimated 30 billion PL were collected per year for CBA, which was the 90% of PL population	Peterssen, 2002; SAPB, 2002
Palinuridae (spiny lobsters) *Panulirus ornatus*	In Viet Nam, >200 pueruli were collected per boat per night during the settlement seasons; about 2 million pueruli were collected by snorkeling divers in 2003; catch volumes of pueruli (about 7–8 mm and 0.25–0.35 g) increased from 25 000 to 126 000 from 2000 to 2002, by seine nets only in Phu Yen Province; about 50–200 pueruli (7.5–10 mm and 0.3–1 g) were collected by traps during the peak seasons of January and February per fisherman; about 100–150 pueruli (12–15 mm and 7–9 g) were collected per boat (5 divers) for 10 days	Hair, Bell and Doherty, 2002; Thuy and Ngoc, 2004
Portunidae (swimming crabs) *Scylla olivacea*	In Taiwan, about 60 000–70 000 megalopa were collected per fisherman per night during peak seasons	Angell, 1992
Anguillidae (freshwater eels) *Anguilla anguilla* *Anguilla japonica*	In Lake Hamana (Japan), the average catch was 500–600 g glass eels (about 5 000 individuals/kg) per boat per night with annual catch of 1–7 tonnes before the 1970s for *Anguilla japonica*; In Japan, the peak year was in 1979 with 130 tonnes of *Anguilla japonica* seeds were collected, follow by a decline (58 tonnes in 1990, 20 tonnes in 1997 and 38 tonnes in 1998); In Asia (China, Japan, Korea Rep., Taiwan PC), the annual total catches were 60–155 tonnes since 2001 for *Anguilla japonica*; In China only, about 40–95 tonnes of *Anguilla anguilla* glass and elver eels were annually imported from Europe to match the seed demand; Estimated about 100–200 tonnes/year of *Anguilla anguilla* glass eels were imported to Asia from Europe since 1996; In Europe, about 500-800 tonnes of *A. anguilla* glass eels caught in the 1980s; In France, catches of *Anguilla anguilla* glass eels (about 2 500 individuals/kg) declined from 1 345 tonnes in 1970 to 520 tonnes in 1989 and 579 tonnes in 1995; In Denmark, catches of glass eels of *Anguilla anguilla* were about 500 tonnes/year; In Portugal, catches of glass eels of *Anguilla anguilla* declined from 20 tonnes in 1976–1984 to 5 tonnes in 1997; In Spain, catches of glass eels of *Anguilla anguilla* declined from 60 tonnes in 1977 to 7 tonnes in 1997; Declines reported in European Union (EU) countries	Korringa, 1976b; Tzeng, 1997; Ottolenghi *et al*., 2004; COM, 2005; The Fisheries Secretariat, 2005; J.B. Liu personal communication, 2007
Chanidae (milkfishes) *Chanos chanos*	About 5 billion seeds were collected from Indonesia, Philippines and Taiwan PC before the 1970s, far fewer in recent years; In Philippines, about 1.35 billion, 1.16 billion and 165 million seeds were collected in 1974, 1976 and 1995 (with estimated seed demand of 1.5 billions), respectively, with a decrease trend; the CPUE was from several thousands to 20 000 larvae per fisherman per day in the peak seasons before 1980, with a declining trend (only 800–1 650 larvae in 1996–1997); In Ilocos Norte (Philippines), about 18.7 and 9.3 million larvae were collected in 1986 and 1987, respectively	Ling, 1977; Kumagai, Bagarinao and Unggui, 1980; Ungson, 1990; Bagarinao, 1998; Ahmed *et al*., 2001
Pangasiidae (shark catfishes) *Pangasius bocourti* *Pangasius hypophthalmus*	In Cambodia, CPUE for *Pangasius hypophthalmus* larvae declined, e.g. 108–165 billions (650 bag nets) in 1981, 5–12 billion (1 050 bag nets) in 1991, 2–4 billion (1 050 bag nets) in 1997, 0.9–2.1 billion (948 bag nets) in 1998–1999; In Cambodia, CPUE for *Pangasius bocourti* by hooks increased from 2001 to 2004; from 6 millions larvae/juveniles in 2001 (2 850 boats) to 3 millions in 2004 (380–470 boats); In Viet Nam, about 200–800 million larvae were collected annually	Trong, Nguyan and Griffiths, 2002; Van Zalinge *et al*., 2002; Lieng and Hortle, 2005

TABLE 5
Continued

Representative species	Catch volume	References
Gadidae (cods and haddock) *Gadus morhua*	In Iceland, about 500 000 juveniles with 3–10 g were collected annually since 2003	Björnsson, Hugason and Gunnarsson, 2005
Mugilidae (mullets) *Liza* and *Mugil* spp.	In Bardawil and Manzala lagoons (Egypt), 18 million seeds (in Aug 1983–Apr 1984) with 20 mm length were caught; In Egypt, >100 million seeds were collected annually; In Greece, about 200 000 seeds were collected annually	MEDRAP/TR, 1985; Sadek, 2000; Sadek and Mires, 2000; MEGAPESCA, 2001
Moronidae (temperate basses) *Dicentrarchus labrax*	In Egypt, 1 million seeds (larvae and juveniles) were collected in 1996–1997; In Turkey, a total of 3–4 million seeds (larvae and juveniles) was collected in 1995–1999;	Sadek, 2000; Sadek and Mires, 2000
Serranidae (sea bases) *Epinephelus* and *Plectropomus* spp.	In Indonesia, tens of thousands of seeds (larvae and juveniles with 10–30 mm) were collected per fisherman per night using a single unit of gear (e.g., a fyke net) during peak seasons; Overall, the regional trade must have involved tens of millions of seeds at a wide range of sizes, from post-settlement to young adults; In China Hong Kong SAR, annual Pandings of *Epinephelus akaara* juveniles for grow-out was around 130–180 tonnes (about 650 000–1 800 000 juveniles of 100–200 g each) in the 1970s, mainly imported from China; In Khanh Hoa (Viet Nam), about 200 000 larvae and juveniles (including six *Epinephelus* spp. with 10–30 mm lenght) were collected annually in the last decade from 650 fishermen	Tseng and Ho, 1988; Sadovy, 2000; Tuan, Nho and Hambrey, 2001
Carangidae **(jacks and pompanos)** *Seriola* spp.	In China, about 10 million seeds were exported to Japan before the 1990s; In Viet Nam, about 450 000 seeds of *Seriola dumerili* were collected and exported to Japan for CBA in 1995; In Japan, annual catches of *Seriola quinqueradiata* juveniles (25–50 mm) were 25–55 millions since 1966, mainly remained at 25–30 millions since 1990 due to the declines of wild seeds; In Goto Islands waters (Japan), 2.5 million larger juveniles of *Seriola lalandi* (>5 kg) were caught in 1997; In Sicily (Italy), about 2 million juveniles of *Seriola dumerili* (<200 g) were collected in recreational fishing although not for the CBA	Dao, 1999; Ottolenghi *et al.*, 2004
Sparidae (porgies) *Sparus aurata* *Pagrus major*	In Bardawil and Manzala lagoons (Egypt), 800 000 (in Apr–May 1983) and 8 million (in 1984–1985) juveniles with 20 mm/2 g were collected, respectively; In Egypt, 3–4 million larvae (0.25–0.5 g) and juveniles (1–10 g) were collected (10 million estimated by fishermen) with one million from hatchery in 1996–1999; In Turkey, a total of 140–160 million seeds (larvae and juveniles) was collected in 1995–1999; In Hong Kong SAR, about 6 million juveniles were collected and exported to Japan for CBA in the 1980s–1990s, and hard to catch now	MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000

- Crustacean wild seeds are collected by various methods for CBA and, as for molluscs, seed collection tends to be concentrated in specific locations and seasons when large numbers become temporarily available (Tables 3 and 5). For shrimps, the process of wild seed collection involves nets of various types, from push nets to towed/dragged nets in shallow coastal waters or creeks. Bycatch using such gears can be high from Asian and South American countries (e.g. Bangladesh, India, Malaysia, Philippines and Ecuador) and involve a variety of larvae and juveniles of commercial fishes and crustaceans as well as discards depending on the area fished (Petersson, 2002; SAPB, 2002; M.L. Cobo personal communication, 2007). Many millions of shrimp post-larvae are collected in the season within small areas (Table 5); mortality levels from capture to transfer to ponds appear to be low for at least one species (*Penaeus monodon*) (Petersson, 2002). For lobsters, wild seed are collected using artificial substrates on which the pueruli settle, as well as by nets of various kinds and while diving (with collection by hand or using cyanide) in some cases. Declines in seed availability have been noted in Asian countries.
- The relationship between the collection of very early stage seeds and the status of adult stocks has been shown in a few species identifying the need for a holistic look at such fisheries. For example, a relationship between settlement stage pueruli and numbers of resulting lobster adults was identified in Australia (Phillips *et al*., 2003; Gardner *et al*., 2006). This finding is extremely important for highlighting the link between settlement numbers and subsequent adult stock size and for setting a fishery quota for both pueruli and adults in this case. For mud crabs, nets, pots, shovels and hooks are all used to collect megalopa with catch rates estimated in one place at 60 000–70 000 per fisherman per night in the peak seasons, which may have negative impacts on wild stocks (Angell, 1992).
- Small holothurians are taken for CBA using specially designed seed collectors and by hand. Adult stocks of a number of species have shown marked declines and populations of some species have suffered over-exploitation for decades in some Asian countries (Lovatelli *et al*., 2004). Hatchery-based holothurian aquaculture (e.g. Japanese sea cucumber *Apostichopus japonicus*) has been well-developed in China in recent years (Chen, 2004); whether HBA of holothurias can reduce the impact on wild stocks and help stock recovery needs further investigation.
- In finfishes, seeds of a wide range of sizes are taken, and in large numbers, from settlement stage larvae through to adults. Adult and seed stocks have shown marked declines in almost all representative species, the result of some combination of over-exploitation of wild stocks of adults and seeds, habitat loss, etc. The heavy take of seed for some species is also prompted by the limited supply of hatchery-reared seeds (Table 4). Associated with seed collection, bycatch and mortalities can be high, leading to much wastage of target and non-target species in some areas or during certain activities. Examples include milkfish in Indonesia and the Philippines, shark catfishes in Cambodia and Viet Nam, mullets in Egypt, sea basses, snappers and porgies in Southeast Asia and Egypt (Table 4). In these species, capture methods range from nets, traps, hook-and-lines and trawlers, to chemicals and artificial shelters; many methods are not species-specific and can cause significant habitat disturbance and damage. Although bycatch species containing some commercially important finfishes and shrimps can also be used for CBA, most tend to be discarded, while a few might be consumed by humans, depending on size.

CBA PRACTICES IN RELATION TO DISEASE, ENVIRONMENT AND BIODIVERSITY

CBA practices need to be considered in relation to disease transfer and environmental impacts including on species diversity. Although these issues are also relevant to HBA, there are certain considerations specifically or indirectly pertinent to CBA practices because some of the impacts on biodiversity are negative (Beveridge, Ross and Kelly, 1994). There are no clear positive impacts on biodiversity yet noted in relation to CBA. Clearly, both CBA and HBA practices are associated with a number of problems such as water pollution and environmental damage, wich are exacerbated where CBA is extensively practised simply because CBA means higher volumes of animal under culture (Tables 3 and 4). With the extensive development of CBA practices and increasing transport and trade of wild seed both regionally and globally, problems of disease and genetic pollution associated with transfers and escapes of wild seeds may be a matter for concern. Below are some examples that illustrate the problem.

- In the case of *Epinephelus* groupers, a *Vibrio* strain in *Epinephelus bleekeri* was transferred from Thailand to China Hong Kong SAR in wild caught seeds and resulted in the elimination of almost all cultured groupers in China Hong Kong SAR in the late 1990s, a serious blow to the industry at the time which took several years to recover (Sadovy, 2000).
- Environmental impacts from CBA practices need to be addressed. Low environmental impacts from CBA practice for *Anguilla* eels are assumed because artificial feed rather than natural feed is provided and because land requirement are low for intensive culture practices in both Asia and Europe (Ottolenghi *et al.*, 2004). However, unregulated use of groundwater for eel culture in China and Taiwan Province of China (Taiwan PC) has caused severe land subsidence (Chen *et al.*, 2006). Moreover, the high demand of fish-meal for eel feed and the use of chemicals for disease treatment and prevention during eel culture in China need to be addressed.
- All crustaceans and a significant number of finfishes in CBA are carnivorous and require feed input that includes wild-caught fish (i.e. fresh feed input). While these are also relevant to HBA species, the extensive use for CBA, especially for carnivorous species, can add significantly to the problems that such practices cause. Uneaten feed, faecal and urinary wastes may have negative environmental impacts and lead to local water quality degradation and sediment accumulation (Wu, 1995). For example, in a tuna (*Thunnus thynnus*) fattening culture farm in the Mediterranean Sea producing 800 tonnes of tuna a year, the use of defrosted fish was shown to affect the benthic environment over an area 400 m diameter, an impact considerably greater than other fish culture practices in the same area (Vita and Marin, 2007). Study of carrying capacity of the local environment (i.e. the maximum numbers of animals or biomass that can be supported by a given ecosystem for a given time) is particularly important for aquaculture practices of this sort which, although they can produce a valued product, can also cause more wide-ranging negative impacts on the natural environment.
- Possible adverse biodiversity impacts from CBA practices in relation to global *Anguilla* eel seed trade are of interest. The introduced European eels (for CBA and restocking proposes in Japan) have been found free in Japanese natural waters in recent years with the silver stage eels migrating downstream at the same time as native Japanese eels form downstream migrations (Miyai *et al.*, 2004). The potential impacts of inbreeding between the two species and on local aquatic biodiversity should be examined, since eels are important predators in freshwater benthic habitats.
- The HBA culture of a number of tropical marine fish species will continue to depend to some degree on wild broodstock to maintain genetic diversity, for feed, and, in some cases, continued contribution of wild seed. In many cases, not only is the target species removed but also a heavy bycatch component. For instance, for 1 kilogram of shrimp post-larvae collected, an estimated 10 kg of larvae and juveniles of other species may be discarded (Beveridge, Ross and Kelly, 1994). More extreme ratios are likely in certain fisheries for grouper juveniles (Mous *et*

al., 2006). Heavy exploitation for target species can mean extremely high levels of associated bycatch with the potential for negative impacts on biodiversity. More generally, high densities of farmed fish and food attract predators that could, conceivably have an impact on local species, while the heavy demand for wild fish feed and fishmeal, intensified by CBA, is exerting growing pressures on such species; in extreme cases this could affect local biological diversity (Beveridge, Ross and Kelly, 1994; Naylor *et al*., 2000).

MANAGEMENT

Current and recent management measures as well as those being developed that are applicable to various aspects of wild seed fisheries associated with CBA are summarized and discussed. Regulations on marine and freshwater invertebrates and vertebrates from around the world are selected to provide a cross-section of the types and extents of protective measures (Table 6). The selection is illustrative, rather than exhaustive.

The development of management measures has been a response to problems noted in various fisheries, usually declining catches but sometimes concern over bycatch or damage to substrate. In some cases the cause of the problem is clear or can be reasonably attributed to a specific cause or causes, but in others, the reason for problems is not necessarily clear and management is precautionary or based on the best available scientific information. Management measures to address overfishing that have been introduced or are under discussion range from gear controls to catch quotas (e.g. total allowable catch), limited fishing seasons and export controls, size controls, permit issuance, rights of access to fishing grounds, to genetic pollution and disease controls.

In cases where habitat damage is a major concern because seed capture methods involve removal of habitat, fishing gears that move closely over the substrate, or poisons, measures used include bans, modification of fishing gear and protection of larval and juvenile settlement or nursery areas. Where there are concerns about possible impacts on biodiversity of non-target stocks, largely because of bycatch, measures address gear characteristics and may involve training fishers in better handling techniques for reducing mortalities. Example include, more careful transfers during transport, lower densities of storage and transit, more oxygenation as needed, etc. Other measures tackle concerns about disease transfer, as seed have increasingly been traded (exported or imported) or exchanged as part of a valuable seed market, with possible genetic "pollution" from reintroductions or escapes of genotypes into non-native areas.

Typically and not surprisingly, wild seed fisheries for CBA often begin with no management and are practised for decades, sometime generations, with little or no controls. Examples range from molluscs, catfish, mullets and milkfish to groupers and eels. Seed fisheries were largely excluded from formal legislation in the past. This is possibly because of their low perceived value and impact and limited information availability. It may also be because of a general perception that taking seed was somehow getting "something for nothing"; that removal of larvae and small juveniles did not affect adult populations because most would die naturally if not fished – indeed CBA is more likely to be viewed to be a means to gain a net increase production. When fishing pressure was low, this may well have been the case. As fishing pressure and demand for seafood increased there has been a general intensification of fishing, including on seed fisheries. In the case of mussel from New Zealand, it is quite possible that highly targeted collection of large numbers of spats could significantly affect population regeneration since a high proportion of settlers are removed for CBA each year. It is only in the last decade or so, often only after stocks have been very severely reduced, or where there are conflicts identified between users of different life history stages of a species (e.g. in the cases of lobsters, shrimps, shark catfishes, eels and tunas) that management is discussed and legislation developed, and the biological and ecological links formally acknowledged. The high value luxury seafood seed fishery sector,

TABLE 6

Examples of current/recent and/or potential management measures for wild seed fisheries and trade for CBA

Country	Current and/or potential management measures	References
EU countries	Species management European eel (*Anguilla anguilla*): wild seed collection of eel elvers needs permit in France; massive declines of eel stocks have prompted the discussion for management which is complicated by the very variable fisheries across Europe (shared resource); a recent proposal from the Commission of European Communities includes a seasonal closure of its fishery (the first 15-day closure each month) since July 2007, restoration of habitat and migration paths, and better fishery regulation, anti-poaching action and improvement of water quality are proposed; by 2013, 60% of catches of glass eels should be used for restocking of inland waters so as to increase escapement of adult eels to the sea; Mullets: wild seed collection of mullets needs permit in France; maximum collection was controlled at 200 000 seeds in Greece; Tuna (*Thunnus thynnus*): catch quota for CBA in the Mediterranean Sea; Cod (*Gadus morhua*): <500 000 juveniles (maximum quota) with 3–10 g allowed to collect annually since 2003 for CBA in Iceland; Mussels: mussel spat collection in Italy are managed including rearing or stocking purposes during certain periods per year, spat collection quotas, maximum size, gear limit, hygiene requirements for the transportation of spats intended for rearing and repopulation purposes; Clams: clam spat collection in Italy are managed including rearing or stocking purposes during certain periods per year, spat collection quotas, maximum size, gear limit, hygiene requirements for the transportation of spats intended for rearing and repopulation purposes; Multiple species: no wild seed collection (all species except mollusc seeds) allowed since 1992 in Portugal. Input control Local management in size limits, permits, close seasons and areas, restoration of habitat and migration paths.	MEDRAP/TR, 1985; Gazzetta Ufficiale della Repubblica Italiana, 1996; Sadek and Mires, 2000; Ringuet, Muto and Raymarkers, 2002; Ottolenghi *et al*., 2004; Björnsson, Hugason and Gunnarsson, 2005; COM, 2005; The Fisheries Secretariat, 2005
China	Species management Groupers (*Epinephelus* spp.): control on number of "seed" collection fishers and amount of "seed" captured; All marine species: license is needed for transporting marine "seed" and export of "seed" is banned to prevent infections or parasites. Input control Illegal fishing (e.g. poison, blasting) is prohibited.	National People's Congress Order, 1991; Sadovy, 2000
Taiwan PC	Species management Groupers: in the Penghu Islands, harvest of grouper seed <60 mm is not permitted. Input control Cyanide cannot be used for fishing (this regulation occurs in many countries and in relation to fisheries in general, not just seed).	
India	Species management All aquatic species: the ban on wild seed collection year-round was announced in 1999 through the State of Fisheries Department and is still valid; local government lacks the economic support to implement this ban; wild seed collection continues.	Petersson, 2002
Indonesia	Species management Humphead wrasse (*Cheilinus undulatus*): wild collected <1 kg and >3 kg fish should be used for CBA or released; capture methods limit to hook-and-line, traps and gillnets; permit is needed for purchase and export 1–3 kg fish.	Sadovy, 2000; Sadovy *et al*., 2003

TABLE 6
Continued

Country	Current and/or potential management measures	References
Philippines	Species management Lobsters: export of juveniles was banned prior February 1992 but subsequently lifted; Humphead wrasse (*Cheilinus undulatus*): small wild collected fish (<300 g) should be used for CBA; All CITES species: ban from export; Milkfish: the Fisheries Code of 1998 bans export of "seed" of milkfish; fishing of broodstock (*bangus*) is banned; Prawns: the Fisheries Code of 1998 bans export of "seed" of prawns; All live fishes: strictly speaking, the export of any live fish (include seeds) is illegal but this is not enforced. Input control Scissor (push) and fyke (bats) nets fishing are illegal; Poison fishing is illegal. Fishing ground management Regulations intended to protect some seed collection grounds (e.g. milkfish) and nursery grounds as "fry reservations" have not been implemented.	Sadovy, 2000; Ahmed *et al*., 2001; Sadovy *et al*., 2003; Juinio-Menez and Gotanco, 2004
Malaysia	Species management Groupers: no grouper seeds can be collected during the peak season; no export of grouper seeds <150 mm; Cockles: removal of cockle spat from a natural cockle bed or cultured cockle bed are banned. Input control Cyanide fishing is prohibited.	FAL, 1986; Fisheries (Riverine) Rules, 1990; Sadovy, 2000
Australia	Species management Tuna (*Thunnus maccoyii*): fishing season and TAC (expressed as weight) of juveniles for CBA are regulated; Rock lobster (*Jasus edwardsii*): to ensure "biological neutrality" between CBA and adult capture fisheries for the species the number of pueruli that can be removed cannot exceed 300 000 annually (calculated using virtual population analysis); pueruli below 76 mm carapace length are protected; applications for culture consider issues of genetic contamination and disease; restocking of partially raised young to enhance capture fishery.	Ottolenghi *et al*., 2004; Gardner *et al*., 2006
Thailand	Input control The use of push nets and fyke nets is limited; The use of bottom nets fishing within 3 km of the shore are regulated; Mesh size ≥25 mm.	Sadovy, 2000
Viet Nam	Species management Groupers: <500 g cannot be exported. Input control Fine-mesh *dai* nets (stationary trawls) are totally banned in some provinces since 2000, which especially for capture wild larvae of shark catfish *Pangasius hypophthalmus*.	Sadovy, 2000 Trong, Nguyan and Griffiths, 2002; Lieng and Hortle, 2005
Cambodia	Input control Fine-mesh *dai* nets (same as above) were outlawed in 1994 but still used by 1998.	Lieng and Hortle, 2005
Bangladesh	Species management Shrimp (*Penaeus monodon*): permits needed, fishing season controlled, restocking of hatchery PL, reducing bycatch by training fishers for better handling of PL and create alternative livelihoods to remove pressure from wild PL collection.	SAPB, 2002

including for southern bluefin tuna, lobster and grouper, have provided much incentive for sustainability. Management has developed quickly that explicitly addresses the links that exist between adults and pre-adult phases taken by different fisheries.

As fishing, in general, has intensified, it is not surprising that the potential for adult capture fisheries and seed fisheries to affect each other has been realized to the extent that there are now management initiatives that seek to ensure that the two fishing sectors are not in conflict by using stock analyses. This will have to be one of the approaches to management in future if stocks are to be sustained, if equity is to be considered between fishing sectors, and if conflicts over resource use are to be minimized and management aims for sustainable practices realized. This balancing of differential life history phase use is referred to under the general name of "biological neutrality" (Gardner *et al*., 2006).

For insight into some of the complexities and issues involved in conserving seed fisheries, the long-standing European eel fishery serves as a good example. Declines in European eel catches, including glass eels, elvers and adults, have occurred throughout the range of the species; the exact cause is unknown. Likely causes are a combination of over-exploitation, oceanographic or climate change, freshwater habitat degradation and pollution, and disease, although overexploitation is clearly one important factor (Knights, 2003; Starkie, 2003; Van Ginneken and Maes, 2005). Since so little is known about the life history stages of the European eel, planning for its sustainable management is a difficult challenge and it is only very recently that serious discussions have started to address the long-recognized, albeit little acknowledged, declines in catches (Table 6). Most recently, a study demonstrated genetic differentiation in the European eel indicating that the species consists of several stocks and not just one, as previously thought (Wirth and Bernatchez, 2001). This information is important for assisting protection because it identifies the geographic scale at which management might be most effective and indicates that the massive transfers of seed that have occurred widely within Europe should be restricted or carefully controlled.

Shrimp seed fisheries can be extremely complex; many have a long history of fishing with the involvement of many different user groups. In one area of Bangladesh, for example, the interest groups for shrimp production range from shrimp farmers, biologists and government, to the fishers and hatcheries that supply the farms and exploitation on both adult and seed stocks all have very different needs and opinions on how to deal with the marked declines noted in one of the two shrimp species they commonly exploit (SAPB, 2002). The long history and complexity of this situation makes management extremely difficult and provides a lesson that management should start early in fishery development rather than long after major conflicts and resource declines have occurred and many users or user groups become involved and dependent.

In summary, the management experience for seed fisheries is extremely varied, most is very recent, and little appears to have been effectively implemented to date. There is little evidence of monitoring of seed fisheries in general, which is essential for understanding the effects of management, or of enforcement. It is clear that many of the management challenges stem from the complexities of understanding and assessing fisheries acting at different life history stages, especially when one of these, the early life history "seed" stage is little understood (either biologically or as a fishery). The general assumptions surrounding the impacts, or, rather, the lack thereof, of removing early life history phases, on later adult stages or wild populations have precluded management discussions until recently.

Regulations that address seed fisheries must focus on specific aspects of the problems encountered and not just treat them as fisheries of "undersized" individuals, except, perhaps in cases such as of the humphead wrasse and bluefin tuna. The problems are compounded when other factors, such as habitat degradation, destruction or water pollution may also be major factors in declines noted. What is clear is that seed fisheries are important and likely to be important for a long time since HBA (i.e. full-cycle aquaculture) is only viable for a small subset of aquatic species. Even in species for which hatchery-reared seed are available, issues of seed "quality", HBA production volumes and costs may mean continued pressure on wild stocks to provide high quality, inexpensive seed. Farmers may prefer wild-caught seeds in some areas, such as milkfish in the Philippines, shark catfish in Viet Nam, shrimps in Bangladesh, or economic factors might mean that wild-sourced seeds are sometimes cheaper than those of the same species that are hatchery produced, as in the case of several grouper species in the Taiwan Province of China culture sector (Sadovy, 2000). The issue of management of wild populations in CBA, therefore, must be addressed, and must specifically seek to tackle the characteristics of "seed" fisheries.

FUNDAMENTALS OF CBA PRACTICE

Several aspects of seed fisheries for fish and invertebrate species can be considered of theoretical importance because they are fundamental to sustainable resource use, yet are either very little understood or extremely difficult to quantify. Therefore, the precautionary approach can, combined with the best available information and scientific reference, address key issues. Central to these, in relation to CBA, is the nature and extent of the linkage between wild seed collection of early life history stages and the condition of adult stocks, and how to manage different fishing sectors exploiting the same species. The key biological information needed includes density-dependent effects among seed, and age-specific natural mortalities, both of which are virtually unknown for marine species with planktonic larval stages. These parameters are of critical important because they dictate how many seeds can be removed from the wild without affecting adult stock numbers.

For some species there is a known quantitative relationship between seed numbers and adults, while for most a relationship is not clear, the implications being that density-dependent effects and total mortality (i.e. natural plus fishing) levels probably have very different significance for different species, or depending on the age of the seed at capture. Illustrative examples are lobster and shrimp. For tiger shrimp (*Penaeus monodon*), the post-larval fishery removes an estimated 90 percent of the seed population, which scientists believe is largely responsible for the heavy declines in the adult shrimp fishery off Bangladesh; in the case of *Metapenaeus monoceros* taken in the same general area, however, the adult fishery is in much better shape because, it is thought, there is little vulnerability of the post-larvae to fishing; less than 10 percent of this early stage is removed by fishing (SAPB, 2002). In the case of lobster, natural mortality estimates of *Panulirus cygnus* in western Australia suggest that this is regulated by density and is so high that even very large removals of pueruli are expected to have negligible effects on wild fisheries (Phillips *et al*., 2003). For the rock lobster (*Jasus edwardsii*), on the other hand, collection of pueruli potentially affect adult numbers and so there is interest in attaining "biological neutrality" whereby excessive seed removal does not compromise the adult fishery (Booth, Davis and Zane, 1999; Phillips *et al*., 2003; Gardner *et al*., 2006). The degree to which density-dependence is important will depend, in part, on whether stocks are habitat or recruitment limited. As fishing pressures increase, the latter becomes more likely and the relevance of density-dependence is likely to decline substantially. Very little is known about either natural mortality levels early in life or the extent to which density-dependent effects can and do occur under different conditions suggesting that a precautionary approach is applicable.

What is known about density-dependent effects and early natural mortality rates in finfishes subjected to seed fisheries that can assist management decisions? For a few reef fishes, although early juvenile survivorship varies among species in the first few weeks or months following settlement, indications are that natural mortality, very high at settlement, drops quickly during the first few months post-settlement

(Sale and Ferrell, 1988; Koenig and Colin, 1999; Doherty *et al*., 2004). For such species, the intense exploitation of older juveniles (which have entered a low natural mortality stage) for CBA clearly increases fishing mortality directly on the stock as a whole, and the fishery should be managed to ensure that sufficient young are allowed to survive to reproduce for population persistence (Sadovy and Pet, 1998; Sadovy, 2000). A specific example of this is the fishery for grouper juveniles, many of which are several years old at capture and are removed prior to sexual maturation for grow-out in captivity to marketable size (Sadovy, 2000). This practice has increased over the last decade as adult stocks have become over-fished, the demand for seed has increased and fishers take ownership of caught fish as soon as they can rather than return undersize fish to the water (Sadovy, 2000; Sadovy *et al*., 2003). The impact of removing grouper juveniles at one week of age or less, compared to removing the same number of juveniles at 6 months or more (both practices are common) could mean the difference between healthy and devastated stocks. In the case of the older juveniles, their capture and the addition of feed is no different from the fattening of juveniles of bluefin tuna species.

A precautionary approach to seed fishery extraction rates, based on what is known currently, and acknowledging how much is still unknown about early life history stage dynamics, is to assume some degree of linkage between adult and seed fisheries and manage accordingly. This approach is already practised in the case of southern bluefin tuna through catch quotas on juveniles taken for fattening and for rock lobster (Gardner *et al*., 2006) (Fishery Status Reports, 2005; 2006); such quotas should be in numbers, rather than weight. Follow-up monitoring allows for adaptive management and adjustment of fishing levels as needed. This precautionary and adaptive approach is particularly relevant as seed fisheries intensify, with possibly billions rather than millions of seeds taken each year, and given how challenging it will be to collect the necessary natural mortality and density-dependent information. Key to such thinking is to acknowledge that the production of large numbers of eggs and larvae in pelagic spawning species is not a redundancy but a fundamental life history strategy. Enormous numbers are produced for a simple but compelling reason – the very low chances that any one propagule will survive to adulthood. Removing a significant number by fishing will inevitably further reduce that possibility to some extent, with negative implications inevitable beyond some threshold of removals. Fisheries for aquarium organisms and food fish, based on the capture of post-larval settlement phase fish, have been proposed as a viable alternative activity to adult capture, although nothing is known of the volumes of post-larvae that could be removed sustainably (Hair *et al*., 2004). A better understanding of such thresholds is needed and/or a means found to ensure it is not exceeded, thereby compromising affected fisheries and the livelihoods that depend on them.

RECOMMENDATIONS

CBA is an economic activity that will almost certainly expand in the short term, and is very likely to continue into the long term for many species. CBA is practised because it has become necessary as a livelihood, as an alternative means to controlling access of fishery resources, to meet market demand and, if practised properly, to enhance yield. It does not necessarily, or even desirably, lead to HBA and does not demonstrably take pressure off wild stocks. For example, despite decades of *Anguilla* CBA, successful HBA is far from certain. Moreover, new species will likely become the focus of CBA while a few species will eventually move to successful hatchery production. Even in the latter case, as for groupers, a mixed model might persist whereby both HBA and CBA practices occur; it took over 10 years to reach successful grouper HBA for just a few species while many others (e.g. the Hong Kong grouper *Epinephelus akaara*) continue to be exploited under CBA despite capacity for HBA. The bottom line, it seems, is that CBA is here to stay and means must be sought to ensure its sustainable practice. Whether or not CBA, or HBA, will take pressure off wild fisheries is entirely another matter that would require specific legislation whereby CBA development is balanced by a corresponding and specific reduction of fishing pressure in concert with CBA expansion. While, for example, the supply of hatchery-reared juveniles for back-yard grow-out of groupers in Indonesia is claimed to have reduced cyanide fishing by replacing fishing with culture practices, there are no quantitative data to support this and no relevant legislation to mandate a the shift from capture to culture.

CBA is truly a hybrid between capture fisheries and aquaculture, with many of the advantages and disadvantages inherent in both activities. Important as an alternative livelihood, CBA also offers opportunities for the development of HBA. However, CBA is not necessarily a stepping stone between the two but rather an activity in its own right which will certainly continue. Because of the impacts and implications of CBA, it needs to be acknowledged as distinct sector and integrated and managed accordingly as a specialized, albeit little understood type of fishery. This means that the objectives of CBA must be clear, the risks identified, activities clearly defined, and practices developed or modified to address the negative aspects of the practice and enhance the benefits.

Based on the present review, eight specific recommendations are proposed to improve CBA practices in a way that will address many of the shortcomings documented:

- **Precautionary approach and FAO Code of Conduct:** There is a need to adopt the precautionary approach in CBA. There is a little biological understanding of early life history stages of species under CBA, and they receive negligible management attention. Moreover, the principles and guidelines of the FAO Code of Conduct for Responsible Fisheries should be applied because CBA involves capture fisheries.
- **Mortality:** There is a need to be realistic. While very early settlement stage larvae almost certainly suffer high mortality reducible by judicious removal from the wild and culture, propagules are not infinite for any species and the highly focused removal of millions to billions of seed will ultimately compromise stocks. Much CBA is practised on older post-settlement stages, in effect capture fisheries of juveniles, that need to be managed accordingly. Management that takes such realities into account need to be developed for many of the CBA species reviewed, and training and outreach is needed to reduce mortalities associated with a range of capture, transfer and culture practices.
- **Bycatch:** In addition to a high capture and culture mortality, there is, for many of the representative species reviewed, a high and often diverse associated bycatch. This aspect of these fisheries can severely undermine the perceived advantages of CBA and measures should be made to develop more selective gears, or, fish in a way that minimizes wasteful bycatch.
- **Objectives of CBA:** The objective(s) of CBA must be clear if it is to capitalize on its potential and be managed and practised sustainably. Nowadays, CBA is largely an economic activity involving many high value species and not necessarily practised with the objective of producing basic, low-cost, seafood for sustenance. It is, therefore, not currently practised as an alternative to fishing for food per se. Rather, it is as an economic activity in its own right, provides livelihoods, and, perhaps, is a means of gaining access to, and control of, increasingly limited resources earlier in their life history. It is only by acknowledging its role in practice that it can be managed effectively.
- **Management:** Management and better practices are possible only when activities are recognized, acknowledged and documented. CBA needs to be monitored and a better understanding of its direct and indirect impacts on targeted and non-targeted (bycatch) species considerably better understood. Other impacts, such

as the effects of fishing gears, have been widely acknowledged and need effective management. Considerations of equity of resource access and user conflicts should be factored into management plans. Moreover, even HBA will depend for genotype refreshment from natural broodstock, such that wild populations will continue to need management. Finally, for managing late stage CBA (e.g. as for tuna), if most juveniles removed are likely to survive to adulthood, it makes more biological sense to manage by number of fish in a quota, rather than by weight as is currently done.

- **CBA to HBA:** It is clear that not all CBA leads to HBA and that mixed models are likely to persist long into the future. For many species, the focus on CBA versus HBA will depend on economic factors and whether CBA moves to HBA is both an economic and a technical matter, and far from inevitable. It may not even be desirable that all mariculture becomes HBA because of the possible control on seed supply by big business that HBA would foster, with possible negative impacts on wild seed prices and livelihoods of seed collectors. Given the inevitable and probably advisable, mixed model, the relationships between the two activities need to be acknowledged and managed practically and realistically.
- **Definitions:** The perspectives on how to manage, understand and monitor CBA are heavily shaped by how it is defined and what are the objectives in its application. The recent introduction of the term CBA has been enormously helpful in better understanding and more easily discussing it. However, the documentation of CBA-cultured species in FAO records appears to be unnecessarily complicated and somewhat misleading. We propose a simpler and more representative set of definitions that directly reflect the nature of CBA in relation to wild resources. For documenting and reporting culture production, we suggest two major categories; "hatchery" and "non-hatchery" sources of seed. Under non-hatchery sources, a subdivision could be used to distinguish between "growing-out" (of eggs, larvae, very early post-settlement stages) and "fattening" (the increase in bulk of settled/juvenile animals or their maintenance until retail). The former would include spat, post-larvae and small juveniles of fish and invertebrates and the latter would include large juveniles and young adults, for example of groupers and tunas. The intention is to distinguish between seeds taken at very high natural mortality stages and seeds taken once natural mortality has likely dropped to near adult levels. Both categories of non-hatchery produced seed would need to be managed and monitored.
- **Species cultured**: The culture of fish centuries ago began with CBA practised on herbivorous and omnivorous species, such as carps, milkfish, mullets, eels and tilapias to address basic needs for food, while expensive, luxury, and carnivorous species appeared only after the 1940s (Ling, 1977; Beveridge and Little, 2002). If CBA is to be used for food security there has to be a greater focus on species that can provide cheap food and do not involve the many problems associated with carnivores in culture and capture. Again the "Objectives" of CBA need to be clear, i.e. why do we need CBA and how can we use it to best advantage? There are tradeoffs to different objectives and some are mutually exclusive: provision of livelihoods for seed supply may compromise the fishery of adults of the same stock; the use of ponds for expensive grouper culture may mean that cheaper food fishes are displaced; in both cases poorer communities might lose out; the removal of massive volumes of fish feed may compromise the feed species (many of them the young of cheap fish consumed by humans) captured, or the ecosystems they belong to. Without clear principles and guidelines, and a realistic evaluation of the constraints and problems associated with CBA, this form of culture cannot realize its full potential and, far worse, may further compromise natural marine resources and human communities.

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REFERENCES

Ahmed, M., Magnayon-Umali, G.A., Valmonte-Santos, R.A., Toledo, J., Lopez, N. & Torres, F. 2001. *Bangus Fry Resource Assessment in the Philippines*. ICLARM Technical Report 58. Manila, Philippines. 38 pp.

Allen, G.R. 1991. *Field Guide to the Freshwater Fishes of New Guinea*. Christensen Research Institute, Madang, Papua New Guinea. 147 pp.

Angell, C.A. 1992. *Report of the Seminar on Mud Crab Culture and Trade*. BOBP/REP/51. Bay of Bengal Programme, Madras, India. 246 pp.

Arcenal, J.M.M. 2004. Sustainable farming of spiny lobster in western Mindanao, Philippines. *In* K.C. Williams, ed. *Spiny Lobster Ecology and Exploitation in the South China Sea Region*. Proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Viet Nam, July 2004, pp. 19–20. ACIAR Proceedings No. 120. Canberra, Australia. 73 pp.

Bagarinao, T. 1994. Systematics, distribution, genetics and life history of milkfish, *Chanos chanos*. *Environmental Biology of Fishes* 39(1): 23–41.

Bagarinao, T. 1998. Historical and current trends in milkfish farming in the Philippines. *In* S.S. De Silva, ed. *Tropical Mariculture*, pp. 381–422. Academic Press, USA.

Bagarinao, T. 1999. *Ecology and Farming of Milkfish*. SEAFDEC Aquaculture Department. Iloilo, the Philippines. 171 pp.

Bagarinao, T.U., Solis, N.B., Villaver, W.R. & Villaluz, A.C. 1986. *Important Fish and Shrimp Fry in Philippine Coastal Waters: Identification, Collection and Handling*. SEAFDEC Aquaculture Department. Iloilo, the Philippines. 51 pp.

Bell, J.D. 2004. Key issues for sustaining aquaculture production of the spiny lobster, *Panulirus ornatus*, in Viet Nam. *In* K.C. Williams, ed. *Spiny Lobster Ecology and Exploitation in the South China Sea Region*. Proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Viet Nam, July 2004, pp. 59–62.

Beveridge, C. M. & Little, D.C. 2002. The history of aquaculture in traditional societies. *In* B.A. Costa-Pierce, ed. *Ecological Aquaculture: the Evolution of the Blue Revolution*, pp. 3–29. Blackwell Science, Oxford.

Beveridge, C. M., Ross, L. G., & Kelly, L. A. 1994. Aquaculture and biodiversity. *Ambio* 23: 497–502.

Björnsson, B., Hugason, K. & Gunnarsson, V.I. 2005. *Cod Farming in Nordic Countries*. Summary of the main points from the conference held in Nordica Hotel, Reykjavik, 6–8 September 2005. 8 pp.

Boonyaratpalin, M., McCoy, E.W. & Chittapalapong, T. 1985. *Snakehead Culture and Its Socio-economics in Thailand*. NACA/WP/85/26. Bangkok, Thailand.

Booth, J., Davies, P. & Zane, C. 1999. Commercial scale collections of young rock lobster for aquaculture. *In* Proceedings of the World Aquaculture Meeting Abstracts, p. 84. Sydney, Australia.

Burton, C.A., MacMillan, J.T. & Learmouth, M.M. 2001. Shellfish ranching in the UK. *Hydrobiologia* 465: 1–5.

Chandrasekaran, V.A. & Natarajan, R. 1993. Mullet seed resources of Pichavaram mangrove, southeast coast of India. *Journal of the Marine Biological Association of India* 35(1-2): 167–174.

Chen, J.X. 2004. Present status and prospects of sea cucumber industry in China. *In* A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.F. Hamek & A. Mercier, eds. *Advances in Sea Cucumber Aquaculture and Management*, pp. 25–38. FAO Fisheries Technical Paper, No. 463. Rome, FAO.

Chen, Y.H., Lee, W.C., Chen, C.C., Chen, Y. & Liao, I.C. 2006. Impact of externality on the optimal production of eel (*Anguilla japonica*) aquaculture in Taiwan. *Aquaculture* 257: 18–29.

Chou, R. & Lee, H.B. 1997. Commercial marine fish farming in Singapore. *Aquaculture Research* 28: 767–776.

COM. 2005. *Proposal for a Council Regulation-establishing Measures for the Recovery of the Stock of European Eel.* COM 472 Final, 2005/0201 (CNS). Commission of the European Communities. 11 pp.

Conand, C. & Tuwo, A. 1996. Commercial holothurians in South Sulawesi, Indonesia: fisheries and mariculture. *SPC Beche-de-mer Information Bulletin* 8: 17–21.

Costa-Pierce, B.A. 1987. Aquaculture in ancient Hawaii. *BioScience* 38(5): 320–331.

Dao, M.S. 1999. Marine fish culture in Viet Nam. *In* A.S. Cabanban & M. Philips, eds. *The aquaculture of Coral Reef Fishes*. Proceedings of the workshop on aquaculture of coral reef fishes and sustainable reef fisheries 1996, pp. 144–152. Sabah, Malaysia.

Delmendo, M.N. 1989. *Bivalve Farming: an Alternative Economic Activity for Small-scale Coastal Fishermen in the ASEAN Region*. ASEAN/SF/89/Tech.11. ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project. Manila, Philippines. 45 pp.

De Silva, S.S. 1998. Tropical mariculture: current status and prospects. *In* S.S. De Silva, ed. *Tropical Mariculture*, pp. 1–16. Academic Press, USA.

Doherty, P.J., Dufour, V., Galzin, R., Hixon, M.A., Meekan, M.G. & Planes, S. 2004. High mortality during settlement is a population bottleneck for a tropical surgeonfish. *Ecology* 85(9): 2422–2428.

Dolmer, P., Kristensen, T., Christiansen, M.L., Petersen, M.F., Kristensen, P.S. & Hoffmann, E. 2001. Short-term impact of blue mussel dredging (*Mytilus edulis L.*) on a benthic community. *Hydrobiologia* 465: 115–127.

Edwards, P., Little, D.C. & Yakupitiyage, A. 1997. A comparison of traditional and modified inland artisanal aquaculture systems. *Aquaculture Research* 28: 777–788.

Ellis, S. & Haws, M. 1999. *Producing Pearls Using the Black-lip Pearl Oyster* (*Pinctada margaritifera*). Center for Tropical and Subtropical Aquaculture Publication No. 141.

Estudillo, C.B. & Duray, M.N. 2003. Transport of hatchery-reared and wild grouper larvae, *Epinephelus* sp. *Aquaculture* 219: 279–290.

FAL. 1986. Fisheries Act 1985 (No. 317 of 1985). FAL No. 35(2): 49–82.

FAO. 1997a. *Review of the state of world aquaculture*. FAO Fisheries Circular. No. 886, Rev.1. Rome, FAO. 163 pp.

FAO. 1997b. *Aquaculture Development*. FAO Technical Guidelines for Responsible Fisheries. No. 5. Rome, FAO. 40 pp.

FAO. 2002. *The state of world fisheries and aquaculture 2002*. Rome, FAO. 150 pp.

FAO. 2004. *The state of world fisheries and aquaculture 2004*. Rome, FAO. 153 pp.

FAO. 2006. *Yearbook of fishery statistics 2004*. Aquaculture production, Vol. 98/2 (Fisheries series No. 73 and statistics series No.191). Rome, FAO. 212 pp.

FAO. 2007. *The state of world fisheries and aquaculture 2006*. Rome, FAO. 162 p.

Fisheries (Riverine) Rules. 1990. Implements of Fisheries Act 1985 (No. 317 of 1985). Official Publication: 144–150.

Fishery Status Reports. 2005. Australia Government, Bureau of Rural Sciences.

Fishery Status Reports. 2006. Australia Government, Bureau of Rural Sciences.

Gardner, C., Frusher, S., Mills, D. & Oliver, M. 2006. Simultaneous enhancement of rock lobster fisheries and provision of puerulus for aquaculture. *Fisheries Research* 80(1): 122–128.

Gazzetta Ufficiale della Repubblica Italiana. 1996. Gazzetta Ufficiale della Repubblica Italiana No. 223: 13–17.

Gervis, M.H. & Sims, N.A. 1992. *The Biology and Culture of Pearl Oysters* (Bivalvia: Pteriidae). ICLARM Studies and Reviews 21. 49 pp.

Glude, J.B. 1982. *The Potential for Seafarming in the Riau Archipelago District of Indonesia*. SCS/82/WP/110. South China Sea Fisheries Development and Coordinating Programme. Manila, Philippines.

Hair, C., Bell, J. & Doherty, P. 2002. The use of wild-caught juveniles in coastal aquaculture and its application to coral reef fishes. *In* R.R. Stickney & J.P. McVey, eds. *Responsible Marine Aquaculture*, pp. 327–353. CAB International, New York.

Hair, C., Warren, R., Tewaki, A., Haro, C. & Phillips, W. 2004. Catching and rearing postlarval cleaner shrimp for the aquarium trade: results from a WorldFish Center project on Solomon Islands. Naga WorldFish Center Quarterly, 27(1/2): 42.

Heemstra, P.C. & Randall, J.E. 1993. *FAO Species Catalogue*. Vol. 16. *Groupers of the world* (Family Serranidae, Subfamily Epinephelinae). *An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date*. FAO Species Synopsis. No. 125, Vol. 16. Rome, FAO. 382 pp.

Hickman, R.W. 1989. *The Potential for Farming Green Mussels in the Federated States of Micronesia, Papua New Guinea, the Solomon Islands and Vanuatu*. GCP/RAS/116/JPN. South Pacific Aquaculture Development Project. Suva, Fiji.

Hickman, R.W. 1992. Chapter 10: Mussel cultivation. *In* E. Gosling, ed. *The Mussel Mytilus: Ecology, Physiology, Genetics and Culture*, pp. 465–510. Elsevier Science Publishers B.V., the Netherlands.

Hong, W.S. & Zhang, Q.Y. 2003. Review of captive bred species and fry production of marine fish in China. *Aquaculture* 227, 305–318.

Huang, G.M. 1998. *Practicable Grouper Aquaculture*. Fisheries Press, Taiwan. 87 pp.

Islam, M.M., Rahman, S.L., Halder, G.C., Mazid, M.A. & Mahmood, N. 1996. Extent of damage to different crustaceans and fin fishes in collecting *Penaeus monodon* (Fabricius) post-larvae in Satkhira coastal region. *Journal of the Marine Biological Association of India* 38 (1/2): 1–7.

Ivin, V.V., Kalashnikov, V.Z., Maslennikov, S.I. & Tarasov, V.G. 2006. Chapter 24: Scallops fisheries and aquaculture of northwestern Pacific, Russian Federation. *In* S.E. Shumway & G.J. Parsons, eds. *Scallops: Biology, Ecology and Aquaculture*, pp. 1163–1224. Elsevier B.V., the Netherlands.

Jeffs, A.G., Holland, R.C., Hooker, S.H. & Hayden, B.J. 1999. Overview and bibliography of research on the greenshell mussel, *Perna canaliculus*, from New Zealand waters. *Journal of Shellfish Research* 18(2): 347–360.

Jia, J.S. & Chen, J.X. 2001. *Sea Farming and Sea Ranching in China*. FAO Fisheries Technical Paper No. 418. Rome, FAO. 71 pp.

Juinio-Menez, M.A. & Gotanco, R.R. 2004. Status of spiny lobster resources of the Philippines. *In* K.C. Williams, ed. *Spiny Lobster Ecology and Exploitation in the South China Sea Region*. Proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Viet Nam, July 2004, pp. 3–6. ACIAR Proceedings No. 120. Canberra, Australia. 73 pp.

Keenan, C.P. & Blackshaw, A. 1999. *Mud Crab Aquaculture and Biology*. ACIAR Proceedings 78. Canberra. 216 pp.

Knights, B. 2003. A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. *The Science of the Total Environment* 310: 237–244.

Koenig, C.C. & Colin, P.L. 1999. Distribution, abundance and survival of juvenile gag grouper, *Mycteroperca microlepis* (Pisces: Serranidae), in seagrass beds of the northeastern Gulf of Mexico. *Proceedings of Gulf Caribbean Fisheries Institute* 45: 37–54.

Korringa, P. 1976a. *Farming the Flat Oysters of the Genus Ostrea*. Elsevier Scientific Publishing Company, the Netherlands.

Korringa, P. 1976b. *Farming Marine Fishes and Shrimps*. Elsevier Scientific Publishing Company, the Netherlands.

Kosaka, Y. & Ito, H. 2006. Chapter 22: Japan. *In* S.E. Shumway & G.J. Parsons, eds. *Scallops: Biology, Ecology and Aquaculture*, pp. 1093–1141. Elsevier B.V., the Netherlands.

Kumagai, S., Bagarinao, T. & Unggui, A. 1980. *A Study on the Milkfish Fry Fishing Gears in Panay Island, Philippines*. Technical Report No. 6. SEAFDEC Aquaculture Department. Iloilo, Philippines. 35 pp.

Le Vay, L. 2001. Ecology and management of mud crab *Scylla* spp. *Asian Fisheries Science* 14: 101–111.

Liao, I.C., Su, H.M. & Chang, E.Y. 2001. Techniques in finfish larviculture in Taiwan. *Aquaculture* 200: 1–31.

Lieng, S. & Hortle, K.G. 2005. Falling Vietnamese demand eases pressure on wild stock of catfish fry. *Catch and Culture* 11(3): 7–9.

Ling, S.W. 1977. *Aquaculture in Southeast Asia: a Historical Overview*. University of Washington Press, USA.

Lovatelli, A. 1987. *Status of Scallop Farming: a Review of Techniques*. NACA-SF/WP/87/1. 22 pp.

Lovatelli, A. 1988a. *Status of Mollusc Culture in Selected Asian Countries*. NACA-SF/WP/88/4.

Lovatelli, A. 1988b. *Status of Oyster Culture in Selected Asian Countries*. NACA-SF/WP/88/2. 96 pp.

Lovatelli, A., Conand, C., Purcell, S., Uthicke, S., Hamek, J.F. & Mercier, A. 2004. *Advances in Sea Cucumber Aquaculture and Management*. FAO Fisheries Technical Paper, No. 463. Rome, FAO. 425 pp.

Lutz, R.A. 1980. *Mussel Culture and Harvest: a North American Perspective*. Elsevier Scientific Publishing Company, the Netherlands. 350 pp.

Major, P.F. 1978. Aspects of estuarine intertidal ecology of juvenile striped mullet, *Mugil cephalus*, in Hawaii. *Fishery Bulletin* 76(2): 299–314.

Masuda, R. & Tsukamoto, K. 1998. Stock enhancement in Japan: review and perspective. *Bulletin of Marine Science* 62: 337–358.

MEDRAP/TR. 1985. *Mediterranean Regional Aquaculture Project-Marine Aquaculture Development in Egypt*. Tunis.

MEGAPESCA. 2001. *Marine Aquaculture in Egypt*. Megapesca Lda. 29 pp.

Minh, T.H., Yakupitiyage, A. & Macintosh, D.J. 2001. *Management of the Integrated Mangrove-aquaculture Farming Systems in the Mekong Delta of Viet Nam*. ITCZM Monograph No. 1. 24 pp.

Miyai, T., Aoyama, J., Sasai, S., Inoue, J.G., Miller, M.J. & Tsukamoto, K. 2004. Ecological aspects of the downstream migration of introduced European eels in the Uono River, Japan. *Environmental Biology of Fishes* 71: 105–114.

Mohan Joseph, M. 1998. Chapter 10: Mussel and oyster culture in the tropics. *In* S.S. De Silva, ed. *Tropical Mariculture*, pp. 309–360. Academic Press, London.

Mous, P.J., Sadovy, Y., Halim, A. & Pet, J.S. 2006. Capture for culture: artificial shelters for grouper collection in SE Asia. *Fish and Fisheries* 7: 58–72.

Munro, J.L. & Bell, J.D. 1997. Enhancement of marine fisheries resources. *Reviews in Fisheries Science* 5(2): 185–222.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effect of aquaculture on wild fish supplies. *Nature* 405: 1017–1024.

National People's Congress Order. 1991. *Law on the Entry and Exit Animal and Plant Quarantine*. National People's Congress, Order No. 53. State Environmental Protection Administration, People's Republic of China.

Nelson, J.S. 2006. *Fishes of the World* (4th edition). John Wiley & Sons, Inc, New Jersey.

Nlewadim, A.A. & Deekae, S.N. 1997. Collection of juvenile mullet species from a brackishwater tidal farm in Nigeria. *The ICLARM Quarterly* 20(2): 19–20.

Norman, M., Román, G. & Strand, Ø. 2006. Chapter 20: European aquaculture. *In* S.E. Shumway & G.J. Parsons, eds. *Scallops: Biology, Ecology and Aquaculture*, pp. 1059–1066. Elsevier B.V., the Netherlands.

Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A. & New, M.B. 2004. *Capture-based Aquaculture. The Fattening of Eels, Groupers, Tunas and Yellowtails*. Rome, FAO. 308 pp.

Park, B.H., Park, M.S., Kim, B.Y., Hur, S.B. & Kim, S.J. 1988. *Culture of the Pacific Oyster (Crassostrea gigas) in the Republic of Korea*. Seafarming Development and Demonstration Project, RAS/86/024.

Parsons, G.J. & Robinson, S.M.C. 2006. Chapter 16: Sea scallop aquaculture in the northeast Atlantic. *In* S.E. Shumway & G.J. Parsons, eds. *Scallops: Biology, Ecology and Aquaculture*, pp 907–944. Elsevier B.V., the Netherlands.

Petersson, M. 2002. *Wild Shrimp Seed Collection of Penaeus monodon in Godavari Estuary, Andhra Pradesh, India*. Minor Field Study 74, Uppsala University, Sweden.

Phillips, B.F., Melville-Smith, R., Rossbach, M., Cheng, Y.W., Caputi, N., Thompson, A.W., Mills, D. & Crear, B. 2003. *FRDC Project 1998/302-Rock Lobster Enhancement and Aquaculture Subprogram: Towards Establishing Techniques for Large Scale Harvesting of Pueruli and Obtaining a Better Understanding of Mortality Rates*. Fisheries research report No. 144, Department of Fisheries, Western Australia. 138 pp.

Phillips, M.J., Lin, C.K. & Beveridge, M.C.M. 1993. Shrimp culture and the environment: lessons from the world's most rapidly expanding warm water aquaculture sector. In *Environment and Aquaculture in Developing Countries*, pp. 171–198. ICLARM Conference, Manila, Philippines.

Pickett, G.D. & Pawson, M.G. 1994. *Sea bass: Biology, Exploitation and Conservation*. Chapman & Hall, London. 337 pp.

Ponia, B., Napara, T., Ellis, M. & Tuteru, R. 2000. Manihiki Atoll black pearl farm census and mapping survey. *SPC Pearl Oyster Information Bulletin* 14: 4–10.

Pullin, R.S.V. 1993. An overview of environmental issues in developing-country aquaculture. *In* R.S.V. Pullin, H. Rosenthal & J.L. Maclean, eds. *Environment and Aquaculture in Developing Countries*. ICLARM Conference Proceedings 31. Manila, Philippines. 359 pp.

Rimmer, M.A. 2006. *Regional Review on Existing Major Mariculture Species and Farming Technologies*. FAO/NACA Regional Mariculture Workshop, 7–11 March 2006, Guangzhou, China.

Ringuet, S., Muto, F. & Raymakers, C. 2002. Eels: their harvest and trade in Europe and Asia. *TRAFFIC Bulletin* 19(2): 81–106.

Rosenberry, R. 2000. World shrimp farming 2000. *Shrimp News International* 13: 1–324.

Sadek, S. 2000. Sea bream culture in Egypt; status, constraints and potential. *Fish Physiology and Biochemistry* 22: 171–178.

Sadek, S. & Mires, D. 2000. Capture of wild finfish fry in Mediterranean coastal areas and possible impact on aquaculture development and marine genetic resources. *The Israeli Journal of Aquaculture-Bamidgeh* 52(2): 77–88.

Sadovy, Y. 2000. *Regional Survey of Fry/Fingerling Supply and Current Practices for Grouper Mariculture: Evaluating Current Status and Long-term Prospects for Grouper Mariculture in Southeast Asia*. Final Report to the Collaborative APEC Grouper Research and Development Network (FWG 01/99). 120 pp.

Sadovy, Y. & Pet, J. 1998. Wild collection of juveniles for grouper mariculture: just another capture fishery? *Live Reef Fish Information Bulletin* 4: 36–39.

Sadovy, Y. & Vincent, A.C.J. 2002. Chapter 18: Ecological issues and the trades in live reef fishes. *In* P.E. Sale, ed. *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem*, pp. 391–420. Academic Press, San Diego, USA.

Sadovy, Y., Kulbicki, M., Labrosse, P., Letourneur, Y., Lokani, P. & Donaldson, T.J. 2003. The humphead wrasse, *Cheilinus undulatus*: synopsis of a threatened and poorly known coral reef fish. *Reviews in Fish Biology and Fisheries* 13: 327–364.

Sadovy, Y., Punt, A.E., Cheung, W., Vasconcellos, M. & Suharti, S. 2007 (in review). *Stock Assessment Approach for the Napoleon Fish, Cheilinus undulatus, in Indonesia: a Tool for Quota-setting for Data-poor Fisheries Under CITES Appendix II Non-detriment Finding Requirement*. FAO Fisheries Circular No. 1023. Rome, FAO.

Sale, P.F. & Ferrell, D.J. 1988. Early survivorship of juvenile coral reef fishes. *Coral Reefs* 7: 117–124.

SAPB. 2002. *Management Options for the Shrimp Fry Fishery: a Regional Stakeholder Workshop in Coxes Bazar*. Shrimp Action Plan for Bangladesh, Department of Fisheries, Bangladesh. 25 pp.

Scott, N. & Tai, M. 1998. Mussel farming: an expanding industry in Shetland. *North Atlantic Fisheries College, Fisheries Information Note* 1: 1–4. (http://www.enaca.org/modules/wfdownloads/singlefile.php?cid=71&lid=423).

Smaal, A.C. & Lucas, L. 2000. Regulation and monitoring of marine aquaculture in the Netherlands. *Journal of Applied Ichthyology* 16: 187–191.

Starkie, A. 2003. Management issues relating to the European eel, *Anguilla anguilla*. *Fisheries Management and Ecology* 10: 361–364.

Southgate, P.C. & Beer, A.C. 1997. Hatchery and early nursery culture of the black pearl oyster (*Pinctada margaritifera* L.). *Journal of Shellfish Research* 16(2): 561–567.

Sugiyama, S., Staples, D. & Funge-Smith, S.J. 2004. *Status and Potential of Fisheries and Aquaculture in Asia and the Pacific*. FAO Regional Office for Asia and the Pacific. RAP Publication 2004/25. 53 pp.

Sutherland, I. 1996. Sea cucumber culture development on the west coast of Canada. *SPC Beche-de-mer Information Bulletin* 8: 42–43.

TAFA. 1999–2004. *Aquaculture Strategic Research Plan, 1999–2004*. Tasmanian Fisheries and Aquaculture, Australia.

Tamaru, C.S., Tamaru, C.C.T., FitzGerald, W.J., Ako, H. & Sato, V. 2001. *Advances in the Culture of the Striped Mullet* Mugil cephalus. World Aquaculture Society.

Tanaka, H. 1992. Sea cucumber culture in Japan. *SPC Beche-de-mer Information Bulletin* 4: 18–20.

The Fisheries Secretariat. 2005. EU eel management (published: 15/11/2005, available http://www.fishsec.org/article.asp?CategoryID=1&ContextID=35). Stockholm, Sweden.

Thuy, N.T.B. & Ngoc, N.B. 2004. Current status and exploitation of wild spiny lobsters in Vietnamese waters. *In* K.C. Williams, ed. *Spiny Lobster Ecology and Exploitation in the South China Sea Region*. Proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Viet Nam, July 2004, pp. 13–16. ACIAR Proceedings No. 120. Canberra, Australia. 73 pp.

Tiensongrusmee, B. & Pontjoprawiro, S. 1988a. *Cockle Culture*. INS/81/008/Manual/12.

Tiensongrusmee, B. & Pontjoprawiro, S. 1988b. *Sea Cucumber Culture: Potential and Prospects*. INS/81/008/Manual/14.

Tisdell, C.A. & Poirine, B. 2000. Socio-economics of pearl culture: industry changes and comparisons focusing on Australia and French Polynesia. *World Aquaculture* 31(3): 30–60.

Tripathi, S.D. 1996. Present status of breeding and culture of catfishes in South Asia. *Aquatic Living Resources* 9: 219–228.

Trong, T.Q., Nguyan, V.H. & Griffiths, D. 2002. *Status of the* Pangasiid *Aquaculture in Viet Nam*. MRC Technical Paper 2. Phnom Penh. 16 pp.

Tseng, W.Y. 1983. Prospects for commercial netcage culture of red grouper. *Journal of World Mariculture Society* 14: 650–660.

Tseng, W.Y. & Ho, S.K. 1988. *The biology and culture of red grouper.* Chien Cheng Publisher, Kaohsiung, ROC.

Tuan, L.A., Nho, N.T. & Hambrey, J. 2000. Status of cage mariculture in Viet Nam. *In* I.C. Liao & C.K. Lin, eds. *Cage Aquaculture in Asia*. Proceedings of the First International Symposium on Cage Aquaculture in Asia, pp. 111–123. Asian Fisheries Society, Manila, Philippines, and World Aquaculture Society-Southeast Asian Chapter, Bangkok, Thailand.

Tuan, L.A., Nho, N.T. & Hambrey, J. 2001. Seed supply for grouper cage culture in Khanh Hoa, Viet Nam. *SPC Live Reef Fish Information Bulletin*, 8: 33–36.

Tuwo, A. 2004. Status of sea cucumber fisheries and farming in Indonesia. *SPC Beche-de-mer Information Bulletin* 19: 5.

Tzeng, W.N. 1997. Short- and long-term fluctuations in catches of elvers of the Japanese eel, *Anguilla japonica*, in Taiwan. *In* D.A. Hancock, D.C. Smith, A. Grant & J.P. Beumer, eds. *Developing and Sustaining World Fisheries Resources, the State of Science and Management*, pp. 85–89. The 2nd World Fisheries Congress, CSIRO, Brisbane, Australia.

UNEP/MAP. 2004. *Mariculture in the Mediterranean.* United Nations Environment Programme. Mediterranean Action Plan. MAP Technical Reports Series No. 140. 50 pp.

Ungson, J.R. 1990. The fry fishery of Ilocos Norte, Philippines. *In* R. Hirano & I. Hanyu, eds. *The 2nd Asian Fisheries Forum*, pp. 777–780. Asian Fisheries Society, Manila, Philippines. 991 pp.

Uwate, K.R. 1988. *Viable Aquaculture Technologies in the Pacific Islands Region*. IPFC WPA/WP 18.

Uwate, K.R., Kunatuba, P., Raobati, B. & Tenakanai, C. 1984. *A review of Aquaculture Activities in the Pacific Islands Region*. Pacific Islands Development Program, East-West Center, Honolulu, Hawaii.

Van Ginneken, V.J.T. & Maes, G.E. 2005. The European eel (*Anguilla anguilla*, Linnaeus), its lifecycle, evolution and reproduction: a literature review. *Reviews in Fish Biology and Fisheries* 15: 367–398.

Van Zalinge, N., Lieng, S., Ngor, P.B., Heng, K. & Valbo-Jørgensen, J. 2002. *Status of the Mekong* Pangasianodon hypophthalmus *Resources, with Special Reference to the Stock Shared Between Cambodia and Viet Nam*. MRC Technical Paper 1. Phnom Penh. 29 pp.

Virvilis, C. & Angelidis, P. 2006. Presence of the parasite *Marteilia* sp. in the flat oyster (*Ostrea edulis* L) in Greece. *Aquaculture* 259: 1–5.

Vita, R. & Marin, A. 2007. Environmental impact of capture-based bluefin tuna aquaculture on benthic communities in the western Mediterranean. *Aquaculture Research* 38: 331–339.

Von Brand, E., Merino, G.E., Abarca, A. & Stotz, W. 2006. Chapter 27: Scallop fishery and aquaculture in Chile. *In* S.E. Shumway & G.J. Parsons, eds. *Scallops: Biology, Ecology and Aquaculture*, pp. 1293–1314. Elsevier B.V., the Netherlands.

Wang, R.B. & Cheng, Y. 2004. Breeding and culture of the sea cucumber *Apostichopus japonicus*. *SPC Beche-de-mer Information Bulletin* 19: 16.

Wee, K.L. 1981. *Snakehead* (*Channa striatus*) *Farming in Thailand*. NACA/WP/81/3. Bangkok, Thailand.

Wilson, K.D.P. 1997. The Hong Kong marine fish culture industry-challenges for sustainable development. *In* B.W. Darvel, ed. *Proceedings of the 1st International Symposium of Marine Conservation in Hong Kong*, pp. 86–97.

Wirth, T. & Bernatchez, L. 2001. Genetic evidence against panmixia in the European eel. *Nature* 409: 1037–1039.

Wu, R.S.S. 1995. The environmental impact of marine fish culture: towards a sustainable future. *Marine Pollution Bulletin* 31: 159–166.

Zheng, W.B. 1994. Chapter 10: Special types of aquaculture. *In* S.F. Li & J. Mathias, eds. *Freshwater Fish Culture in China: Principles and Practice*, pp. 347–385. Elsevier Science B.V., the Netherlands.

Social and economic impacts of capture-based aquaculture

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SUMMARY

This paper reviews the social and economic impacts of capture-based aquaculture, and specifically the capture of early life-history phase animals from the wild for use as seed material in marine and freshwater grow-out. The considerations and impacts highlight the overlap of capture fisheries and aquaculture in capture-based aquaculture. Capture-based aquaculture has social and economic advantages and disadvantages compared to full-cycle aquaculture. In many situations, especially in developing countries, capture-based aquaculture can provide income and livelihoods to sectors of the population that may otherwise be excluded from aquaculture. However, it can also result, among others, in conflict and the loss of societal benefits from the loss in yield from the wild stocks. Markets have been the driving force behind the development of the capture-based aquaculture industry as the selection of species for culture reflects demand in local and international markets and consumer's tastes and preferences. It is expected that markets will continue to drive development in the future. It is anticipated that capture-based aquaculture will continue to expand in the short-term, both for those finfish and non-finfish species currently being cultured and possibly with others that may be selected for aquaculture in the future. Other economic issues include costs and profitability (private and social), market channels and externalities. Social issues include employment, livelihoods, rural development, property rights, conflicts, technology, culture/traditions, ethical opinions and public participation. The main constraint to expansion is "seed" supply. Wild seed supply has not been able to keep up with the increasing demand from farms. The capture of wild seed is being increasingly regulated. It is important that means be found to rear these species throughout their full life-cycle that are economically viable. Farmers will also need to reduce their production costs to meet changing market demands. Any future expansion of capture-based aquaculture will also need to address potential damage to the environment caused by its activities and regulate itself in a more sustainable manner. In all cases, there will be positive and negative social and economic impacts that will need to be managed more strategically.

INTRODUCTION

Aquaculture is seen as a solution and alternative to meet current and future demand for aquatic products. However, many aquaculture practices still need considerable refinement to make them more sustainable and to reduce their dependence on wild fisheries stocks and to avoid harming aquatic habitats (Naylor *et al.*, 2000). Major constraints in the development of sustainable aquaculture include the continuing dependence on small low value or bycatch fish, commonly called trash fish, for feed, and environmental impacts such as nutrient discharge into coastal waters. Another constraint is the capture of early life-history phase (ELP) animals (i.e. settlement stage larvae, fry, fingerlings and juveniles) or "seed material" from the wild for grow-out to market size in aquaculture facilities (Mous *et al*., 2006). Sustainable access to fry and fingerlings can constitute a significant constraint to aquaculture development. This practice has been called "capture-based aquaculture" to address the overlap between capture fisheries and aquaculture (Ottolenghi *et al*., 2004). This activity is reported in FAO statistics as aquaculture rather than capture fisheries even though it depends on seed supply from the wild rather than from hatcheries.

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. In addition, the hatchery production of many cultured species is still well below demand and is constrained by poor and unreliable survival of larvae in hatcheries. Supplies of fry and fingerlings of many cultured species taken from the wild have declined and these declines are likely caused by overfishing, habitat destruction, destructive fishing practices, pollution, high export demand and high mortality of captured fry. Examples of such capture-based aquaculture include tuna (*Thunnus* spp.) in Australia, Japan, Canada, Spain, Mexico, Croatia, Italy, Malta, Morocco and Turkey; milkfish (*Chanos chanos*) in the Philippines, Sri Lanka and Indonesia; eels (*Anguilla* spp.) in Asia, Europe, Australia, and North America; grouper (*Epinephelus* spp.) in Asia; and settlement phase reef fish for the marine aquarium trade (Ahmed *et al*., 2001; Hair, Bell and Doherty, 2002; Ringuet, Muto and Raymakers, 2002; Phillips, Melville-Smith and Cheng, 2003; Miyake, Miyabe and Nakono, 2004; Ottolenghi *et al*., 2004; Mous *et al*., 2006).

The purpose of this paper is to review the social and economic impacts of capture-based aquaculture, and specifically the capture of ELP animals from the wild for use as seed material in marine and freshwater grow-out. The considerations and impacts highlight the overlap of capture fisheries and aquaculture in capture-based aquaculture. Markets have been the driving force behind the development of the capture-based aquaculture industry as the selection of species for culture reflects demand in local and international markets, and consumer's tastes and preferences. Other economic issues include costs and profitability (private and social), market channels, and externalities. Social issues include employment, livelihoods, rural development, property rights, conflicts, technology, culture/traditions, ethical opinions and public participation. These issues and their impacts will be discussed in this paper.

THE ROLE OF CAPTURE-BASED AQUACULTURE IN AQUACULTURE PRODUCTION

The system of aquaculture production called capture-based aquaculture has differing characteristics and techniques depending upon the area of the world and species. The use of this aquaculture practice is constantly evolving as demand and technology change.

Use of wild seed for capture-based aquaculture

Aquaculture with seed harvested from the wild is practiced worldwide on a variety of marine and freshwater species. Due to lack of reporting and statistics, it is extremely difficult to make an accurate estimate of the scale of such practices or the percentage of aquaculture production in the freshwater and marine environment which is reliant on the capture of ELP animals from the wild. FAO (2006) has estimated that 20 percent of marine aquaculture production comes from such capture-based aquaculture representing a value of US$1.7 billion. The culture of many freshwater species also relies partly or fully on wild seed because the supply from hatcheries is not adequate to meet demand or because the quality of hatchery produced seed is felt to be inferior to wild caught seed. No estimate has been made for freshwater capture-based aquaculture production. Reports suggest that there is increasingly more use of hatchery-reared seed for many species as the technology improves and due to the diminishing supply of wild seed. The lack of a stable wild seed supply has been a significant obstacle to the further expansion and development of many aquaculture species. The changing nature of seed supply in aquaculture, from wild to hatchery-produced, adds to the complexity of developing an accurate estimate of reliance of aquaculture on wild caught seed.

While accurate figures on the scale of capture-based aquaculture are not available, a number of papers and reports from around the world provide estimates for individual species which illustrates aquaculture's continued reliance on wild caught seed. It has been reported that for some freshwater species, such as omnivorous river catfish (*Pangasaianodon hypophthalmus*) and carnivorous giant snakehead (*Channa micropeltes*) in Cambodia, that all of the seed is obtained from the wild (APFIC, 2005). In the Philippines, while hatcheries are becoming an increasingly more important source of milkfish fry, Ahmed *et al.*, (2001) estimated that the hatcheries are only supplying approximately 15 to 20 percent of the demand. Although many species of bivalves are routinely produced in hatcheries, the scale of wild spat collection often dwarfs hatchery production (Hair, Bell and Doherty, 2002). It is estimated that up to 95 percent of mussel (Mytilidae) spat is collected from the wild; approximately 15–20 percent of edible oysters (Osteridae); and approximately 50 percent of scallops (Pectenidae). The production of spiny lobsters (mainly *Panulirus ornatus*) in Asia (China, India, Malaysia, Myanmar, Philippines, Singapore, Taiwan Province of China, Thailand, Viet Nam) is based mainly on the capture of wild juveniles (Hair, Bell and Doherty, 2002; Tuan and Hambrey, 2000). Although hatchery-reared groupers are available, wild-caught juveniles remain the primary source of seed for aquaculture of these species in Asia (Sadovy and Vincent, 2002). Approximately one half to two-thirds of the regional supply of grouper comes from wild-caught adult fish. Major sources of wild-caught grouper are the Philippines, Indonesia, Thailand, and Malaysia. In addition, Australia, Viet Nam, Myanmar, Papua New Guinea and China also supply wild-caught grouper. New supply sources include remote islands in the Indo-Pacific such as Micronesia (Federal State of), Maldives, Solomon Islands, Fiji and Kiribati (Pomeroy, Parks and Balboa, 2006). In Viet Nam, the giant freshwater prawn *Macrobrachium rosenbergii*, which is indigenous to the Mekong Delta, is becoming an increasingly important cultured species. The culture of this species, especially in rice fields, is based mainly on wild seed collected from rivers and other freshwater bodies (Phuong *et al*., 2006). The seed for sand goby culture in Viet Nam is obtained primarily from the wild (Phillips, 2002). While not for food, ornamental fish production is an important component of the worldwide aquaculture industry in several nations. Most of the aquaculture production of ornamental fish focuses on freshwater species. Approximately 90 percent of freshwater ornamental fish are captive bred (Bartley, 2000). While marine ornamentals capture higher price, their captive breeding and culture is much less advanced. Only 100 of 800 marine species traded in the pet industry are routinely bred in captivity, with approximately 21 of these being commercially feasible (Tlusty, 2002). As can be seen, many important cultured species still rely on the use of wild organisms as seed material.

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 km^2 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).

SOCIAL IMPACTS

In many situations, and especially in developing countries, the collection and grow-out of juveniles present more socio-economic advantages than hatchery-based aquaculture since the collection and sale of juveniles to grow-out operators can provide employment and income for sectors of the population that are otherwise not able to participate in the aquaculture industry. This is especially important where advanced technology and expensive hatcheries are limited. In addition, capture-based aquaculture can support rural development and provide alternative or supplemental livelihoods, especially to women and children. There is also a strong relationship with the capture fisheries industry.

Ogburn and Johannes (1999) report the positive effects of collection of grouper juveniles in the Philippines, where fewer people now practice destructive fishing and where there has been a reduction in fishing pressure on wild caught adults and less targeting of spawning aggregations, which otherwise leads to overexploitation (Johannes and Riepen, 1995; Birkland, 1997). Tisdell and Poirine (2000) report that in one island group in French Polynesia a quarter of all families earn a living from the pearl industry by selling spat to larger farms. This reliance on wild spat has led to conservation of adults to ensure continued supply of oysters, and provided a model for other nations in the Pacific which have begun to conserve wild stocks of blacklip pearl oysters to pave the way for development of their own pearl industries (Friedman, 1999). The economic returns to a Muslim community in Northeast Sumatra in Indonesia have meant that its members can now make the pilgrimage to Mecca thanks to the profits of the grouper business (Ottolenghi *et al.*, 2004). Hair *et al.* (2002) state that in response to McAllister's (1999) concerns about aquaculture depriving local fishers of their livelihood, the capture and culture of wild juveniles should actually increase the opportunities to earn income, provided the grow-out of the animals occurs in the country of harvest.

Capture-based aquaculture operations are generally located in rural areas and can make considerable contributions to rural economies. Capture-based aquaculture can result in significant economic multipliers through the economy through employment, more diverse household livelihoods, small business development, purchase of goods and services, increases in income and food security and generation of foreign exchange. This is especially true for areas with depressed and marginal economies and limited employment opportunities, such as occurred with bluefin tuna aquaculture near Port Lincoln, Australia (Ottolenghi *et al.*, 2004). With the constant reduction in fishing opportunities, another fishery-related industry is often a welcome alternative for the existing workforce. New skills are developed for aquaculture operations, for example, specialized divers to capture and handle tuna. In addition to the actual capture of wild seed, employment opportunities are also made available in aquaculture production and marketing. Many fishers have become active partners in aquaculture activities, either as suppliers of inputs or as farmers.

On the other hand, the collection and grow-out of juveniles present a number of socio-economic disadvantages to hatchery-based aquaculture. Capture-based aquaculture can employ inappropriate technologies and skills, and users may undertake unsustainable practices to supply farmers with wild seed. Other impacts may include exclusion of the poor from participating in (by being physically removed), or enjoying the benefits of, wild seed collection and aquaculture production; resource appropriation by elites and/or politically powerful sectors; conflict and violence.

The use of wild seed puts stress on fish recruitment for the capture fisheries and on the biodiversity of the capture areas. The harvest of gravid female shrimp and post-larvae can negatively affect biodiversity by contributing to declining fish stocks. This ecological decline results in social disruptions as well. Epler (1992) states that fishers feel that the methods used to capture post-larvae shrimp in Ecuador negatively affect the finfish and crustacean fisheries because of bycatch. Cruz (1992) notes that conflicts such as these threatened relationships among community members in Mexican coastal communities. In the Solomon Islands, the introduction of the live reef food fish trade brought about three issues of highest concern to community members: the low prices paid by the company (prices were the same as, or only slightly above, the rates for dead fish); the wastage of fish, both bycatch and post-capture mortality (the fishery obtained a reputation for being wasteful of food resources, especially in remote areas where the bycatch and dead target fish could not be fully used by the villages due to the large amounts and limited consumption and/or storage ability, or due to the distances of the fishing sites from the village); and concern over the targeting of spawning aggregation sites (especially related to ownership and use-rights disputes) (Sadovy, Donaldson and Graham, 2003).

Haylor and Bland (2001) report that many negative consequences associated with aquaculture in rural development relate to a weak institutional context. These include poor coordination and coherence between sectors (e.g. Ministry of Fisheries promoting aquaculture and Ministry of Environment promoting environmental protection); unclear mandates; unclear public/private sector responsibilities; tenure, property and user right uncertainties; weak regulatory regimes and enforcement capacity; rent seeking; ineffective communication strategies; and little involvement of primary stakeholders. Without some form of intervention, short-term financial perspectives tend to dominate environmental and social issues. Thus, there is a strong case for strategic planning of aquaculture development, rather than being reactive and uncoordinated. There is also a need for a partnership between the public and private sectors to address this weak institutional context.

Marketing and credit relationships between wild seed collectors and buyers and middlemen, such as the "*suki*" patronage relationship in the Philippines and "*bertaukeh*" in Malaysia, can affect harvesting patterns and buying and selling practices, and force fry collectors to use unsustainable practices (Pomeroy and Trinidad, 1995). Collectors may over harvest certain areas to repay outstanding loans, be dictated to as to whom the seed should be sold, or be exploited by receiving lower prices for the seed. This patronage can further contribute to the perpetuation of an oligopsonistic market structure in which each of a few buyers exerts a disproportionate influence on the market. Reporting on the live reef food fish trade, Sadovy, Donaldson and Graham (2003) state that while fishers may gain income in the short-term, in many cases they end up indebted to brokers or required to fish in a way that is incompatible with local practices and habits.

The waters from which wild seed are collected are most often considered to be open access. These waters provide multiple social, economic and environmental goods and services to local users. The harvest of wild seed does not always benefit society, as there is high wastage and dissipated economic benefits from bycatch, and can lead to a variety of user conflicts. It can also threaten traditional marine tenure arrangements and social and cultural practices and norms. Corruption and coercion may also increase. Seed collection concessions, as exist in the Philippines, privatize the resources and restrict access by certain users. In the Kei Islands in Indonesia the arrival of outside catchers for groupers saw conflicts soon develop between local fishers and the "foreign" fishing operations. These conflicts were in part over the perceived damage to the reefs from the use of cyanide, but of possibly greater significance was the villagers' perception that the outside operators were violating local access rights. As the industry matured, conflicts and tensions developed more within the communities – fisher against fisher, family against family – over rights to fish areas and over the methods used (Sadovy, Donaldson and Graham, 2003). Conflicts can arise between collectors and other resource users such as fishers and tourism. There can be a loss of potential alternative income generating opportunities, such as scuba diving and other ecotourism related activities, with loss of biodiversity and habitat destruction. The types of conflicts and the impacts of exploitation of wild seed for aquaculture can be unpredictable and site- and species-specific.

Access to marine resources once utilized solely by small capture fishers, for example, can be opened to local and migratory wild seed collectors through capture-based aquaculture. Epler (1992) notes that the need for post-larvae shrimp has contributed to social problems which are not specifically tied to user conflicts. Coastal communities seasonally inundated with post-larval fishers do not have the resources to cope with the influx of so many newcomers. They lack adequate sanitation, education and medical facilities and there were complaints about dirty beaches and shanty towns. The economic gains to these communities are minimal as the wealth associated with shrimp mariculture returns with the transient fishers or is exported out of the country. In Bermuda, the fishing and capture-based aquaculture industries wanted to increase the quantity of fish that they were allowed to catch, in order to satisfy local demand and increase both market shares and income. However, the tourism industry wanted to decrease fishing quotas because it needs a thriving aquatic life for tourists to enjoy. By the 1980s, the stock of grouper had declined, and tourism had the upper hand (Ottolenghi *et al.*, 2004).

Padilla *et al.* (2003) conducted a community and social impact assessment to determine the relationship between the live reef fishing industry and social issues and problems. They found that the current state of the live reef fish trade in the Calamianes Islands in the Philippines is socially unsustainable. There is greater competition among fishers, both locally and from outside the area, for resources causing increased damage to the ecosystem. The fishers have a low regard for local government and national line agencies in resource management, seeing them as ineffective. Local governments are seen as being controlled by official's vested interests and controlled by local financial and political elites. The *barangay* local government is regarded as having more significance and potential relevance than municipal or provincial governments. Fishers have little regard for their role in overall decision-making and for their relation with local government units regarding the live reef fish trade. Most fishers believe that only local and financial elites have the capacity to make decisions. There is a high level of dependency of fishers on brokers and financiers for money which has resulted in an inequitable distribution of benefits. Live reef fishing has become the major economic activity for most of the communities in the Calamianes Islands. The dependency arrangements, inequitable distribution of benefits, growing threat to food security, limited access to basic services and weak socio-cultural cohesion in the communities is leading to a significant level of social instability.

Several case studies are presented to further illustrate the social advantages and disadvantages of capture-based aquaculture.

Case study: Philippine milkfish fry collectors

Two major studies of milkfish fry collection have been undertaken in the Philippines. One was undertaken in the early 1980s (Chong, Smith and Lizarondo, 1982) and the other in the late 1990s (Ahmed *et al.*, 2001). A brief summary of these reports provides a good description of milkfish seed collectors and collection practices.

Chong, Smith and Lizarondo (1982) found that there are a number of different passive or active filtration methods used to gather fry, ranging from the simple scissors dip-net that can easily be used by children, to the more sophisticated bulldozer net which can be operated with a motorized vessel. By far the most common method used by gatherers is *sagap*, a seine of up to five metres in length. Gatherers work in teams, the composition of which depends upon the gear used. *Sagap* requires two members to use the net, and an optional third member to carry fry from the net to a basin on shore in which fry are temporarily stored, and to sort out predators and other unwanted species. The attractiveness of the *sakag* or *hudhud* and the sweeper comes from their being easily handled by a single gatherer. Bulldozer nets are used primarily at night with lanterns and propelled by bamboo poles by a pair of gatherers at depths of up to three meters. Fry are scooped from the net with a white porcelain basin, against the background of which the eyes of the almost transparent fry can be seen. After being stored temporarily on the beach, fry are either delivered to the concessionaire, to be counted so that the gatherer can be paid for the day's catch, or stored by the gatherer for later sale. Counting fry is done by a two-member team. While fry are being temporarily stored in clay pots or plastic basins, predatory and competitive species are sorted out and discarded. Unwanted fish are most often discarded on the beach rather than returned to the sea. Revenue from the daily catch is usually divided equally among team members, with an extra share going to the owner of the gear. Most gatherers are part-time fishers, with fry gathering contributing only 22 percent to total household income. Rates of return are lowest in the fry gathering sub-sector, in comparison to fry traders and dealers, where thousands of fry gatherers participate. The low returns to fry gatherers reflect, in part, the lack of other income-generating opportunities available to them, and also the effect on fry prices of the concession arrangement. Because gatherers are restricted to selling only to the concessionaire, they receive a lower price than would prevail if there were open-access to the fry fishery and they could sell freely in the open market. One solution to this dilemma is to encourage the formation of gatherer cooperatives to be awarded concession rights for a possibly reduced fee, in which case they could earn the profits that formerly accrued to concessionaires plus a share of the resource rent.

Ahmed *et al.* (2001) found that fry gathering has been a traditional family activity for the majority of the respondents. They joined the fry gathering business through the influence of their neighbours and friends. They saw fry gathering as a lucrative additional source of income to supplement their income from other sources (i.e. fishing). In addition to fry gathering, respondents were also engaged in fishing, fish vending, daily labour, *nipa*-making and farming. About 65 percent were involved in fishing. Despite the alleged scarcity of fry in the wild, 97 percent of the respondents did not plan to stop their involvement in fry gathering. This is probably because the activity gives them an income with little requirement of capital. During the peak season of fry demand, the average monthly income from gathering fry was approximately US$90. During lean months, the monthly average income was approximately US$10.

The milkfish fry of the Philippines are essentially an open access resource. The national government has empowered coastal municipalities to grant local "monopsonies" (limited to one buyer) to concessionaires in the form of exclusive rights of first purchase of fry. These concessions are generally awarded through a public bidding process. Access to fry gathering, however, is not restricted in any way, as long as the gatherer sells to the designated concessionaire. The concessionaires have two options in fry gathering: (i) to employ fry gatherers on a daily wage, or (ii) to allow the fry gatherers to use the fry grounds on the condition that 2/3 of the total catch will go to the concessionaire and the remaining 1/3 to the fry gatherers. Some concessionaires require fry gatherers to sell their share to them at a price lower than the prevailing market price. Income from the concession license fee goes directly to the municipality. Because fry grounds are, for the most part, in rural areas, municipalities with fry grounds often have very limited income from other sources. The high value of a concession compared with other components of municipal income has thus resulted in the vast majority of fry grounds in the country being managed under concession license fees. Concessionaires are free to dispose of their fry as they please provided they comply with the government auxiliary invoices required for interregional shipment of fry (Chong, Smith and Lizarondo. 1982; Ahmed *et al.*, 2001).

The concession arrangement has a major effect on the incidence of risk in the short run. Because annual bidding for concession rights is held before the fry season begins, the risks of poor catch (and windfall profits in good years) are very neatly passed from the municipality to the entrepreneur who is awarded the concession. In the long run, of course, these risks and windfalls would be taken into account by prospective concessionaires before they bid for the concession. Since the municipality collects from a single entity for each fry ground or fry zone, the risk of lost income to the municipal government, due to collection difficulties, is also much reduced. The system of awarding concessions also provides incentive for the development of new fry grounds, as the initial investment of the concessionaire is protected through a one- to three-year contract of exclusive rights granted him by the municipal council (Chong, Smith and Lizarondo, 1982). The concession arrangement severely restricts the level of competition at the early stages after fry catch due to large capital requirements to finance concession fees, especially for the most sought after fry grounds. This has encouraged vertical integration in the industry as nursery pond operators, in particular, have sought to assure supply of fry for their ponds.

Case study: Viet Nam grouper seed collectors

Tuan and Hambrey (2000) examined technical, environmental and socio-economic issues related to wild grouper seed supply in Khanh Hoa Province in Central Viet Nam. The households studied collect approximately 200 000 seed each year, mainly "black grouper": *Epinephelus akaara, Epinephelus bleekeri, Epinephelus coioides, Epinephelus malabaricus, Epinephelus merra* and *Epinephelus sexfasciatus*. Among the fishing gears, seine net, scoop net and push net were mainly used for collecting small fish of 1–3 cm. Seine nets provided the highest yield (catch per unit effort) in terms of number of pieces per trip. For larger seed, encircling nets, used together with artificial reefs, were the most important in terms of quantity and quality of catch. The seasonality of use of different gears reflects the growth of the seed and their move to deeper water as the season progresses.

The fishers reportedly had to spend more time to catch the same amount of seed compared with previous years. Seed production appears to be in decline, as is the capture trend for grouper in the province, and for the demersal marine finfish. The reasons for the decline of fishing production of commercial demersal marine finfish in general, and grouper in particular, include overexploitation, especially of broodstock; using harmful fishing gears such as motorized push-nets, trawling nets, dynamite, and sodium cyanide; and nursery habitat destruction. The primary buyers were nursery farmers, grow-out farmers and middlemen. The middlemen were the main buyers, and their price was up to double the fishermen's price.

The average income of collector households from seed collection was approximately US$700 per year, and return on labour varied between US$1–3 per day. Sadovy (2000) found that income from grouper fry/fingerling fisheries contributes 10–50 percent to the annual income of fishers, and a single fisher's income from this source can reach as much as US$3 080 annually. In recent years, the number of collectors has decreased as some have moved to offshore fishing activities, which were funded by the central government. The fishermen prefer the new job where they can receive a higher return on labour than from collecting fry. Alternative non-fishing jobs such as aquaculture can help the fishers in lower income classes to escape from poverty. Small-scale, mainly family-run, cage culture of grouper in Khanh Hoa Province (Viet Nam) is now a significant activity, providing a relatively high return to labour compared with existing alternative activities. For the future, hatchery production will be the only way to provide sufficient seed to allow the industry to expand. The high and increasing price of seed should make hatchery production economically viable, despite its technical difficulty.

Case study: Coral reef species

A suggested alternative to the hatchery production of many coral reef species is the feasibility of harvesting pre-settlement fishes from the plankton in numbers that do not affect the replenishment of natural populations and rearing them for sale to the ornamental trade or as juveniles for grow-out (Hair, Bell and Doherty, 2002). The fact that only a small percentage of marine species that settle into nursery habitats survive to become breeding adults is a persuasive argument for using some of the settling cohort to increase productivity through grow-out in aquaculture. Responsible application of aquaculture based on animals captured from the wild will depend on capturing juveniles before they experience the severe mortality associated with settlement, limiting the catch to ensure replenishment of spawning biomass, returning sufficient juveniles to the wild to compensate fisheries targeting adults and use of capture methods that minimize bycatch of non-target species and do not damage supporting habitats. If artisanal fisheries for the capture and culture of pre-settlement fish can be established in a responsible manner, they should enhance the employment and economic opportunities for coastal communities (Hair, Bell and Doherty, 2002). Although the capture and culture of post-larvae is unlikely to meet the demand for all the tropical marine fish required by the ornamental trade, it has created important niche markets, for example, for eco-labelled specimens which increase the value of the fish caught and reared in an environmentally sustainable manner and provides economic returns to coastal villagers (Wood, 2001; Ottolenghi *et al.*, 2004).

ECONOMIC IMPACTS

As Ottolenghi *et al.* (2004) state, markets are the key drivers for capture-based aquaculture. The selection of species for culture reflects their acceptability and demand in local and international markets. Market requirements are determined primarily by people's tastes and customs. As capture-based aquaculture potentially generates higher profits than other aquaculture systems and as the market demand for the products and species cultured remains high, it is likely that efforts to promote this activity will significantly increase.

The products of capture-based aquaculture have been able to be differentiated in the market. As the availability of cultured fish has increased, consumers have become more selective about quality and food safety issues, and farmers have sought to address consumer demand. Currently, a special brand of cultured Japanese amberjack will fetch a higher price than ordinary products. Product quality is obtained by discarding second grade fish and paying special attention to handling systems to maintain freshness. Sales have been expanded in supermarkets and retail fish stores through the marketing of special brands produced by Kagawa and Kagoshima Federation of Fisheries Cooperatives, amongst others (Nakada, 2000). Greater amberjack and yellowtail amberjack are becoming more popular than Japanese amberjack because they can be kept for more than three days under refrigeration without losing any of their flavour, colour, and firmness. Currently, the demand for them exceeds supply (Nakada, 2000).

The products of capture-based aquaculture will complement, but sometimes also compete with, those supplied from capture fisheries or other aquaculture systems. This will influence price and markets. Ottolenghi *et al.* (2004) report that the impact of capture-based farmed bluefin tuna on the Japanese market has been significant. Products are of the middle quality category, and fill the gap between top (pre-spawning bluefin tuna) and lower (smaller and post-spawned bluefin tuna) qualities. The availability of capture-based farmed products has expanded the range of products available in Japan, guaranteeing middle quality at a good price. The capture-based farmed tuna have provided the consumer with a fatty meat called "*toro*", which only rich people could have afforded before (Miyake *et al.*, 2003). Farmed tuna are now even sold in supermarkets and used in the popular, but inexpensive, "*sushi*" bars. The availability of this new category has forced prices down for both high and low quality tuna meat. The unique tuna markets of Japan, especially for tuna from capture-based aquaculture, is becoming risky for both fishermen and farmers. The high priced "*sashimi*" tuna market in 2002 has been strong, with relatively soaring demand despite the weakness of the Yen that has affected returns on investments. However, Japanese consumers have started changing their consumption habits, choosing less expensive products (de Monbrison and Guillaumie, 2003). Competition and substitution with other less expensive tuna species has already been observed in the market, with big eye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) being sold at US$5–11/kg in Japan versus bluefin tuna sold at US$30–60/kg.

Ottolenghi *et al.* (2004) state that the structure of the capture-based aquaculture industry may be described at a number of levels in the hierarchy of the system, from the local production scale to the macroeconomic scale of the international trade in capture-based aquaculture species. This incorporates all the aspects related to the profitability of capture-based species culture: "seed" availability, marketing from the local production level to customers (through middlemen, exporters and wholesalers) and market trends and influences. A limit to capture-based aquaculture will be the availability of the "seed" resource. From an economic point of view, a poor supply of "seed" is the greatest risk to production. For example, wild caught farm seed availability for European eels represents 50 percent of the total production costs at present, and if there is a continuing decline in availability, this will seriously affect the overall operating costs – and future profitability. In addition to seed availability, another factor affecting capture-based aquaculture will be the price of wild seed versus the price and availability of seed from hatcheries. As new hatcheries come on line, prices of seed should decline and become more available, causing a shift in source of seed for the farmer.

Phillips (2002) reports that in the case of cage culture in Cau Doc, An Giang Province, Viet Nam, the changing role of traders is of particular interest. Different trading networks supporting this cage culture emerged in parallel. The provision of small freshwater cyprinids from nearby traps reached around 1 000 tonnes per day in the wet season. This is traded through Cau Doc town on a daily basis to feed pangasiid and snakehead being raised in the surrounding area. *Pangasius bocourti* and snakehead (*Channa* spp.) fingerlings caught in *dai* traps, mainly in Cambodia, are also sold for grow-out in cage culture operations in Viet Nam. The trading networks that supply feed fish for aquaculture appear to have developed outside the table fish networks.

So Nam and Haing Leap (2006) described the general channels of distribution of fish seed collected from the wild in Cambodia. Fishers collected fry and/or fingerlings from lakes, reservoirs and/or rivers. The fishers stocked the fish seed in *hapas* set in large earthen ponds or rivers/lakes to hold the seed. Customers for the fish seed were middlemen, licensed companies and fish farmers. The majority of sales were to middlemen or traders, who bought fingerlings from fishers for resale.

Ahmed *et al.* (2001) described the marketing of milkfish fry in the Philippines. In Sarangani and Antique, the fry catch was all purchased by the concessionaires. In Palawan, 88 percent of the catch was bought by concessionaires, while in Ilocos Norte and Bohol, gatherers could choose to sell to others. The pricing system varies, ranging from buyers dictating the price to sellers setting the price for their catch. In some cases, open bidding takes place. Fry is either picked up by the buyer, as in the case of Ilocos, Bohol, Antique, and Palawan, or delivered by the gatherers, as is the practice for Sarangani. In most cases, cash is paid on delivery. In general, fry price during lean months is higher than in the peak months. Price is relatively lower in Puerto Princessa, Philippines, and highest in Pandan, during peak months. Gatherers received the lowest price from concessionaires and the highest from dealers/brokers and runners. Gatherers in Puerto Princessa are members of the cooperative and thus received a low price while gatherers from Pandan enjoy an open access to their shoreline and could choose where to sell their catch. Fluctuations in prices are mostly attributed to the quantity of fry available in the market.

While decreased impacts to wild stocks have been hypothesized for food production aquaculture (such as declines of certain stocks, impacts on breeding populations, food web interactions, and introduction of pathogens), and can occur in ornamental production, the decreased impacts are not as dramatic as theorized. In the food production sector, wild harvests have not declined even with increasing aquaculture production (Naylor *et al.*, 2000). In the ornamental fish industry, breeders (particularly those of cichlids) utilize wild stock every two to three generations (Dawes, 2001), thus there is a continued dependence on wild stocks. One of the main arguments against aquacultural production of seahorses (*Hippocampus* spp.) is that captive culture relies heavily on repeated removals of wild animals and thus, provides no net benefit to wild seahorse populations (Tlusty, 2002).

Capture-based aquaculture may develop or be constrained by the level of technology and investment. Grouper culture can be small-scale and family-owned and operated, while tuna culture is high tech and requires considerable investment, often by larger companies in partnership with local partners. Successful examples of where small-scale finfish culture has benefited poor coastal communities exist in Tubigon, Bohol, Philippines, where the small-scale cage culture of grouper was introduced by local government as an alternative to destructive fishing practices. There are now 141 grouper farmers organized into nine groups throughout several villages (Gonzales, 2006). Another Philippine example is the so-called "backyard type of grouper culture" such as in Day-asan, Surigao City. Here each farmer owns between two and four 3x3 m cages, each stocked with around 100 fish. These are fed wild caught fish as feed and cultured for a period of five to six months. Production costs are estimated at US$3.88 per kilogram, with farmers claiming it is more profitable than more familiar livelihoods such as backyard pig production. The average selling price ranges from US$7.77–19.42 per kilogram depending on the type of grouper and season. There are questions about the sustainability of this system due to the dependence on wild caught fish for feed (Gonzales, 2006).

However, there are also many potential constraints to finfish culture and its suitability as an alternative livelihood for poor fishers. These include the high-technology, capital-intensive and long term payback characteristics of finfish farming, and the difficulty of uptake of mariculture, including breaking the cycle of debt among poor fishers, and persuading people to change vocations (Haylor *et al.*, 2003). The development of small-scale or backyard hatcheries, however, can help alleviate this risk and still involve poor stakeholders in mariculture activities (Gonzales, 2006). Small-scale hatcheries are those where the capital costs are relatively low, technologies are accessible, and which focus on the larval rearing and nursery aspects of fingerling production. They do not hold broodstock; instead they purchase fertilized eggs from larger hatcheries. They offer the advantages of low capital costs, simple construction, ease of operation and management, flexibility and use for a range of marine fish species, and they offer quick economic returns (Sim *et al.*, 2005).

In the Ilocos region of the Philippines, where the milkfish industry is concentrated, the production costs per cage are reported as US$23 504, although a profit of just over US$3 000 is expected (Gonzales, 2006). Such high costs have deterred small-scale fishers from investing in these technologies and the cages are owned by wealthier individuals (Gonzales, 2006).

A financial feasibility analysis for the culture of *E. coioides* and *E. malabaricus* in the Philippines provided financial information on individual broodstock, hatchery/nursery, and grow-out stages and for an integrated broodstock/hatchery/nursery/grow-out system (Pomeroy, Parks and Balboa, 2006). The findings of the analysis indicate that, based on the assumptions, all four scenarios are financially feasible. However, the capital requirements for the broodstock, hatchery/nursery, and integrated system may be beyond the financial means of many small producers. A broodstock and hatchery/nursery system in the Philippines has capital investment costs of US$68 400. The capital investment requirements for grow-out (not including purchase of transport boxes) would be US$1 470 in the Philippines and is within the financial means of small producers. The high cost of transport boxes (200 boxes at US$4 000) is a potential problem for the small producer, but could be shared with the fish buyer or the fish buyer could provide the boxes. A 6 cm fry in the Philippines cost US$0.23 to produce. This compares to an average price in the Philippines in 2002 of US$0.36–0.50 for a 6 cm fry caught from the wild. Seed cost was approximately 19–26 percent of total costs in grouper culture, depending upon stocking rate.

A financial feasibility analysis for the culture of the humpback grouper (*Cromileptes altivelis*) in Indonesia provided financial information on individual broodstock, hatchery/nursery, and grow-out stages (Pomeroy, Parks and Balboa, 2006). The findings of the analysis indicate that, based on the assumptions, all three scenarios are financially feasible. However, the capital requirements for the broodstock and medium-size hatchery/nursery scenarios may be beyond the financial means of many small producers. The broodstock scenario has capital investment costs of US$15 366 and a medium-size hatchery/nursery scenario of US$38 795. The small-size hatchery/nursery scenario has approximately one-tenth the capital investment cost (US$3 258) of a medium-size scenario. The capital investment cost for grow-out (US$1 010) (not including purchase of transport boxes) is within the financial means of many small producers. The high cost of transport boxes (200 boxes at US$4 000) is a potential problem for the small producer, but could be shared with the fish buyer or the fish buyer could provide the boxes. The total cost per 5 cm fry from the hatchery/nursery (medium-size: US$0.26 and small-scale: US$0.23) was less than the average selling price in Indonesia in 2002 of US$0.82 and the average price of US$0.49 for a 5 cm fry caught from the wild. Seed cost was approximately 50 percent of total costs in grouper culture.

In Thailand, revenue and profit of grouper capture-based aquaculture has average annual total production costs per farm of US$5 000, while the gross revenue was

US$9 800, giving a net profit of US$4 800 to the farmer, with a 96 percent rate of return (net profit/total cost). Feed accounted for 57 percent of culturing costs, whereas "seed" accounted for 24 percent. Other costs (opportunity, depreciation, repairs, etc.) accounted for 19 percent (Boonchuwong and Lawapong, 2002).

The market for glass eels for direct human consumption is one of the main competitive problems affecting the availability of eel "seed" for capture-based aquaculture, since it forces the prices of glass eels upwards. Seed costs can be as much as 50 percent of the total production costs and in the future could limit the profitability of the eel farming industry. For example, American glass eel prices in the United States of America rose over 500 percent between 1994 and 1998. In the past 20 years, prices for live glass eels have been as high as US$2 000/kilogram, and this lucrative new market potential has been attractive to many countries, triggering a global eel industry. The market is not quite so lucrative now, due to the recent slump in the Asian economies and a slight recovery of native eel stocks (Tibbetts, Lall and Anderson, 2001).

The direct effect of the collection of wild seed – overfishing, bycatch and discards, ecological disturbance and habitat destruction – will lead to a conflict between short-term private economic benefits and longer term economic losses to society. Economic theory makes it possible to treat environmental externalities as economic externalities and to validate costs and benefits in money terms to different groups as part of an economic analysis. Environmental externalities may include obtaining fry for stocking from wild stocks. Capture-based aquaculture can serve as a good example in estimating environmental sustainability by evaluating each of the various sub-activities in relation to their resource use. If, for example, seed collection is operating at a level that permits sustainable use of the underlying resources, then the activity is environmentally sustainable. If seed collection is undertaken in a non-sustainable manner (e.g. large amounts of bycatch), substitution may be possible only for small-scale systems as the overall recruitment depends on large areas and is not hampered in principle. The collection and use of wild seed for capture-based aquaculture has implications in terms of economic values gained and lost. These losses have not been quantified to date but could be significant and far greater than the profits earned by those in the capture-based aquaculture industry. It will be important to assess capture-based aquaculture in terms of both its overall economic efficiency and its distributional implications.

Although growth and diversification in farmed marine finfish species generate certain benefits to the aquaculture industry, governments (in the form of foreign exchange earnings) and consumers (in terms of a wider selection of seafood products at lower prices), there are also ecological and resource costs. In contrast to the majority of freshwater farming systems, almost all aquaculture production of diadromous and marine finfish species is dependent on capture fisheries for essential inputs, such as seed and feed. The increased production from the culture of juveniles should at least offset any loss in yield from the wild stocks, and collection should not affect wild populations negatively or disadvantage other users of the resource. As this segment of the aquaculture industry continues to expand to satisfy market demand, more pressure will likely be placed on marine ecosystems and, subsequently, more pressure will be placed on the industry to undertake sustainable practices from environmental groups and governments.

The future of capture-based aquaculture will be influenced by improving the environmental sustainability of aquaculture through the use of market-based approaches, including the certification of products produced by sustainable means, and the ecolabelling of products from certified farms. The intention is to use the power of markets as an incentive to induce more sustainable aquaculture and to highlight the products to consumers.

Case study: Live reef fish, specifically groupers, in Palawan and the Calamianes Islands, Philippines

A case study of grouper in the Philippines further describes the role of economics and markets in driving capture-based aquaculture.

In many Asian regions, there is a focus on the capture-based aquaculture of groupers. Globally the grouper market is not large and the market demand/supply relationship can seriously influence prices, making it very sensitive due to the high exclusivity of the product (Svennevig, 2002). In Asia, there was a falling market trend (1995–1999) in the consumption of live seafood (Pawiro, 2002), especially for high-value species such as grouper. The markets for "luxury food items" such as live fish is determined by the strength of the economy, in particular the level of disposable incomes, and the prevailing exchange rate between the exporting and the importing country.

The economics of marketing capture-based aquaculture products in Asia, such as live grouper, functions at two levels, namely local and export. The local level involves the collectors and brokers. Collectors, either in the local area or from the region, are responsible for the collection of fish from the local small-scale farmers for the market. Brokers are responsible for the monitoring and movement of prices, informing farmers, and contacting collectors and wholesalers. The export level consists of marketing involving agencies or network companies. The marketing margin (the difference between the purchasing price and the selling price after the deduction of sales costs) for exporters is much higher than that for the collectors, even though the sales costs of exporters are higher. Boonchuwong and Lawapong (2002) calculated that the rate of return on total costs was as high as 94.4 percent for exporters and 49.2 percent for collectors. Exporters receive the highest returns of all traders involved in the live grouper marketing system, as they must carry all of the risks during the collection and export of the live fish – fish deaths, damage, packaging and other export costs.

While the live reef fish trade (LRFT) operates throughout the Philippines, the Calamianes Group of Islands in the northern part of Palawan is the centre of the live food fish trade fishery. According to Padilla *et al.* (2003), "Initially, fishermen from the distant provinces of Surigao, Bohol and Leyte were brought to the area to fish and to train locals in catching live fish. The activity slowly grew among fishing communities. Fish soon replaced lobster as the main live aquatic product in trade. By late 1990s, 60–70 percent of fishing communities were engaged in live reef fish collection". It is estimated that there are about 1 000 fishers that target live reef fish. Over time, hook and line replaced fish traps. Many fishers eventually shifted to using cyanide. It is estimated that up to 50 percent of the fishers use cyanide. There are three categories of fishers operating in the area: (1) fishers who own their own boat and sell their fish to a dealer offering the highest price; (2) fishers who own their own boat but because of debt are obliged to sell to a certain dealer and accept the price offered; and (3) fishers who work on boats owned by dealers (about 80 percent of the fishers).

The live food fish trade in the Calamianes is characterized by dynamic arrangements between and among fishers, boat owners/operators, traders/middlepersons, financiers, and exporters. Most of the LRFF trade middlepersons in the area own multiple boats. Fishers are often indebted to them in a *suki* (regular customer) relationship. Transactions take place in four geographical stages – in the islands, in the town of Coron, in Manila and eventually in China Hong Kong Special Administrative Region (Padilla *et al.*, 2003). The majority of fish are shipped by air to Manila. Most live fish in the Calamianes are held in indoor "aquarium" tanks. Only undersized fish are impounded in floating cages.

Although the live reef food fish trade has been operating for several decades, economic and trade information is scant. Price and volume data are collected and reported by municipality in Palawan Province by the Palawan Council for Sustainable Development (PCSD) and the Palawan Provincial Fishery Office, BFAR-Region

TABLE 1
Quantity and value of exports of live grouper, Philippines, 1991–2004

Year	Quantity (kg)	FOB Value (US$)
1991	1 001 846	970 367
1992	2 285 691	2 008 005
1993	5 657 325	4 472 150
1994	5 328 763	4 521 186
1995	5 819 857	4 857 583
1996	3 062 569	2 674 603
1997	3 638 577	4 166 669
1998	3 298 647	4 335 509
1999	3 720 907	4 622 687
2000	7 070 842	14 344 337
2001	5 153 767	12 045 944
2002	6 789 883	10 916 245
2003	6 819 413	9 186 614
2004	5 497 699	7 557 375

Source: National Statistics Office and Bureau of Agricultural Statistics, Quezon City, Philippines.

No. IV-B. PCSD reports on key status indictors by municipality for the live reef fish for food industry such as reef status, total production, shipment, number of accredited actors in the industry and cyanide detection test incidence.

Export data on a national level is collected and reported by the National Statistics Office and the Bureau of Agricultural Statistics. The quantity and value of exports of live grouper from 1991 to 2004 are reported in Table 1.

The imports of live grouper into China Hong Kong SAR from the Philippines was 1 200 963 kg (10.25 percent of all live grouper imports) in 2001, 1 425 664 (12.52 percent) in 2002 and 1 578 384 (13.27 percent) in 2003. The leopard coral trout and the green grouper were the two top imported live grouper species into China Hong Kong SAR.

Prices paid to the fisher or fishing company that caught the fish are generally in the range of 2–4 times the prices paid for the same fish when dead. Higher-value fish are usually graded as undersize (<500 g), good or "plate" size (500 g to 1 kg), oversize (>1 kg), or per piece (>1.5 kg). In the Philippines, where size limits are not enforced or not in place, all fish are purchased and fish that are undersize or not ready for market are moved to grow-out cages where they are held until they reach plate size.

Two characteristics of the trade are its volatility and its geographic expansion. Prices and consumption vary substantially by season, especially with the arrival of important holidays in consuming countries. Prices in Coron, Philippines, for example, peak in December–February, with lower prices occurring during April–August. Less predictable factors that have strongly impacted demand in recent years have been the state of the economy; the occurrence of health issues, such as ciguatera; and the occurrence of red tides in the vicinity of fish holding and culture facilities. Fisheries have started and stopped several times in source countries for various reasons, including decisions by governments and communities, and civil unrest. Traders are constantly seeking new sources of fish and the frontier of the fishery has continually expanded in the last 25 years (Graham, 2001).

Muldoon, Peterson and Johnston (2004) reported that in general the market for LRFF has contracted over the past five years, becoming more focused on fewer species (primarily high and medium-value groupers). The following are thought to be the main causes of these shifts:

1. Overall improvements in transport technology and access to air transport that have helped to increase imports of high-value species. This has been reinforced by relative increases in operating costs for transporting fish by sea.

2. A decline of 40 percent in the LRFF market since 1998. This falling demand has led to weaker retail prices, making purchase and transport of lower-value fish unviable.
3. Increased aquaculture production of lower-value groupers in Southeast Asia from wild-caught fish. The increase in grow-out from hatchery production is seen as a positive industry development, but there is growing concern over the parallel increase in grow-out of wild-caught juveniles for market.
4. Downturn in general business because of international health scares, such as the severe acute respiratory syndrome (SARS) and ciguatera poisoning.

The decrease in the China Hong Kong SAR consumer price index from the end of 1997 to the end of 2002 was accompanied by falls in wholesale and retail prices for LRFF. There is a growing market expansion for LRFF in the China with increasing incomes. Source countries have experienced decreasing prices for LRFF in recent years, but the impact of these price declines has been mitigated by favourable exchange rates fluctuations. Padilla *et al.* (2003) reported that the Philippines has a comparative advantage in the constantly growing fish trade. The government provided a supportive trade policy environment, particularly in the export of various fish products, to harness such potential. This resulted in such economic benefits as foreign exchange earnings, jobs and higher income for those directly involved in the export industry.

Padilla *et al.* (2003) found that for the live food fish trade, the premium price on preferred size of fish results in the targeting of young and sexually immature fish, which in turn leads to recruitment overfishing. Second, the significantly higher price of live fish drives the collection of fish well beyond limit and without regard to the capacity of the stock to regenerate. Third, cheap capital from traders and exporters further fuels the fishing trade. International demand accounts largely for the unsustainable path of the industry. Traders and exporters move fishing operations in response to shifting supply in the country.

Padilla *et al.* (2003) report that economic indicators also support the result that the industry is "mining" and degrading the resource base, greatly compromising its current and future regenerative capacity. Income from fishing has been dissipated by declining catches due to overfishing and to the growing number of fishermen. Returns from capital and labour have been greatly diminished over time, despite the increase in price of fish in nominal peso terms. The reason why fishers remain in the fishery is primarily the lack of non-fishing employment alternatives in the remote islands.

Management of seed fisheries

As capture-based aquaculture is an overlap between fisheries and aquaculture, the management of the resources and the species involved must take into account the requirements of both practices. Aquaculture production methods are constantly changing with new technologies being introduced. An issue in managing capture-based aquaculture, which operates in many locations within a country, is the inadequacy of existing legislation to address the many aspects of this aquaculture practice. Countries need to create or amend the comprehensive regulatory framework to ensure that the sector develops in a sustainable manner. In most fishery management laws there are minimum sizes on harvested species, and often restrictions on the harvest of spawning adults. In some situations, governments have tried to outlaw such fisheries, but these attempts have mostly not been supported by scientific data, and have generally been unsuccessful due to inadequate enforcement (FAO, 2006). Management of seed fisheries requires a sound knowledge base and a decision-making process based on the participation of the different stakeholders.

FAO (2006) states that responsible application of aquaculture based on seed fisheries requires that juveniles are caught before they experience severe mortality, recruitment must be sufficient to ensure that fisheries targeting adults are compensated, and capture methods must minimize bycatch of non-target species and may not damage supporting habitats.

A number of measures have been developed to manage seed fisheries:

– Many collecting localities currently limit either the number of fish or the number of species taken, or both. The Bahamian government has a limit of 50 individuals per permitted species, the Florida Keys, United States of America, has imposed size restrictions on 49 species of fish, while Brazil allows only 180 species to be exported.

– Traditionally, river catfish culture systems in Viet Nam relied entirely on wild-caught fry, with 200–800 million fry being caught annually. In the process of catching catfish fry, unwanted fry of other species were also caught, which were then discarded. This made the fishery for river catfish fry highly destructive. An estimated 5–10 kg of other fish species were killed for each kilogram of river catfish fry caught. The quantity of wild-caught river catfish fry declined tenfold in a decade because of overfishing for fry. Recognition of this problem and the successful artificial spawning of river catfish led to the banning of the fishery for wild river catfish fry in both An Giang and Dong Thap provinces in February 2000 (Trong, Hao and Griffiths, 2002).

– In the northeast region of the United States of America, dramatic declines in eel populations in the 1990s and increasing harvest pressure on all life stages prompted most states to tighten the regulatory control of these fisheries. Minimum size limits of 4–6 inches (10–15 cm) and moratoria on elver collection are now in effect. In addition, many states have gear fees, harvest locality limitations and restrictions on or banning of certain fishing gears. Stocks have begun to recover. The Queensland government in Australia manages the collection of glass eels and does not permit their export. The impact on eel fisheries globally caused by farming activities is already evident, with a decline in eel catches from 18 600 tonnes in 1994 to 12 700 tonnes in 2000 (Ottolenghi *et al.*, 2004). It is possible that the capture and export of elvers for seed may become totally banned.

– In a report on the AdriaMed Expert Consultation on interactions between aquaculture and capture fisheries (FAO, 2003), it was recommended that tools to regulate the use of wild seed/juvenile/sub-adult and adult collection for farming include quotas and licenses for collection. It was also recommended that there be the development of specific legislation to inform the consumer on the traceability of fish products.

– In 2004, the International Standard for the Trade in Live Reef Food Fish was produced. This voluntary LRFF Standard was produced through an international consultation process and covers the capture of wild live reef food fish; the aquaculture of live reef food fish; and the handling, holding distribution and marketing of live reef food fish. It is aimed at being a standard to which all responsible members of the LRFF trade will adhere so as to enable the trade to continue. The LRFF Standard aims to promote a "sustainable fishery", i.e. one in which the harvesting of the target species is conducted in such a way, and at a rate, that 1) it does not threaten the health of the stock and the ecosystem on which it depends, or 2) it does not inhibit recovery of the stock or the ecosystem if it has previously been reduced below appropriate levels.

The Standard[1] makes specific reference to seed fisheries in section 3. Requirements of Live Reef Food Fish Aquaculture, 3.1 Management Requirements, 3.1.2 Limits to harvesting wild caught fry, fingerlings and juveniles:

a) The harvesting of wild-caught fry and fingerlings shall occur only when it can be demonstrated that it does not damage or negatively impact the sustainability of wild stocks.
b) Aquaculture farms that use wild-caught fry, fingerlings and juvenile must have a programme in place to eliminate their use for LRFF aquaculture.

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1 http://www.livefoodfishtrade.org/aquaculture/part1/requirement1_2/index.htm

The LRFF Standard provides interpretation of this management requirement by stating that where wild-caught fry and fingerlings are harvested, best-practices with respect to fishing gear should be adhered to so that: a) bycatch and waste are minimized, and b) mortality of target and non-target fish are minimized.

The LRFF Standard states responsible practice should include:

- Capture of pre-settlement fry/juvenile fish. Aquaculture should reduce its reliance on the capture of wild-caught reef fish to remove pressures on wild stocks. Harvesting of wild-caught fry and fingerling should only be carried out where it can be shown not to damage of affect sustainability of wild stocks.
- Reduction of post-harvest mortality. Fishing gears used in the fishery should minimize bycatch and waste and minimize the mortality of target and non-target species. Post-capture, handling and transportation practices should likewise reduce current mortality levels.
- Limits on exports of fry and fingerlings. Limits should be considered for the volume of fry and fingerlings able to be exported as well as specific measures to restrict exports of endangered species or fish which are under given minimum.
- Ongoing government endorsed research. A present lack of knowledge of the impacts of harvesting at different sizes/stages of life history, which fishing gears can reduce mortalities and mortality rates caused by capture and handling highlights the need for further research to identify best practices.
- Improve fisher and farmer awareness of current practices. There is a lack of awareness by fishers and farmers on post-harvest mortality, bycatch, and impacts of catching immature fish. This constraint calls for hands on extension and demonstration could be more effective in some cases. This manual should raise awareness of the issue of resource wastage.

– Several potential problems will need to be overcome with grouper aquaculture. The future of the industry will depend on having a regular supply of hatchery-raised seed and fry. The collection of seed and fingerlings from the wild is not sustainable in the long term and the export of wild-caught grouper seed needs to be regulated or prohibited. Cultured grouper can be certified for quality and good culture practices. Grouper grown from hatchery reared seed, as compared to wild-caught seed and fingerlings, can be certified. Sadovy (2000), in a survey of grouper fry/fingerling supply in Southeast Asia, made several recommendations in relation to the seed fishery and in respect to future development of mariculture in the region:

1) Prohibit all export of wild-caught grouper seed. Grouper should be cultured to market-size within the source countries.
2) Develop and implement careful and controlled studies on selected grouper seed fisheries in major producing areas, whereby information is integrated on catches, socioeconomics, market forces, associated adult fisheries, and habitats.
3) Reduce or eliminate the use of destructive (of habitat) or particularly wasteful (producing high mortality in, or damage to, target and/or non-target species) fishing gears or methods (like adding lights) and carry out studies on preferred gears to ensure that their operation does not incur greater waste or damage than is absolutely necessary.
4) Ensure better use of existing resources and reduce wastage of grouper seed biomass (and bycatch) arising from unnecessary mortality from harvest, transport and culture.
5) Examine, scientifically, the possibility of focusing the capture fishery on the smallest seed available and improve the means of nursing this phase to one suitable for widespread, small-scale culture.
6) Develop management approaches to protect key seed settlement and nursery habitats, such as mangrove areas and seagrasses in river mouths and estuaries,

and protect the production of those seed by safeguarding the spawning adults (i.e. in spawning areas or spawning aggregations).

7) Provide government assistance both in terms of incentives, or low-interest loans, to enable small-scale fishers to enter the culture sector to produce low intensity, high quality, cultured grouper, in suitable grow-out areas, and in terms of training in post-capture handling to reduce mortalities, and in nursing.
8) Develop certification systems for quality and good practice. For example, a distinction between hatchery produced and wild-caught and reared seed could provide incentives for producing good seed quality and good-quality cultured (i.e. ciguatera-free, not caught with cyanide, etc.) fish, as well as for good aquaculture practices.
9) Examine the role of hatcheries in supplying grouper seed for culture.
10) Promote the active application of the precautionary principle in the exploitation of grouper resources and the adoption by Asia-Pacific Economic Cooperation (APEC) member economies of the FAO Code of Conduct for Responsible Fisheries (CCRF).

– Sadovy (2000) compiled information on the status of regulation on grouper "seed" capture and exports that concern capture-based aquaculture. The People's Republic of China limits the number of grouper seed fishers and the quantities of grouper seed captured. A license is needed for transporting marine seeds and this export is prohibited. In West Malaysia, the fishing of seed is not allowed during November and December; it is permitted during the peak season from January to April. No export of seeds smaller than 15 cm is permitted. In the Philippines, the use of scissor nets and fyke nets has been banned. The Philippines Fisheries Code of 1998 prohibits the export of seed milkfish and prawns but its application to grouper is not clear. In Penghu Island, Taiwan Province of China, fisheries are not permitted to catch any grouper seed of <6 cm. In Thailand, the use of push nets and fyke nets is limited.

– Many shrimp farmers in South and Central America, Bangladesh and India depend on wild-caught post-larvae shrimp, usually harvested by local fishers. In Bangladesh, the shrimp culture industry used to be entirely dependent on natural shrimp fry collected from coastal rivers, estuaries and mangrove areas. About 400 000 people are said to be engaged seasonally in fry collection activities, most of them are women and children. According to a recent survey by DOF (2004), there are 40 *Upazilas* (sub-districts) under 12 coastal districts along the 710 kilometres long coastal area where shrimp fry are collected. The fry collection is not their permanent or main occupation, rather it is a seasonal opportunity to earn money. Shrimp fry collection is a recent occupation in the last two decades. The demand for shrimp fry has tremendously increased with the rapid expansion of the shrimp industry after the mid-1980s. Many coastal people have taken this up as an alternative option for their livelihoods. But the increased fishing pressure to collect more fry is thought to be contributing to the gradual decline of abundance and distribution of mother shrimp and shrimp fry, thereby causing serious damage to the productivity of coastal and marine fisheries resources. Moreover, the huge numbers of bycatch, such as eggs, larvae and juveniles of non-target fish and shrimp during shrimp fry collection are mostly discarded on the land after sorting of target fry. It is reported that coastal biodiversity has been decreasing (DOF, 2004).

The Government of Bangladesh made a decision to impose a ban on shrimp fry collection (DOF, 2004). To address the issue of displaced fry collectors, the government initiated a programme on alternative livelihoods. Two groups of fry collectors (including males, females and children) were targeted. The non-migratory fry collectors live in cluster villages and slums around the *polders*. They are organized into groups by non-governmental organizations (NGOs) to provide training. The other group is migratory and used to live in temporary huts during collection season and move to other areas when shrimp fry are less abundant. Rapid rural appraisals are being undertaken of this group by NGOs . Suggested alternative livelihood options include:

1. operation of shrimp fry nursery;
2. shrimp fry trading;
3. making fishing traps and gears;
4. operation of fish feed mills;
5. shrimp de-heading for processing;
6. crab fattening;
7. *hogla* and mat making;
8. bee keeping;
9. *coir* industry;
10. tree plantation;
11. horticulture; and
12. tailoring and knitting, etc.

– In 1966, the Japanese Fisheries Agency (JFA) imposed regulations limiting the number of amberjack fry (2.5–5 cm long called "*mojako*") that can be caught annually for aquaculture purposes to about 40 million in order to protect the resource. Allocations are made to each prefecture by the Japan Seawater Fishery Culture Association. Each prefecture government decides on the allowable period for catching *mojako* and allots the number of fish allowed to be caught to the individual Federation of Fisheries Cooperatives in the prefecture (Ottolenghi *et al.*, 2004).

Currently, most legal frameworks do not provide for the zoning of aquaculture areas to reduce user conflicts, and for holding consultations to resolve conflicts. Zoning can control the distribution of fishing effort. Areas can be closed seasonally or permanently as protected areas. Given capacity limitations in many countries, the use of closed areas to protect juveniles and immature fish may be easier to enforce than size limits or gear restrictions (Sadovy, Donaldson and Graham, 2003). However, past conflicts seem to indicate that these approaches are not always adequate. These conflicts usually arise because rights over access and use of resources are not well defined or equitably applied. The conflicts may be minimized and resolved through sensitive application of appropriate laws and regulations and stakeholder participation.

Lack of institutional and enforcement capacity and a limited willingness on behalf of responsible authorities to impose management restrictions remain a key impediment to successfully managing seed fisheries in many countries. Conflicts of interest and corruption are common.

Codes of practice and industry standards can improve the conduct of the industry and move toward industry sustainability. Standardization results from consensus agreements reached between all players in the industry, both private and government. As described above, one such set of standards has been developed for the live reef food fish trade.

In the long term, the capture-based aquaculture of selected species of finfish may have to be prohibited, through legislation, if it is viewed as a threat to fisheries, to natural recruitment in the wild and perhaps to the very existence of certain species. Fry collectors will be displaced as a result of legislation to end seed fisheries. This could potentially have impacts on the livelihoods and incomes of hundreds of thousands of people in developing countries that rely on seed fisheries for part or all of their income. To address the issue of displaced fry collectors, a programme on alternative livelihoods may be initiated to assist households in the transition to other livelihood opportunities.

THE FUTURE OF CAPTURE-BASED AQUACULTURE

Capture-based aquaculture has social and economic advantages and disadvantages compared to full-cycle aquaculture. In many situations, especially in developing countries, capture-based aquaculture can provide income and livelihoods to sectors of the population that may otherwise be excluded from aquaculture. However, it can also result, among others, in loss of societal benefits from the loss in yield from the wild stocks and conflict. Markets have been the driving force behind the development of capture-based aquaculture and will continue to be in the future. It is anticipated that capture-based aquaculture will continue to expand in the short-term, both for those finfish and non-finfish species currently being cultured and possibly with others that may be selected for aquaculture in the future. However, the main constraint to expansion is "seed" supply. Wild seed supply has not been able to keep up with the increasing demand from farms. The capture of wild seed is being increasingly regulated. It is important that means be found to rear these species throughout their full life-cycle that are economically viable. Farmers will also need to reduce their production costs to meet changing market demands. Any future expansion of capture-based aquaculture will also need to address damage to the environment caused by its activities and regulate itself in a more sustainable manner. In all cases, there will be positive and negative social and economic impacts that will need to be managed more strategically.

REFERENCES

Ahmed, M., Magnayon-Umali, G.A., Valmonte-Santos, R.A., Toledo, J., Lopez, N. & Torres Jr, F. 2001. Bangus fry assessment in the Philippines. ICLARM Tech. Rep. 58. WorldFish Center, Penang, Malaysia.

Allan, G. & Fielder, D. 2003. Mud crab aquaculture in Australia and Southeast Asia.

Proceedings of a Scoping Study and Workshop. ACIAR Working Paper No. 54. Australian Centre for International Agricultural Research, Canberra, Australia.

Asia-Pacific Fishery Commission (APFIC). 2005. APFIC regional workshop on low-value and "trash fish" in the Asia-Pacific region. Hanoi, Viet Nam, 7–9 June 2005. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific. Bangkok.

Bartley, D. 2000. Responsible ornamental fisheries. FAO Aquaculture Newsletter. April, #24: 10–14. United Nations Food and Agriculture Organization, Rome.

Birkeland, C. 1997. Disposable income in Asia – a new and powerful external pressure against sustainability of coral reef resources on Pacific islands. Reef Encounter, 22: 9–13.

Boonchuwong, P. & Lawapong, A. 2002. Marketing and exporting of grouper in Thailand. *In* APEC/NACA, (eds). *Report of the APEC/NACA Cooperative Grouper Aquaculture Workshop, Hat Yai, Thailand, 7–9 April 1999*, pp.45–51. Bangkok, Thailand, NACA. (available at www.enaca.org/Grouper/Publications/HatYaiProceeding.pdf)

Bunting, S.W. 2006. Low impact aquaculture, Centre for Environment and Society Occasional Paper 2006–3, University of Essex, Colchester UK.

Chong, K.C., Smith, I.R. & Lizarondo, M.S. 1982. Economics of the Philippine Milkfish Resource System. The United Nations University Press, Tokyo, Japan.

Cruz, M.L. 1992. Evaluation of the impact of shrimp mariculture development upon rural communities in Mexico. In R.B. Pollnac and P. Weeks (eds) Coastal aquaculture in developing countries: problems and perspectives. International Center for Marine Resource Development, University of Rhode Island, Kingston, RI. pp. 54–72.

Dawes, J. 2001. International aquatic industry perspectives on ornamental fish conservation. In: Chao, N.L., Petry, P., Prang, G., Sonneschein, L., Tlusty, M.F. (eds), Conservation and Management of Ornamental Fish Resources of the Rio Negro Basin, Amazonia, Brazil–Project Piaba. Editora da Universidade do Amazonas, Manaus, Brazil, pp. 109–124.

de Monbrison, D. & Guillaumie, B. 2003. Preliminary studies for DOTT symposium – BFT impacts on local development a socio-economic approach. *Cahiers Options Méditerranéennes*, 60: 127–138.

Department of Fisheries (DOF). 2004. Management options for the shrimp fry fishery: A regional stakeholder workshop. A workshop hosted by the Department of Fisheries and funded through Fourth Fisheries Project by the Department for International Development as part of the Shrimp Action Plan. Coxes Bazaar, 11 August 2002. http://www.enaca.org/modules/mydownloads/viewcat.php?cid=19

Edwards, P., Little, D.C. & Demaine, H. 2002. Issues in rural aquaculture. Chapter 23 in Edwards, P., D.C. Little and H. Demaine (eds) Rural Aquaculture. CABI Publishing, Wallingford, UK.

Epler, B. 1992. Social ramifications of mariculture on coastal Ecuadorian communities. In R.B. Pollnac and P. Weeks (eds) Coastal aquaculture in developing countries: problems and perspectives. International Center for Marine Resource Development, University of Rhode Island, Kingston, RI. pp. 24–33.

FAO. 2003. Report of the AdriaMed Expert Consultation "Interactions between Aquaculture and Capture Fisheries", Rome, 5–7 November. FAO-AdriaMed Scientific Cooperation to Support Responsible Fisheries in the Adriatic Sea. GCP/RER/010/ITA. Rome.

FAO. 2006. Species Choice in Aquaculture: Domestic processes, genetic improvement, and their role in sustainable aquaculture. Advisory Committee on Fisheries Research, Sixth Session. Rome, Italy, 17–20 October 2006. ACFR/VI/2006/3. Rome.

Friedman, K. 1999. Pearl culture using wild caught spat of blacklip oysters in the Solomon Islands. PhD thesis. James Cook University, Queensland, Australia.

Gonzales, E. 2006. The current status of mariculture in the Philippines and livelihood opportunities for coastal communities. The future of mariculture: A regional approach for responsible development of marine farming in the Asia-Pacific Region. Bangkok: STREAM.

Graham, T. 2001. A Collaborative Strategy to Address the Live Reef Food Fish Trade. Asia Pacific Coastal Marine Program, Report No. 0101. Honolulu: The Nature Conservancy.

Hair, C.A., Bell, J.D. & Doherty, P.J. 2002. The use of wild-caught juveniles in coastal aquaculture and its application to coral reef fishes. Chapter 17 In Stickney, R.R. and McVey, J.P. (eds) Responsible Marine Aquaculture. CABI Publishing, Wallingford, UK.

Haylor, G. & Bland, S. 2001. Integrating aquaculture into rural development in coastal and inland areas. In R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, (eds) Aquaculture in the Third Millennium. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20–25 February 2000. pp. 73–81. NACA, Bangkok and FAO, Rome.

Haylor, G., Briggs, M.R.P., Pet-Soede, L., Tung, H., Yen, N.T.H., O'Callaghan, B., Gow, C., DeVantier, L., Cheung, C., Santos, R., Pador, E., de la Torre, M., Bulcock, P. & Savage, W. 2003. Improving Coastal Livelihoods Through SustainableAquaculture Practices: A Report to the Collaborative APEC Grouper Research and Development Network (FWG/01/2001). STREAM Initiative. Bangkok: Network of Aquaculture Centers in Asia-Pacific.

Job, S. 2005. Integrating marine conservation and sustainable development: Community-based aquaculture of marine aquarium fish. SPC Live Reef Fish Information 24 Bulletin #13 – January.

Johannes, R. & Riepen, M. 1995. Environmental, economic and social implications of the live reef fish trade in Asia and the Western Pacific. The Nature Conservancy and the South Pacific Forum Fisheries Agency. Honiara, Solomon Islands.

Larsson, J., Folke, C. & Kautsky, N. 1994. Ecological limitations and appropriation of ecosystem support by shrimp farming in Colombia. Environmental Management 18: 663–676.

McAllister, D. 1999. Is mariculture the remedy to problems of coastal communities. South Pacific Commission Live Reef Fish Information Bulletin. 5: 47–48.

Miyake, M.P., Miyabe, N. & Nakono, H. 2004. Historical trends of tuna catches in the world. *FAO Fisheries Technical Paper* 467. Food and Agriculture Organization, Rome. 74p.

Mous, P.J., Sadovy, Y., Halim, A. & Pet, J.S. 2006. Capture for culture: artificial shelters for grouper collection in SE Asia. Fish and Fisheries. 7: 58–72.

Muldoon, G., Peterson, L. & Johnston, B. 2004. Trade and market trends in the live reef food fish trade. Asia-Pac. Mar. Finfish Aquacult. Network Mag. (July-September) (No. 2): 27–32. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Nakada, M. 2000. Yellowtail and related species culture. *In* R.R. Stickney, ed. *Encyclopedia of Aquaculture*, pp. 1007–1036. New York, USA., J. Wiley & Sons Inc.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature 405: 1017–1024.

Ogburn, N.J. & Johannes, R.E. 1999. Grouper post-larvae, fry and fingerling collection devices in the Philippines. Report prepared for The Nature Conservancy Asia/Pacific Coastal and Marine Program, May.

Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A. & New, M.B. 2004. Capture-based aquaculture: the fattening of eels, groupers, tunas and yellowtails. Food and Agriculture Organization, Rome. 308p.

Padilla, J.E., Mamauag, S., Braganza, G., Brucal, N., Yu, D. & Morales, A. 2003. Sustainability assessment of the live reef fish for food industry in Palawan, Philippines. World Wildlife Fund-Philippines, Quezon City.

Pawiro, S. 2002. Markets for cultured grouper and other marine finfish. *In* APEC/NACA/BOBP/GOI, (eds). Report of the Regional Workshop on Sustainable Seafarming and Grouper Aquaculture, Medan, Indonesia, 17–20 April 2000, pp. 199–207. Bangkok, Thailand, NACA. (available at www.enaca.org/Grouper/Publications/GROUPER_Medan_Workshop.pdf)

Phillips, M.J. 2002. Fresh water aquaculture in the Lower Mekong Basin. MRC Technical Paper No. 7, Mekong River Commission, Phnom Penh. 62 pp. ISSN: 1683–1489.

Phillips, M.J., Melville-Smith, R. & Cheng, Y.W. 2003. Estimating the effects of removing Panulirus Cygnus pueruli on the fishery stock. Fisheries Research 65: 89–101.

Phuong, N.T., Hai, T.N., Hien, T.T.T., Bui, T.V., Huong, D.T.T., Son, V.N., Morooka, Y., Fukuda, Y. & Wilder, M.N. 2006. Current status of freshwater prawn culture in Viet Nam and the development and transfer of seed production technology. Fisheries Science 72: 1–12.

Pomeroy, R. 2007. Public policy for sustainable grouper aquaculture development in Southeast Asia. Chapter 29 In Leung, P., C.-S. Lee, and P.J. O'Bryen, (eds). Species and System Selection for Sustainable Aquaculture. Blackwell, Ames, Iowa, USA. 488 pp.

Pomeroy, R., Parks, J. & Balboa, C. 2006. Farming the reef: is aquaculture a solution for reducing fishing pressure on coral reefs? Marine Policy 30: 111–130.

Pomeroy, R. & Trinidad, A. 1995. Industrial organization and market analysis: fish marketing. Chapter 9 in G.J. Scott (ed.) Prices, Products and People: Analyzing agricultural markets in developing countries. Lynne Rienner Publishers, Boulder, Colorado.

Ringuet, S., Muto, F. & Raymakers, C. 2002. Eels-their harvest and trade in Europe and Asia. TRAFFIC Bulletin 19: 81–106.

Sadovy, Y. 2000. Regional survey for fry/fingerling supply and current practices for grouper mariculture: evaluating current status and long term prospects for grouper mariculture in South East Asia. Final report to the Collaborative APEC grouper research and development network (FWG 01/99). (available at www.enaca.org/Grouper/Publications/FWG01-99.pdf)

Sadovy, Y.J. & Vincent, A. 2002. Ecological issues and the trades in live reef fishes. Chapter 18 in P. Sales (eds) Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem, Academic Press.

Sadovy, Y.J., Donaldson, T.J. & Graham, T.R. 2003. The Live Reef Food Fish Trade While Stocks Last. Asian Development Bank, Manila.

Sim, S.Y., Rimmer, M.A., Toledo, J.D., Saguma, K., Remengan, I., Williams, K. & Phillips, M.J. 2005. A guide to small-scale marine finfish hatchery technology. Bangkok: NACA.

Sinh, L.X. 2005. Issues Related to Sustainable Farming of Catfish (*Pangasius* spp.) in Viet Nam. Paper presented at the "Socio-economic aspects of species for sustainable aquaculture farming" workshop organized by Oceanic Institute, Hawaii, 17–20 October, 2005.

So Nam, Eng Tong, Souen Norng & Hortle, K. 2005. Use of freshwater low value fish for aquaculture development in the Cambodia's Mekong basin. Paper presented at the Regional Workshop on Low Value and "Trash Fish" in the Asia-Pacific Region, Hanoi, Viet Nam 7–9 June.

So Nam and Haing Leap. 2006. A Review of Freshwater Fish Seed Resources in Cambodia. Consultancy Report for Food and Agriculture Organization (FAO) and Network of AquacultureCentres in Asia-Pacific (NACA). Department of Fisheries, Phnom Penh, Cambodia.

Svennevig, N. 2002. Perspective on future directions in cage culture related to Asia. *In* APEC/BOBP/NACA, (eds). Report on the Regional Workshop on Sustainable Seafarming and Grouper Aquaculture, Medan, Indonesia, 17–20 April 2000, pp. 143–160. Bangkok, Thailand, NACA. (available at www.enaca.org/grouper/publications/grouper_medan_workshop.pdf)

Tibbetts, S.M., Lall, S.P. & Anderson, D.M. 2001. Optimum dietary ratio of digestible protein and energy for juvenile American eel, *Anguilla rostrata,* fed practical diets. Aquaculture Nutrition, 7: 213–220.

Tisdell, C.A. & Poirine, B. 2000. Socioeconomics of pearl culture: industry changes and comparisons focusing on Australia and French Polynesia. World Aquaculture. 31(3): 30–33.

Tlusty, M. 2002. The benefits and risks of aquacultural production for the aquarium trade. Aquaculture 205: 203– 219.

Trong, T.Q., Hao, N.V. & Griffiths, D. 2002. Status of Pangasiid aquaculture in Viet Nam. MRC Technical Paper No. 2, Mekong River Commission, Phnom Penh. 16 pp.

Tuan, L.A. & Hambrey, J. 2000. Seed supply for grouper cage culture in Khanh Hoa, Viet Nam. Aquaculture Asia. 5(2): 39–41.

Wood, E.M. 2001. Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. Marine Conservation Society, Ross-on-Wye, UK.