Capture-based aquaculture of groupers

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SUMMARY

The economies of China and Southeast Asia have developed rapidly over the past two decades, leading to the emergence of a wealthy class with substantial disposable income. This has led to an increasing demand for fish in the region (Birkeland, 1997). The "live fish trade" of the Indo-Pacific has expanded rapidly in recent years, and now targets many species (Johannes and Riepen, 1995; Sluka, 1997, Sadovy and Vincent, 2002). Groupers are greatly valued for the quality of their flesh, and most species command high market prices. Groupers are the most intensively exploited group in the live fish trade, and the high prices paid by exporters to local fishermen mean that target species may be heavily over-fished (Morris, Roberts and Hawkins, 2000). In order to alleviate the pressure on wild grouper stocks, many nations have promoted aquaculture in the hopes of producing a more sustainable grouper yield. However, full-cycle culture of most grouper species is not yet possible, although several important advances have been made in recent years. For this reason, about two-thirds of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). This is known as capture-based aquaculture (CBA).

There are at least 16 species of groupers that are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, China Hong Kong Special Administrative Region (SAR), the southeast of the China and Viet Nam (Sadovy, 2000). Grouper culture is also undertaken in India, Sri Lanka, Saudi Arabia, Republic of Korea, Australia, the Caribbean and in the southeastern United States of America. Despite the huge popularity of live fish in China and Southeast Asia, only 15–20 percent of the amount consumed each year comes from aquaculture, as culture is principally constrained by limited and unreliable supplies of wild seed and the difficulties of spawning in captivity.

Grouper seed is collected using a variety of methods. Capture methods are generally artisanal and the fishermen employ a variety of artificial habitats. Some grouper seed collection methods are more damaging than others. Clearly destructive methods include those that result in high mortality, involve high levels of bycatch, and/or cause damage to the fish habitat. A further problem is that some methods result in monopolization of

the local fishery by a few individuals. Destructive methods include scissor nets and fyke nets, which are already banned in some areas. The mortality rates that follow capture and transport are not well documented; estimates for over the first 2 months after harvest are quite variable (30–70 percent), depending on the quality of fry, the level of transport stress, and the presence of disease and cannibalism (Pudadera, Hamid and Yusof, 2002).

Because full-cycle culture of most grouper species is not yet possible, approximately 66–80 percent of all grouper culture involves the capture and grow-out of wild seed and the volume of seed caught each year exceeds hundreds of millions of individuals (Sadovy, 2000). When seed catches are compared to the numbers of marketable fish produced, the results strongly suggest crude and wasteful culture practices. Sadovy (2000) estimated that about 60 million seed fish are needed to produce the regional total of 23 000 tonnes of table-size live fish from culture annually.

Trash fish is commonly used for feeding in grouper cage culture, but its increasing cost, shortage of supply, variable quality and poor feed conversion ratios indicate that this form of feed may not be the best from either a nutritional or an economic point of view. A dependable supply of cost-effective, non-marine, sources of alternative protein must be provided if grouper farming is to remain profitable. Millemena (2002) demonstrated that up to 80 percent of fishmeal protein can be replaced by processed meat meal and blood meal derived from terrestrial animals with no adverse effects on growth, survival, and food conversion ratio (FCR). From an economic standpoint, replacement of fishmeal with cheaper animal by-product meals in practical diets can alleviate the problem of low fishmeal availability and high costs.

Recent research suggests that the ecological footprint of capture-based grouper aquaculture is large (Mous *et al.*, 2006). Support for grouper CBA is often based on the assumption that the natural morality of early juvenile grouper is very high, so that the fishery is not adding substantially to this natural mortality and therefore not affecting adult population size to any great extent. This assumption remains untested for most grouper species. However, recent research suggests that the period of very high mortality occurs during and immediately after settlement, and that juvenile grouper surviving more than a few days have a much higher chance of survival (Tupper, 2007). In addition to problems of bycatch, wasteful mortality, and overfishing, cage and net culture can create other environmental problems, most notably point-source pollution which can have adverse effects on coastal waters, and particularly on coral reefs.

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. Despite high initial investment costs, studies have shown that with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. However, based on the information reviewed in this report, capture-based aquaculture may not be the best means to ensure a steady and sustainable supply of grouper for either the live or "non-live" fish trades. This is due to a number of problems including low availability of seed, destructive and wasteful seed collection techniques, removal of large numbers of early life history stages with subsequent impacts on adult populations and conflicts with capture fisheries, and pollution and disease resulting from culture operations.

The obvious solution to some of the problems of CBA for grouper is to develop closed-cycle hatchery rearing for all the grouper species sought by the market. Important advances in full-cycle culture have been made for several species, particularly in Taiwan Province of China, and full-cycle culture appears financially feasible given a large enough capital investment. However, given the financial means of most grouper culturists, and the difficulty in rearing most grouper species, it remains unlikely that many of these species will be hatchery-reared in the near future. In the meantime, steps must be taken to improve the management of both CBA and capture fisheries for grouper.

INTRODUCTION

The economies of China and Southeast Asia have developed rapidly over the past two decades, leading to the emergence of a wealthy class with substantial disposable income. This has led to an increasing demand for fish in the region (Birkeland, 1997). The "live fish trade" of the Indo-Pacific has expanded rapidly in recent years, and now targets many species (Johannes and Riepen, 1995; Sluka, 1997; Sadovy and Vincent, 2002). Groupers are greatly valued for the quality of their flesh, and most species command high market prices. Groupers are the most intensively exploited group in the live fish trade, and the high prices paid by exporters to local fishermen mean that target species may be heavily over-fished (Morris, Roberts and Hawkins, 2000). Trade often follows a pattern of sequential over-exploitation; the most highly sought species are fished-out in country after country, before the less valuable species are targeted and fished intensively (Sluka, 1997; Johannes and Riepen, 1995). Wealthy customers pay very high prices for endangered species in Chinese and Southeast Asian markets. In 1997 the red grouper, *Epinephelus akaara*, fetched US$42/kg in China Hong Kong SAR markets. In 2004, restaurants were charging US$225 for only the lips of the humphead wrasse, *Cheilinus undulatus*. Thus, fishermen will go to great lengths in order to catch every fish, and this has already contributed to regional population crashes of species, including *Epinephelus akaara* and *Epinephelus striatus* (Morris, Roberts and Hawkins, 2000; Sadovy, 2001a).

The impact of intensive fishing is exacerbated by the K-selected life strategies of these genera, their tendency to form predictable spawning aggregations and their occurrence on relatively shallow, easily accessible coral reefs, which are severely over-exploited in many parts of the world. For many of these species, spawning aggregations represent the total reproductive output for a given year, and many species consistently return to the same aggregation area, year after year. Fisheries often target spawning aggregations, since they are consistent in time and space and large numbers of fish can easily be caught in a short time (Rhodes and Tupper, 2007). When fishing pressure removes a high proportion of the fish forming these aggregations, these may quickly decline, and within a few years may cease to form altogether (Johannes *et al.*, 1999; Sadovy and Eklund, 1999).

A large proportion of the world's groupers are caught in artisanal fisheries, and even low-level artisanal fisheries can adversely affect stocks of these highly vulnerable species. Recreational fishing may also have significant impact on stocks; for example, the recreational fishery of groupers accounts for up to 35 percent of Florida's (United States of America) total grouper catch (Morris, Roberts and Hawkins, 2000). The global catch of groupers showed a 68 percent increase from 100 724 tonnes in 1991 to 168 943 in 2000. In order to alleviate the pressure on wild grouper stocks, many nations have promoted aquaculture in the hopes of producing a more sustainable grouper yield. Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible (although several important advances have been made in recent years). For this reason, about two-thirds of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). This is known as capture-based aquaculture (CBA).

There is a strong link between fishing activity and the capture-based seed used for farming, with declines in premium species from the overfishing of grouper adults. However, the reasons for this decline cannot be evaluated without careful, controlled studies, as falling catches may in fact be due to a combination of different causes: overfishing of the adults which produce the juveniles, habitat degradation and pollution, destructive fishing techniques, high export demand, etc. (Johannes, 1997; Sadovy, 2000). A more holistic management approach to establish the links between adults and juveniles is necessary.

SPECIES DESCRIPTIONS AND THEIR USE IN AQUACULTURE

Groupers (class Actinopterygii, order Perciformes, family Serranidae, sub-family *Epinephelinae*) comprise 14 genera and 449 species of the subfamily Epinephelinae, or roughly half of all species in the family Serranidae (groupers and sea basses) (Heemstra and Randall, 1993). There are 16 major grouper species that are cultured; the dominant species vary somewhat regionally. The most consistently abundant species that are captured for culture purposes and also reared in hatcheries are *Epinephelus coioides* and *E. malabaricus*. Other important species are *E. bleekeri*, *E. akaara*, *E. awoara* and *E. areolatus*. *E. amblycephalus*, *E. fuscoguttatus*, *E. lanceolatus, E. sexfasciatus, E. trimaculatus, E. quoyanus, E. bruneus, Cromileptes altivelis, Plectropomus leopardus* and *P. maculatus* are cultured in small amounts. In the southeastern United States of America and the Caribbean, *E. striatus*, *E. itajara*, *Mycteroperca microlepis* and *M. bonaci* seem to have good farming potential (Tucker, 1999). However, CBA for groupers in the western hemisphere has not been developed to any large extent, unlike in Southeast Asia.

Juveniles and adults of some grouper species live in coastal or lagoonal waters and estuaries, while others prefer the cleaner waters of offshore reefs. Their eggs are single, non-adhesive, and buoyant at normal salinities. The larvae of most species spend about 30–50 days as planktonic larvae (Colin, Koenig and Laroche, 1996). As they become juveniles, groupers settle in shallow waters where they seek shelter in seagrass beds, mangrove prop roots, coral rubble, branching coral or branching macroalgae. Some juvenile groupers are habitat generalists, settling in any available shelter, while other species have specific nursery habitats in which their growth and survival are enhanced (Tupper, 2007). After hatching, wild grouper larvae eat copepods and other small zooplankton. They switch to larger crustaceans, such as amphipods and mysid shrimp, as they grow. Wild juveniles and adults eat fish, crabs, shrimp, lobsters and molluscs (Tucker, 1999), although the genus *Plectropomus* tends to be predominantly piscivorous.

Groupers range in maximum size from only 12 cm (e.g. *Paranthias colonus*) to over 3 m (e.g. *Epinephelus lanceolatus*). Most groupers that have been studied are sexually mature within 2–6 years, but some of the larger species may take longer to mature, e.g. *Epinephelus fuscoguttatus*, which matures at about 9 years. Most serranids are protogynous hermaphrodites. As a rule, some change from female to male as they grow older; others may change only if there is a shortage of males. In nature, many species spawn in large aggregations (hundreds to thousands of fish) with a sex ratio nearing 1:1 (Rhodes and Sadovy, 2002). In some cases, several grouper species may share the same aggregation site (e.g. in Palau and Pohnpei; see Johannes *et al.*, 1999; Rhodes and Tupper, 2007).

Groupers are some of the top predators on coral reefs, and tend to be K-strategists demonstrating slow growth, late reproduction, large size and long life-spans which make them vulnerable to overexploitation. Also contributing to their vulnerability is the fact that they are sex-changers with a low proportion of males in the smaller cohorts, which means that heavy fishing pressure often removes most of the males (or removes fish before they can become male). Additionally, many groupers form spawning aggregations that are predictable in space and time, making them extremely easy to harvest. These aggregations can represent the entire annual reproductive output for some species. Groupers are sedentary in character and strongly territorial, making them easy targets for spear fisheries (Bullock *et al.,* 1992; Heemstra and Randall, 1993; Sadovy, 1996; Domeier and Colin, 1997; Sadovy and Eklund, 1999; Morris, Roberts and Hawkins, 2000). Tables 1–16 summarize the characteristics of grouper species most commonly encountered in CBA, while Figures 1–32 illustrate their appearance and geographical distribution.

Cromileptes altivelis (Valenciennes, 1828)

FIGURE 1
Humpback grouper (*Cromileptes altivelis*)

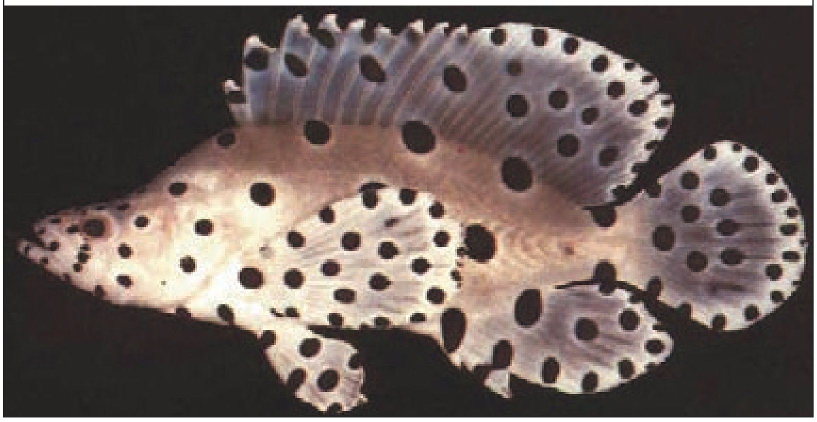
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TABLE 1
Characteristics of the humpback grouper, *Cromileptes altivelis*

Common names:	Humpback grouper, panther grouper, mouse grouper, highfin grouper
Size and age:	Max size 70.0 cm TL
Environment:	Reef-associated; marine; depth range 2–40 m
Climate:	Tropical; 32°N - 23°S, 88°E - 168°E
Importance:	Juveniles are commonly caught for the aquarium trade while adults are utilized as a food fish. Very high value in China Hong Kong SAR live fish markets.
Resilience:	Low, minimum population doubling time 4.5–14 years.
Biology and ecology:	Generally inhabits lagoon and seaward reefs and are typically found in dead or silty areas. Also found around coral reefs and in tide pools. Growth is very slow. Feed on small fishes and crustaceans.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 2
Distribution of *Cromileptes altivelis* (FishBase, 2007)

Epinephelus akaara (Temminck and Schlegel, 1842)

FIGURE 3
Hong Kong grouper (*Epinephelus akaara*)

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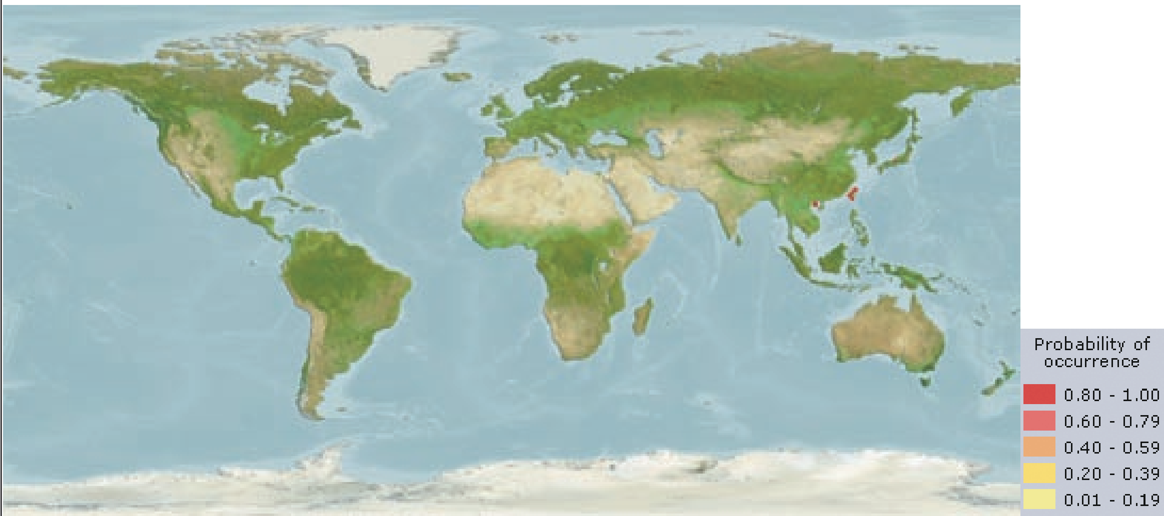
TABLE 2
Characteristics of the Hong Kong grouper, *Epinephelus akaara*

Common names:	Hong Kong grouper
Size and age:	53.0 cm TL; max. published weight: 2 470 g
Environment:	Reef-associated; marine
Climate:	Tropical; 39°N - 20°N, 109°E - 143°E
Importance:	A highly prized food fish in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Little is known about the biology and ecology of this species. Usually caught by hand-lining over rock strata. Listed as endangered by IUCN Grouper And Wrasse Specialist Group.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 4
Distribution of *Epinephelus akaara* (FishBase, 2007)



Epinephelus amblycephalus (Bleeker 1857)

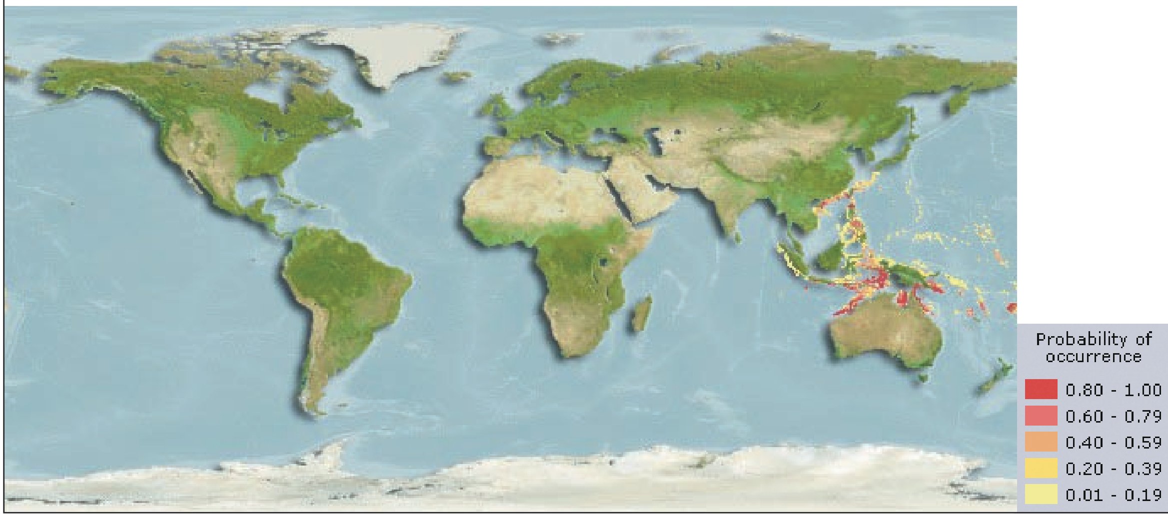
FIGURE 5
Banded grouper (*Epinephelus amblycephalus*)

TABLE 3
Characteristics of the banded grouper, *Epinephelus amblycephalus*

Common names:	Banded grouper
Size and age:	50.0 cm TL
Environment:	Reef-associated; marine; depth range 80–130 m
Climate:	Tropical; 35°N - 20°S, 95°E - 179°W
Importance:	Fisheries: minor commercial.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Little known.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 6
Distribution of *Epinephelus amblycephalus* (FishBase, 2007)



Epinephelus areolatus (Forsskål, 1775)

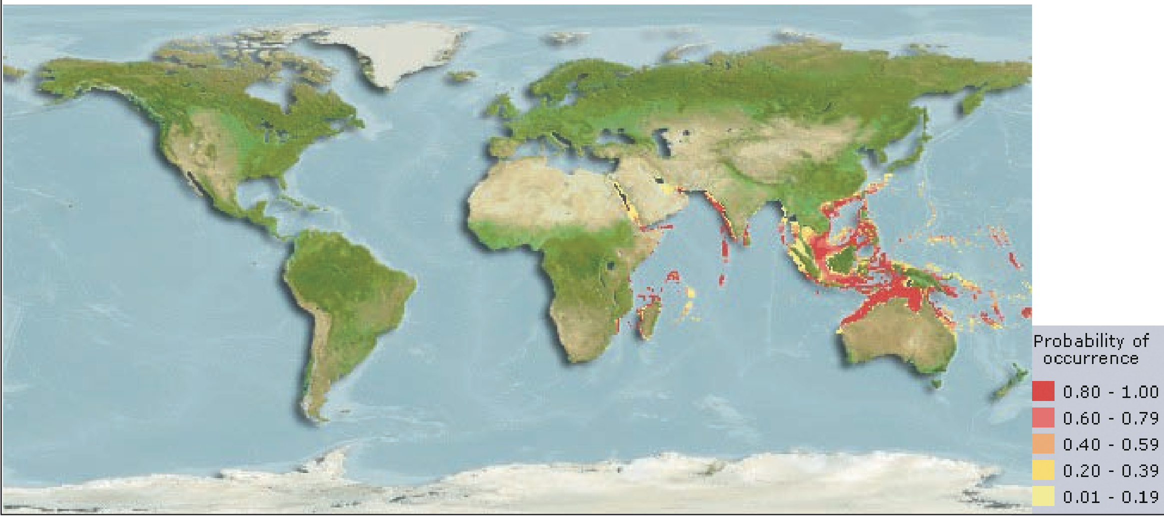
FIGURE 7
Areolate grouper (*Epinephelus areolatus*)

TABLE 4
Characteristics of the areolate grouper, *Epinephelus areolatus*

Common names:	Areolate grouper
Size and age:	47.0 cm TL; max. published weight: 1 400 g; max. reported age: 15 years
Environment:	Reef-associated; marine; depth range 6–200 m
Climate:	Tropical; 35°N - 33°S, 29°E - 180°E
Importance:	An important fisheries and aquaculture species in the Live Reef Fish Trade (LRFT).
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Usually found in seagrass beds or on fine sediment bottoms near rocky reefs, dead coral, or alcyonarians, in shallow continental shelf waters. Juveniles are common at water depths to 80 m. Probably spawn during restricted periods and form aggregations when doing so. Eggs and early larvae are probably pelagic. Feed on fish and benthic invertebrates, primarily prawns and crabs.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 8
Distribution of *of Epinephelus areolatus* (FishBase, 2007)



Epinephelus awoara (Temminck & Sclegel 1842)

FIGURE 9
Yellow grouper (*Epinephelus awoara*)

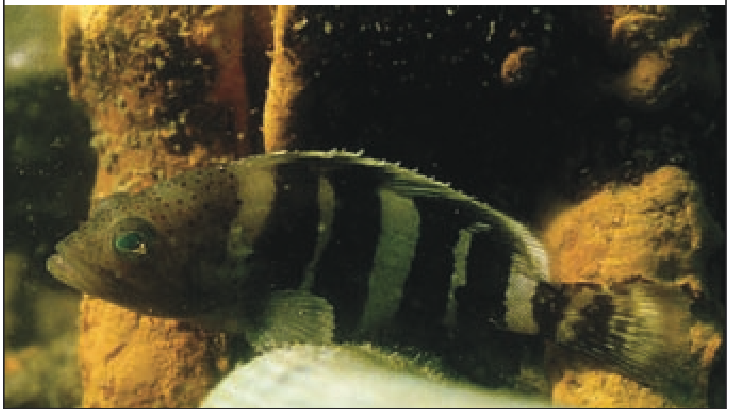


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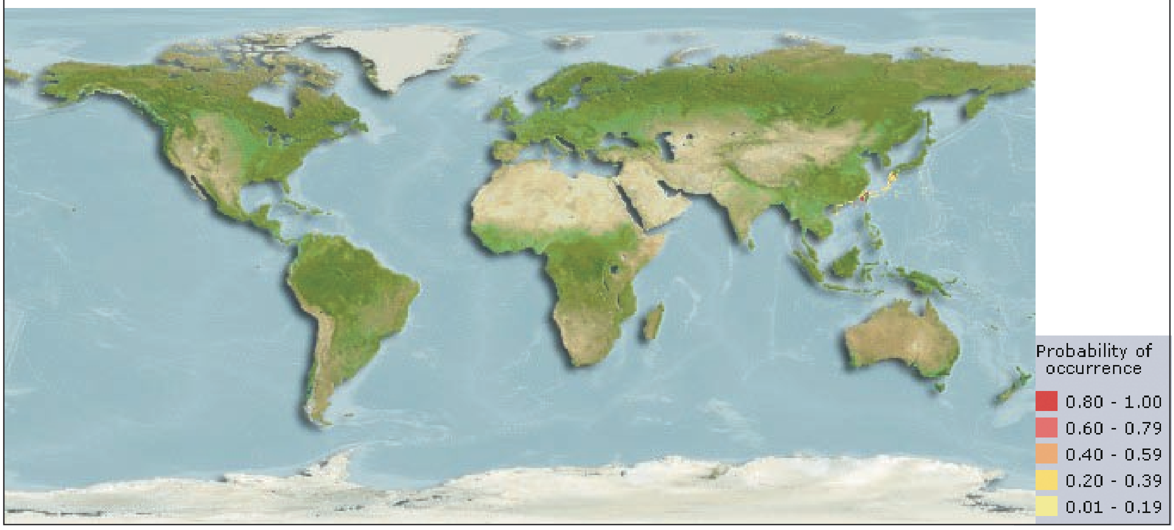
TABLE 5
Characteristics of the yellow grouper, *Epinephelus awoara*

Common names:	Yellow grouper
Size and age:	60.0 cm TL
Environment:	Reef-associated; marine; depth range 10–50 m
Climate:	tropical; 39°N - 12°N, 110°E - 143°E
Importance:	Commercial fisheries and aquaculture; medium value in China Hong Kong SAR live fish markets.
Resilience:	High, minimum population doubling time less than 15 months (Fecundity = 24 329).
Biology and ecology:	Occurs in rocky areas as well as on sandy-mud bottoms. Juveniles are common in tide pools. In captivity, the species is aggressive, chasing and biting other species, especially members of its own species. Protogynous hermaphrodite. Artificial fertilization of eggs was done and the longest survival time for the larvae was 15 days.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 10
Distribution of *Epinephelus awoara* (FishBase, 2007)



Epinephelus bleekeri (Temminck & Sclegel 1842)

FIGURE 11
Duskytail grouper (*Epinephelus bleekeri*)

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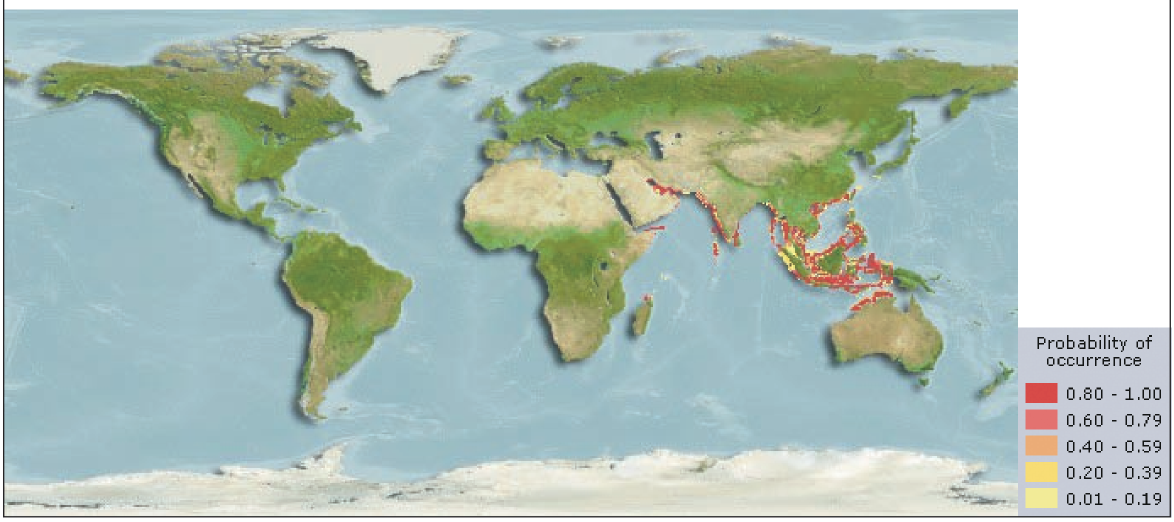
TABLE 6
Characteristics of the duskytail grouper, *Epinephelus bleekeri*

Common names:	Duskytail grouper
Size and age:	76.0 cm TL
Environment:	Demersal; marine; depth range 30–104 m
Climate:	Tropical; 32°N - 17°S, 48°E - 136°E
Importance:	Minor commercial fisheries value, moderate commercial aquaculture value. In China Hong Kong SAR live fish markets.
Resilience:	Low, minimum population doubling time 4.5–14 years (t max=24).
Biology and ecology:	Occurs on shallow banks, but is not known from well-developed coral reefs. Usually taken by trawling in 30–45 m or by hand-lining over rocky banks.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 12
Distribution of *Epinephelus bleekeri* (FishBase, 2007)



Epinephelus bruneus (Bloch, 1793)

FIGURE 13
Longtooth grouper (*Epinephelus bruneus*)

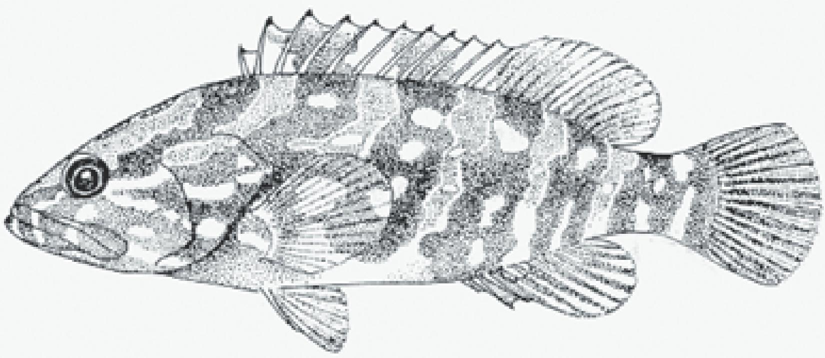


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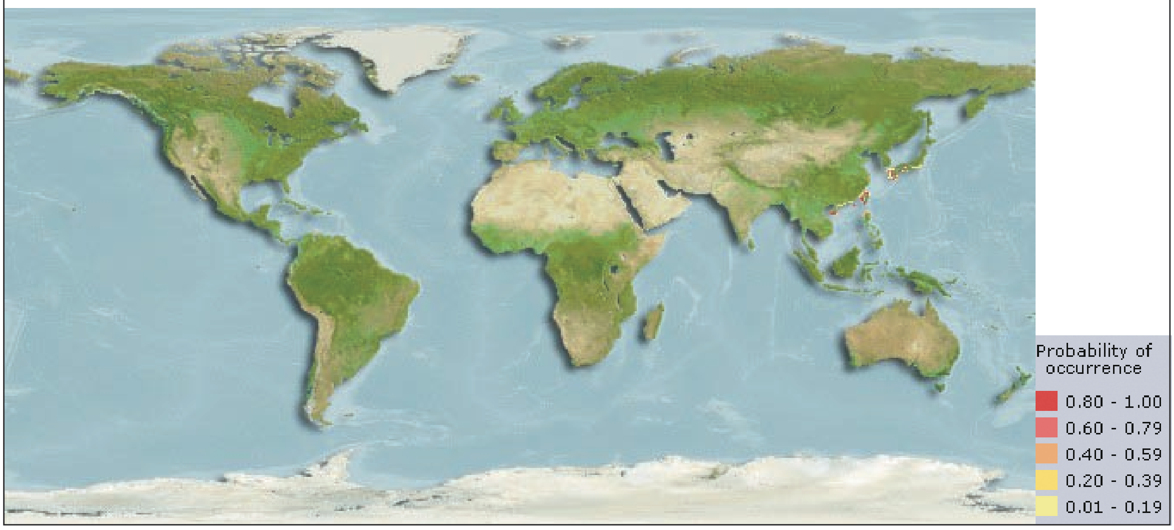
TABLE 7
Characteristics of the longtooth grouper, *Epinephelus bruneus*

Common names:	Longtooth grouper
Size and age:	128 cm TL (male/unsexed; Ref. 40637); max. published weight: 33.0 kg (Ref. 40637)
Environment:	Reef-associated; marine; depth range 20–200 m
Climate:	Tropical; 38°N - 17°N, 108°E - 142°E
Importance:	Important in commercial and recreational fisheries. Commercially cultured in Japan and China Hong Kong SAR.
Resilience:	Very low, minimum population doubling time more than 14 years.
Biology and ecology:	Inhabits rocky reefs; also found on muddy grounds. Juveniles occur in shallow waters.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 14
Distribution of *Epinephelus bruneus* (FishBase, 2007)



Epinephelus coioides (Hamilton, 1822)

FIGURE 15
Orange-spotted grouper (*Epinephelus coioides*)

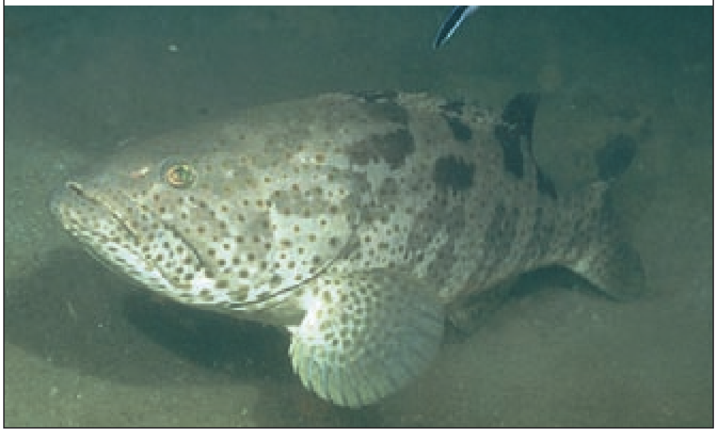


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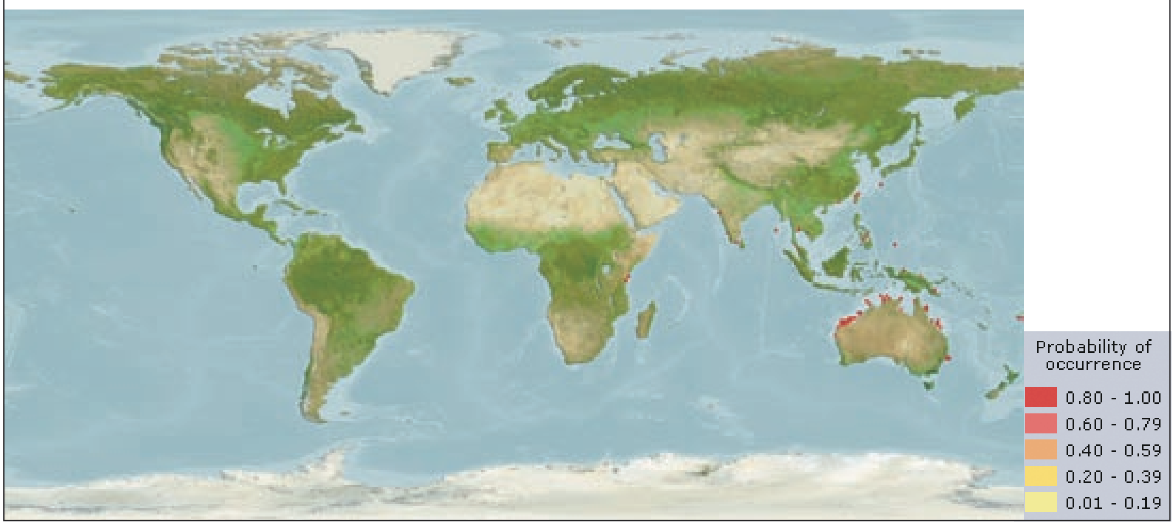
TABLE 8
Characteristics of the orange-spotted grouper, *Epinephelus coioides*

Common names:	Orange-spotted grouper, estuary grouper, green grouper
Size and age:	120 cm TL (male/unsexed; Ref. 47613); max. published weight: 15.0 kg (Ref. 11228); max. reported age: 22 years
Environment:	Reef-associated; brackish; marine; depth range 2–100 m
Climate:	Subtropical; 37°N - 34°S, 28°E - 180°E
Importance:	Important for commercial fisheries and aquaculture throughout Southeast Asia; major species in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.17; tmax=22).
Biology and ecology:	Inhabit turbid coastal reefs and are often found in brackish water over mud and rubble. Juveniles are common in shallow waters of estuaries over sand, mud and gravel and among mangroves. Feed on small fishes, shrimps, and crabs. Probably spawn during restricted periods and form aggregations when doing so. Eggs and early larvae are probably pelagic.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 16
Distribution of *Epinephelus coioides* (FishBase, 2007)



Epinephelus fuscoguttatus (Forsskål, 1775)

FIGURE 17
Brown-marbled grouper (*Epinephelus fuscoguttatus*)

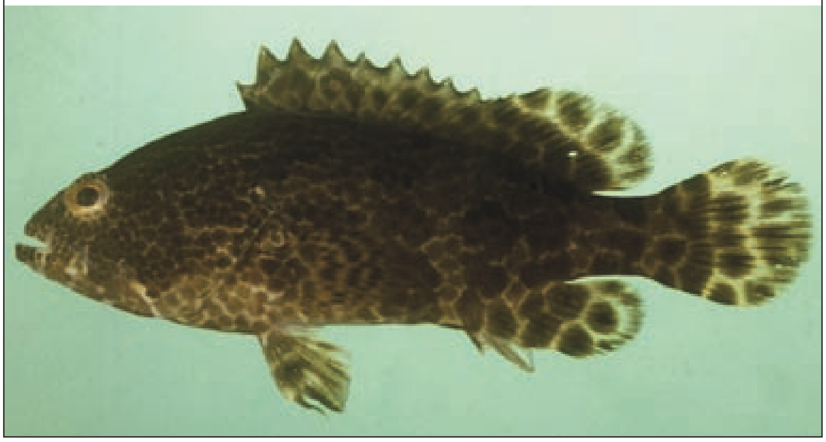


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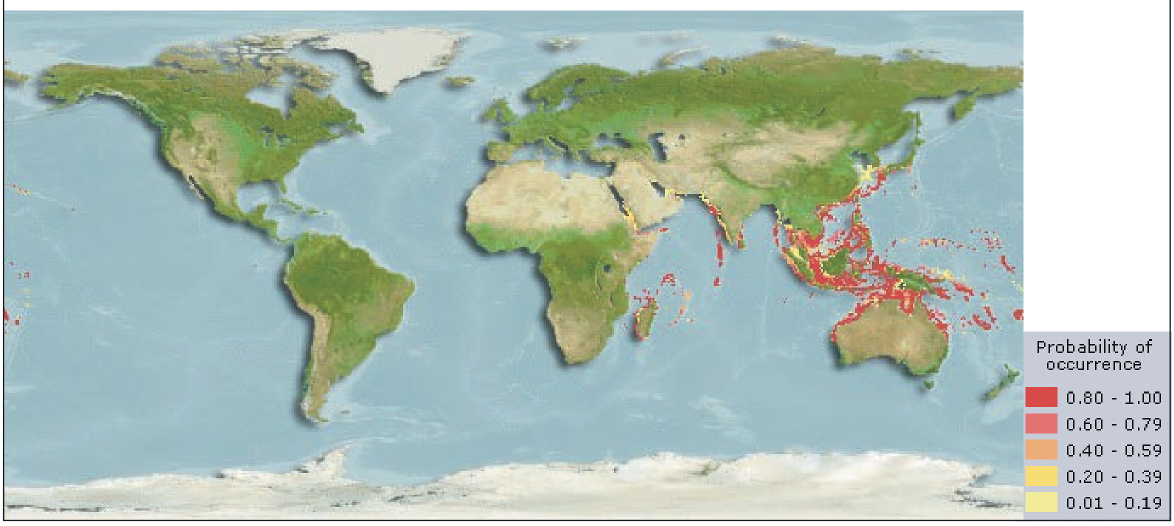
TABLE 9
Characteristics of the brown-marbled grouper, *Epinephelus fuscoguttatus*

Common names:	Brown-marbled grouper, tiger grouper, dusky grouper, flowery grouper, flowery cod
Size and age:	120 cm TL; max weight 35.0 kg, max. age >40 years
Environment:	Reef-associated; marine; depth range 1–60 m
Climate:	Tropical; 35°N - 27°S, 39°E - 171°W
Importance:	Minor commercial fisheries, moderate importance in aquaculture and live reef fish trade. Cultured in Singapore, Philippines and Indonesia.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.16-0.20).
Biology and ecology:	Occurs in lagoon pinnacles, channels, and outer reef slopes, in coral-rich areas and with clear waters. Juveniles in seagrass beds. Feeds on fishes, crabs, and cephalopods. May be ciguatoxic in some areas. Mainly active at dusk.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 18
Distribution of *Epinephelus fuscoguttatus* (FishBase, 2007)



Epinephelus lanceolatus (Bloch, 1790)

FIGURE 19
Giant grouper (*Epinephelus lanceolatus*)

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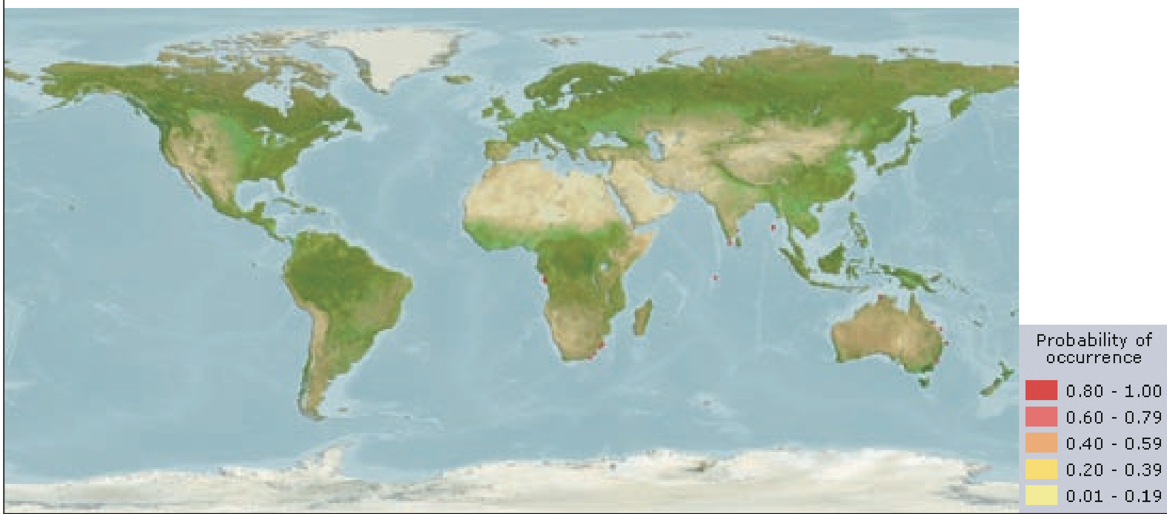
TABLE 10
Characteristics of the giant grouper, *Epinephelus lanceolatus*

Common names:	Giant grouper, Queensland grouper
Size and age:	270 cm TL; max. published weight: 455.0 kg
Environment:	Reef-associated; brackish; marine; depth range 1–100 m
Climate:	Tropical; 28°N - 39°S, 24°E - 122°W
Importance:	Important in subsistence fisheries, commercial aquaculture, recreational gamefish. Cultured in Taiwan PC. In live reef fish markets. Juveniles sold in ornamental trade as "bumblebee grouper".
Resilience:	Very low, minimum population doubling time more than 14 years.
Biology and ecology:	The largest bony fish found in coral reefs. Common in shallow waters. Found in caves or wrecks; also in estuaries, from shore and in harbours. Juveniles secretive in reefs and rarely seen. Feeds on spiny lobsters, fishes, including small sharks and batoids, and juvenile sea turtles and crustaceans. Nearly wiped out in heavily fished areas. Large individuals may be ciguatoxic.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 20
Distribution of *Epinephelus lanceolatus* (FishBase, 2007)



Epinephelus malabaricus (Bloch and Schneider, 1801)

FIGURE 21
Malabar grouper (*Epinephelus malabaricus*)

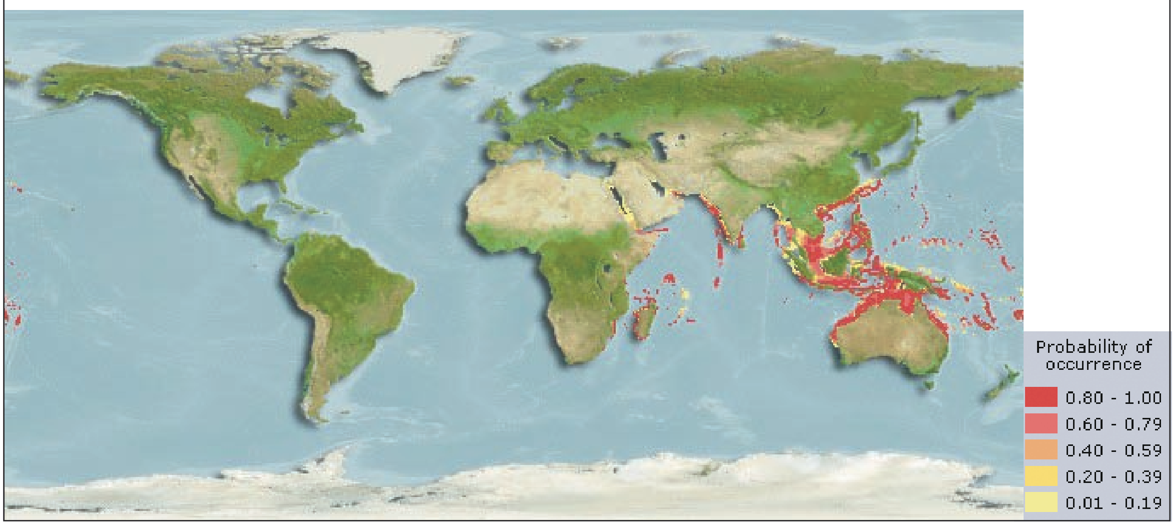
COURTESY OF D. FIRST

TABLE 11
Characteristics of the Malabar grouper, *Epinephelus malabaricus*

Common names:	Malabar grouper, estuary grouper, green grouper
Size and age:	234 cm TL; max. published weight: 150.0 kg
Environment:	Reef-associated; amphidromous; brackish; marine; depth range 0–150 m
Climate:	Tropical; 30°N - 32°S, 29°E - 173°W
Importance:	High value commercial and recreational fisheries and aquaculture. Cultured throughout Asia. Along with *E. coioides*, the most common species in live reef fish markets.
Resilience:	Very low, minimum population doubling time more than 14 years. Listed as Near Threatened (NT) by the IUCN Grouper and Wrasse Specialist Group.
Biology and ecology:	A common species found in a variety of habitats: coral and rocky reefs, tide pools, estuaries, mangrove swamps and sandy or mud bottom from shore to depths of 150 m. Juveniles found near shore and in estuaries; sex reversal probable. Feeds primarily on fishes and crustaceans, and occasionally on cephalopods.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 22
Distribution of *Epinephelus malabaricus* (FishBase, 2007)



Epinephelus quoyanus (Valenciennes, 1830)

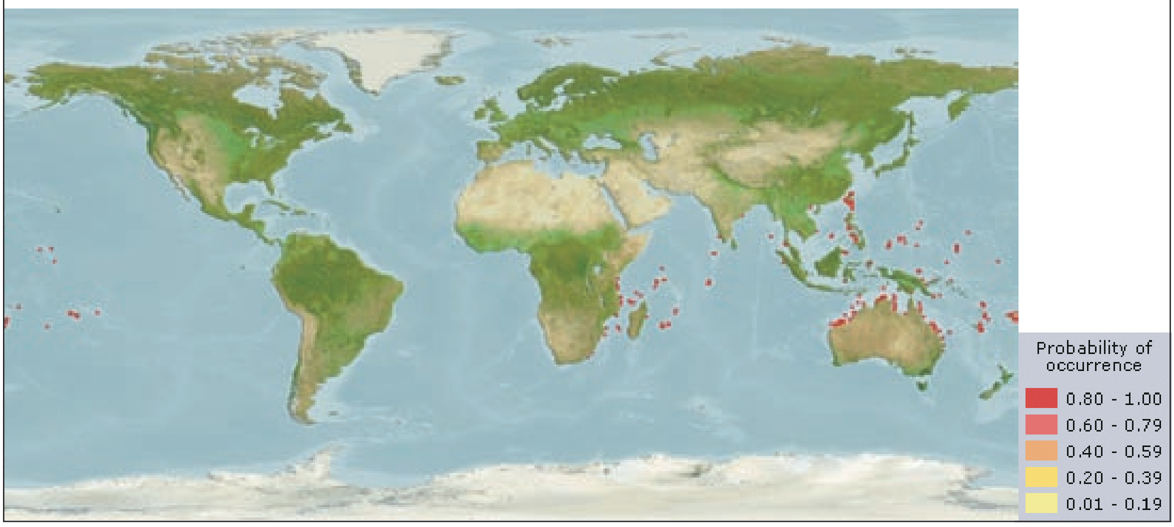
FIGURE 23
Longfin grouper (*Epinephelus quoyanus*)

TABLE 12
Characteristics of the longfin grouper, *Epinephelus quoyanus*

Common names:	Longfin grouper
Size and age:	40.0 cm TL
Environment:	Reef-associated; marine; depth range 0–50 m
Climate:	Tropical; 35°N - 32°S, 110°E - 156°E
Importance:	Commercial fisheries and minor aquaculture; in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Inhabits inshore silty reefs; there are no records from depths greater than 50 m. Feeds on crustaceans, fishes, and worms. The enlarged fleshy pectoral fins appear to have resulted from its habit of sitting on the substrate.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 24
Distribution of *Epinephelus quoyanus* (FishBase, 2007)



Epinephelus sexfasciatus (Valenciennes, 1828)

FIGURE 25
Sixbar grouper (*Epinephelus sexfasciatus*)

TABLE 13
Characteristics of the sixbar grouper, *Epinephelus sexfasciatus*

Common names:	Sixbar grouper, six-banded grouper
Size and age:	40.0 cm TL
Environment:	Reef-associated; marine; depth range 10–80 m
Climate:	Tropical; 21°N - 21°S, 94°E - 143°E
Importance:	Fisheries: commercial.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.16).
Biology and ecology:	Common on silty sand or mud bottoms. Its preference for soft-bottom habitats may account for its restricted distribution and absence at oceanic islands. Feeds on small fishes and crustaceans.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 26
Distribution of *Epinephelus sexfasciatus* (FishBase, 2007)

Epinephelus trimaculatus (Valenciennes, 1828)

FIGURE 27
Threespot grouper (*Epinephelus trimaculatus*)

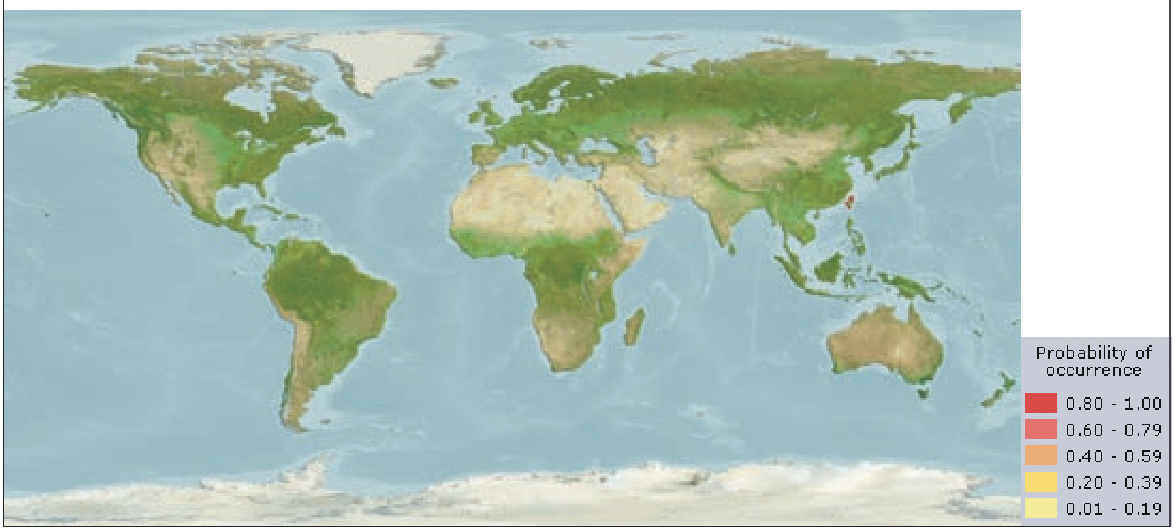
COURTESY OF A. CORNISH

TABLE 14
Characteristics of the threespot grouper, *Epinephelus trimaculatus*

Common names:	Threespot grouper
Size and age:	40.0 cm SL
Environment:	Reef-associated; marine
Climate:	Tropical; 37°N - 20°N, 112°E - 143°E
Importance:	Commercial fisheries and minor aquaculture. In China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Juveniles are common in tide pools and in shallow clear water around rocks and coral reefs; adults found in deeper water.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 28
Distribution of *Epinephelus trimaculatus* (FishBase, 2007)



Plectropomus leopardus (Lacepède, 1802)

FIGURE 29
Leopard coralgrouper (*Plectropomus leopardus*)

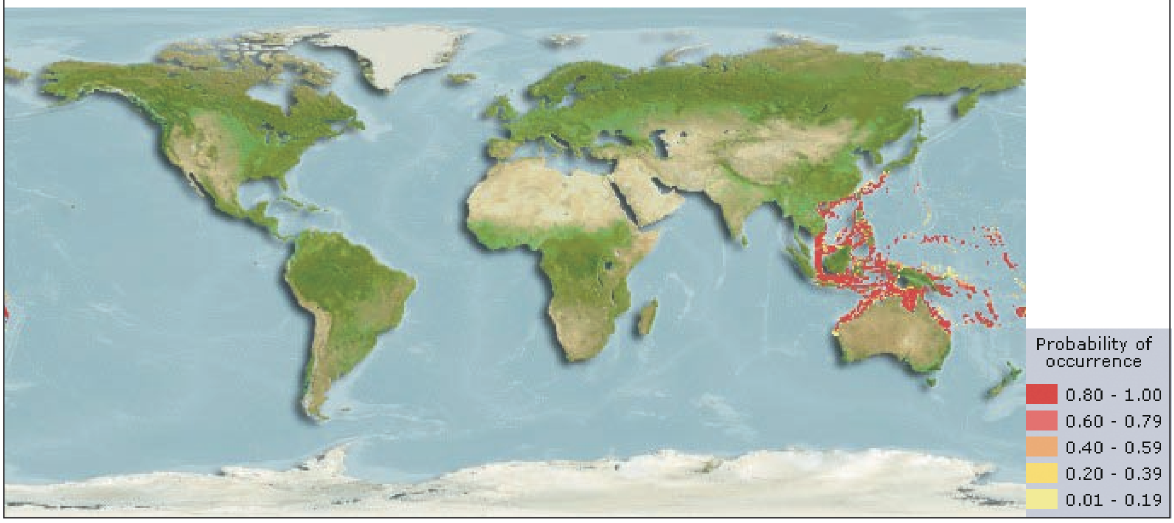
COURTESY OF J.E. RANDALL

TABLE 15
Characteristics of the leopard coralgrouper, *Plectropomus leopardus*

Common names:	Leopard coralgrouper, coral trout
Size and age:	120 cm SL; max. published weight: 23.6 kg; max. reported age: 26 years. On the Great Barrier Reef, lifespan is 14 years.
Environment:	Reef-associated; marine; depth range 3–100 m
Climate:	Tropical; 24; 35°N - 30°S, 106°E - 178°W
Importance:	Commercial and recreational fisheries and aquaculture, juveniles in ornamental trade.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (tm = 2–4; tmax = 26; Fecundity = 457 900). Listed as Near Threatened by IUCN Grouper and Wrasse Specialist Group.
Biology and ecology:	Inhabit coral-rich areas of lagoon reefs and mid-shelf reefs. Juveniles in shallow water in reef habitats, especially around coral rubble. Adults piscivorous. Juveniles feed on small fish and invertebrates such as crustaceans and squid. A protogynous hermaphrodite forming spawning aggregations on a reef around the new moon.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 30
Distribution of *Plectropomus leopardus* (FishBase, 2007)



Plectropomus maculatus (Bloch, 1790)

FIGURE 31
Spotted coral grouper (*Plectropomus maculatus*)

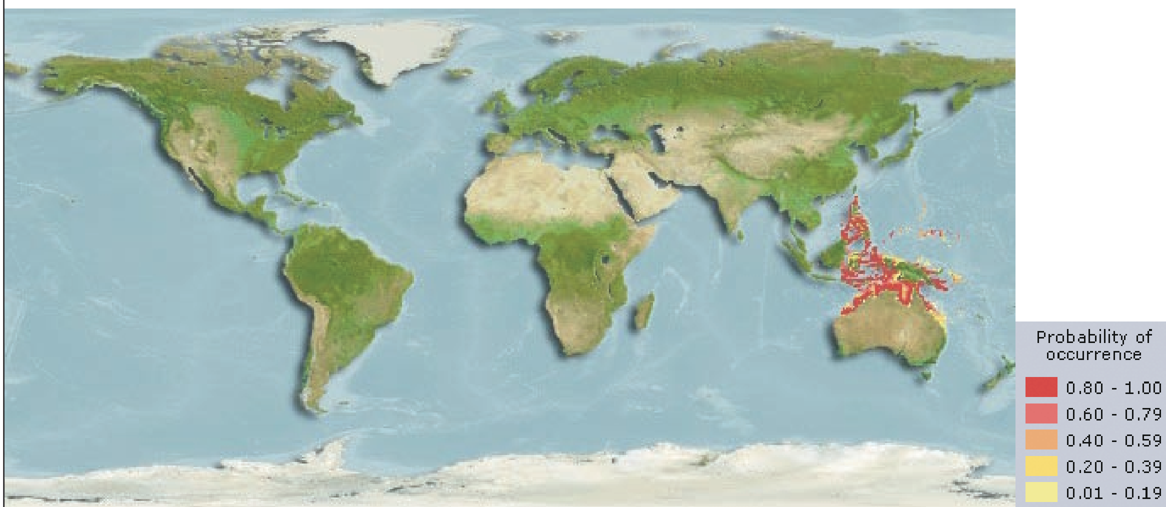
COURTESY OF J.E. RANDALL

TABLE 16
Characteristics of the spotted coralgrouper, *Plectropomus maculatus*

Common names:	Spotted coral grouper, spotted coral trout
Size and age:	100.0 cm SL; max. published weight: 25.0 kg
Environment:	Reef-associated; marine; depth range 5–100 m
Climate:	Tropical; 21°N - 28°S, 117°E - 159°E
Importance:	Commercial and recreational fisheries and aquaculture. In China Hong Kong SAR live fish markets. Commonly used for food. Its flesh is delicate and well appreciated.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.21; tm=2–3).
Biology and ecology:	Found in protected coastal reef in mixed algae and coral habitat Common on inshore coastal reefs but absent in clear offshore reefs. Juveniles in shallow water in reef habitats, especially around coral rubble. Migrate over short distances to spawn, forming aggregations.

Source: Modified from FishBase (Froese and Pauly, 2007).

FIGURE 32
Distribution of *Plectropomus maculatus* (FishBase, 2007)



Trends in production of cultured grouper

Groupers are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, China Hong Kong SAR, the southeast of China and Viet Nam (Sadovy, 2000). Grouper culture is also undertaken in India, Sri Lanka, Kingdom of Saudi Arabia, Republic of Korea, Australia, the Caribbean as well as in the southeastern United States of America.

Despite the huge popularity of live fish in China and Southeast Asia, only 15–20 percent of the amount consumed each year comes from aquaculture, as culture is principally constrained by limited and unreliable supplies of wild seed and the difficulties of spawning in captivity. However, hatchery production has increased in recent years (e.g. Taiwan Province of China and Kuwait) (Tucker, 1999). It is difficult to get accurate statistics on farmed grouper production because statistics do not differentiate between those simply being caught from natural sources and held for a few weeks in cages before being sold, and those cultured for a longer period of time (Ottolenghi *et al.*, 2004).

Grouper production through aquaculture is mainly reported by countries in Asia, where over 9 300 tonnes were produced in 2000. The actual figures of grouper production in Southeast Asia are reported by Sadovy (2000) to be far higher, at 23 000 tonnes; however, about 20 percent of this production may be based on hatchery produced fry, while the remainder is from wild seed. Kongkeo and Phillips (2002) estimated Asian production to be around 15 000 tonnes. In each case, these figures are significantly higher than the official statistics published by FAO. According to official statistics, Taiwan Province of China was the leading producer, with nearly 5 100 tonnes (54 percent of the global total). A total of 7 200 tonnes was produced in brackish water in Taiwan Province of China, Malaysia and Thailand. The remaining production was from mariculture a total of 2 100 tonnes, mainly in Indonesia, China Hong Kong SAR and Taiwan Province of China.

Grouper culture systems

There are many different systems used for the culture of groupers worldwide, although there seems to be an agreed set of stages: nursery, transition, and on-growing (Ottolenghi *et al.*, 2004). Grouper seed must be nursed before being cultured to marketable size. The nursery stage is reared either in tanks, net cages and *hapas* (nylon netting enclosures), or in earthen ponds. Grading is a prerequisite to minimize cannibalism, especially in the nursery and early grow-out stages. After nurseries, there are two main systems used for on-growing: pond culture or cage culture. The stocking density and rearing conditions in both nursery and grow-out phases vary, depending on the site, the fish sizes, and the grouper species cultured.

Wild fry (2.5–7.2 cm) or fingerlings (7.5–12 cm) may initially be held in tanks or net cages or earthen ponds for a month or more (nursing period) after harvest (Ottolenghi *et al.*, 2004). The density may range from 100 to 150 fish/m^2, e.g. a net of 2 x 2 x 2 m would hold 400–600 fingerlings. Sorting is undertaken weekly and stock sampling every 2 weeks. Groupers are normally retained in the nursery until they reach about 16 cm, when they are thinned out and transferred to transition nets (5 x 5 x 5 m) that each hold 1 100 fish. The fish are finally transferred to production nets after 2–3 months. Floating cages are often constructed from bamboo poles and polyethylene netting material (25–50 mm mesh size). Net cages are formed by two types of panels: 4 side panels forming the walls, and one bottom panel. The net is secured to the raft structure (bamboo poles) by ropes. Ropes are also used to lash the bamboo poles together. Buoyancy is provided by empty plastic containers attached to the bamboo frames (www.seafdeec.org.ph). Net cages come in several sizes (3 x 3 x 2.5 m; 4 x 4 x 2.5 m; 10 x 10 x 3 m); the mesh size ranges from 10 to 35 mm (Agbayani, 2002). The optimum stocking density averages 120 fish/m^3. Growth to marketable size (600–800 g) takes approximately 8 months, with survival rates of 50 percent or less. Groupers can grow to 600 g in 12 months, to 1 kg within 18 months, and to 2 kg within 24 months (Tucker, 1999).

Harvesting of groupers is relatively simple (Ottolenghi *et al.*, 2004). Selective harvesting of groupers weighing 400–600 g is best. A drag net is placed at the farthest end of the pond or cage, and dragged slowly towards the other end in the early morning. Fish are then transferred to a holding net where grading is carried out; undersized fish are returned to the pond or cage.

FISHERIES FOR JUVENILE GROUPER

Collection of grouper seed

Grouper seed is collected using several different methods, depending on location (Table 17). Capture methods are generally artisanal and the fishermen employ a variety of artificial habitats. Moreover, different fishing gears are used at different times of the year: the gear change follows the growth of the seed and their movement to deeper waters as the season progresses. Gears used to take grouper seed can be divided into 8 different categories: large fixed nets (e.g. fyke nets), traps and shelters, hook and line, scoop and push nets, artificial reefs, fish attractors, tidal pools and chemicals. The sizes of grouper seed caught and traded vary between 1 and 25 cm, i.e. from the moment of settlement to fish that are over one year old. However, most of the catch focuses on fish up to about 15 cm (Sadovy, 2000).

Some grouper seed collection methods are more damaging than others. Clearly destructive methods include those that result in high mortality, involve high levels of

TABLE 17
Overview of seed collection methods for capture-based aquaculture of groupers in Southeast Asia

Gear type	Description	Location	Fish size (cm)
Gango (fish nests)	Conical pile of waterlogged, criss-crossed wood or of rocks, sometimes in combination, together with old car tires, PVC pipe cuttings, bamboo sections, or other shelter materials. Covers 5–10 m², with a 2–3 m diameter or 2.5–3x2–3 m base and 0.5–1.5 m height. The largest may be 5 m diameter at the base.	Philippines	2–15 cm
Fish shelters	Formed by hanging brushes, nets or clusters of grasses, leaves or other materials. Used with or without lights.	Philippines China Thailand	1–3 cm
Fish traps	Vary in shape and size, and in mesh size. The trap frame is made of metal, wood or bamboo.	Indonesia Malaysia Philippines China Taiwan PC Viet Nam	2–25 cm
Fyke net	Big collectors, stationary nets installed in river mouths during high tides. Three mesh sizes are used: larger at the aperture, followed by medium and finer net at the end.	Philippines Thailand Viet Nam	1–15 cm
Hook and line		Indonesia Malaysia Philippines China Taiwan PC Thailand Viet Nam	>7.5 cm
Scissor net	A triangular bamboo frame of various dimensions, which may or may not have "shoes" to assist it in moving over the substrate. Fine meshed netting is attached to the frame and the bamboo poles are crossed over each other.	Philippines Thailand	2.5–15 cm
Miracle hole	Shallow holes are excavated on tidal flats. Sometimes the wall of the hole is built up with rocks.	Philippines	5–10 cm
Temarang	Artificial aggregating device (fish shelter), which consists of a bunch of twigs from wild shrubs; about 20–30 bunches of 50 cm length are tied to a 5 m rope and hung over sandy sea bottom between two poles.	Malaysia	2–2.5 cm

Source: Modified from Ottolenghi *et al.*, 2004.

bycatch, cause damage to the fish habitat and/or result in monopolization of the local fishery by a few individuals. Destructive methods include scissor nets and fyke nets, which are already banned in some areas. Lift nets are also destructive, particularly in terms of bycatch. Gangos, miracle holes and other types of artificial shelters and seed aggregation devices do not possess the above drawbacks. Methods that target postlarvae seem less likely to deplete wild stocks because of the high natural mortality that probably characterizes this stage in the wild (Johannes and Ogburn, 1999; Sadovy, 2000).

Mortality rates from catching to stocking

Seed quality depends on the type of fishing gears used, and there are significant differences in seed mortality rates. Mortality rates associated with fish traps are usually low. For example, the use of "*Bubu*" (fish traps used in Malaysia) cause a 5 percent mortality rate, while artificial aggregators such as *Temarang* (also used in Malaysia) cause 3 percent mortality. Other catching methods, like scissor nets and fyke nets, can generate a high mortality. "*Pompang*" (fyke net) and "*Wunron*" (push/scissor net), which are used in Thailand, are reported to cause 20–30 percent and 80 percent mortality rates, respectively (Sadovy, 2000). It is likely that subsequent mortalities during transport and stocking will also be high, as many of the seed fish will also have been damaged, and are therefore susceptible to stress and disease.

The problems that arise during seed transport to the net cages or to the middleman/farmer/exporter, depend on seed size, quality, fitness and the locality. For transport over short distances, in Thailand, for example, "seeds" are placed in styrofoam boxes or buckets, with or without aeration (often provided by middlemen), or with holes in the bottom for water exchange.

Transport time is typically from about 10 minutes up to two hours. Post-harvest mortality is low. For longer transit periods, fish are packed in 23–25°C seawater with aeration. Transport densities are about fifty 7.5 cm fish per bag, or one hundred 1 cm fish/l, or two to three hundred 3–7.5 cm fish per bucket. For a 7-hour journey, ice can be used to keep the water cool. Some exporters use an anaesthetic, either quinaldine or MS222, but consider the latter to be rather expensive. The use of anaesthetic is considered important to reduce the likelihood of spines piercing the plastic transport bag. For export, fish are packed into styrofoam boxes of various sizes; each shipment has about 20 000 fish in 30 boxes (Sadovy, 2000).

In the Philippines, approximately 10 percent of the seed caught is used domestically, while the remainder is exported. There can be significant mortalities during local transportation. The movement of seed from the catchers to the middlemen or the farmers is carried out by keeping fish in plastic containers or basins with holes for water circulation. Mortality rates are quite low under such circumstances. If destined for trade, the fish may be maintained for short periods by the middleman, prior to packing and shipping, either domestically or internationally. In some cases, they may be transferred temporarily (for a few days) to an "aquarium box" to await buyers who come to collect fish and who are responsible for the export of the fry. Mortality rates can reach 10–20 percent at this stage, i.e. prior to selling to buyers for export or domestic trade (Sadovy, 2000). Mortality rates are low if the transit time is less than an hour. However, for longer periods, if there is no aeration or frequent water changes, mortality increases and oxygen may have to be added. Buyers pack fry in double plastic bags with pre-cooled water using ice (18–22°C) and a salinity of 15–18 ppt. 2.5 cm "seeds" are packed 400–500 per box and 7.5–10 cm "seeds" are packed 20–40 per box (Sadovy, 2000).

The mortality rates that follow capture and transport are not exactly known; estimates for over the first 2 months after catching are quite variable (30–70 percent), depending on the quality of fry, the level of transport stress, and the presence of disease and cannibalism (Pudadera, Hamid and Yusof, 2002). According to a report from the Secretariat of the Pacific Community (www.spc.org.nc/coastfish/News/LRF/5/15GrouperHK.htm), the survival rate for imported fry is low, at 10–20 percent.

AQUACULTURE DEPENDENCY ON WILD SEED

Generally, groupers spawn on offshore reefs where they form aggregations of hundreds to tens of thousands of individuals, in a few specific locations (Johannes *et al.*, 1999; Rhodes and Sadovy, 2002). They produce pelagic larvae that may disperse over hundreds of kilometres in the course of 30–45 days and experience high density-independent mortality. However, recent research suggests that groupers and other reef fishes may have greater control over their distribution than previously thought, and that at least some proportion of the gametes spawned may be retained near their natal reef (Jones *et al.*, 1999; Jones, Planes and Thorrold, 2005; Swearer *et al.*, 1999). Larvae, transported to near-shore nursery habitats settle as juveniles in sea-grass beds, mangroves, algal beds, coral rubble, oyster reefs and marshes (Coleman *et al.*, 1999; Tupper, 2007). For this reason grouper seed is mainly caught in coastal areas, particularly around sea-grass, mangrove and shallow brackish water areas near river mouths and estuaries, as well as in tidal pools, tidal channels and around reefs.

The peak grouper seed season is often associated with the relatively wet months in the year (e.g. monsoon seasons); in several areas, grouper seed collectors have claimed that their best catches were associated with strong onshore winds (Johannes and Ogburn, 1999). This is consistent with a number of recent studies into recruitment pulses of settlement-stage reef fish – including groupers – that accompanied cyclonic storms, which apparently caused the fish to be transported shoreward (Shenker *et al.*, 1993; Dixon, Millich and Sugihara, 1999).

Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible. For this reason, approximately 66–80 percent of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). The volume of seed caught each year exceeds hundreds of millions of individuals (Sadovy, 2000). The greatest catches tend to be of the smallest size classes (1–3 cm); during peak seasons a catch can be of tens of thousands by a single unit of gear, in a single night, by one fisherman (e.g. using a fyke net). Even larger sizes of fish are being captured in massive numbers region-wide each year. It is important to realize that the equivalent of the typical annual amount of seed produced in the hatcheries in the whole of Southeast Asia (excluding Taiwan Province of China), i.e. 20 000 to 80 000 fry, can be caught by one fisherman in one night (Sadovy, 2000).

When seed catches are compared to the numbers of marketable fish produced, the results strongly suggest crude and wasteful culture practices. Sadovy (2000) estimated that about 60 million seed fish are needed produce the regional total of 23 000 metric tonnes of table-size live fish from culture annually.

FISH FEED

As with all culture systems, there are many local variations in the feeds and feeding regimes utilized. There appears to be no universal system, and local availability seems to be the key criteria in developing a feeding schedule (Ottolenghi *et al.*, 2004). Fry and fingerlings are fed with mysids and small shrimp for a couple of days post-capture in tanks, to acclimatize them and check that all individuals are eating. Trash fish forms the main feed in nursery and production cages, which is minced or chopped to suit each size group; trash fish may be supplemented with vitamins and minerals. This kind of feed is gradually being replaced by moist pelleted feed.

Trash fish is commonly used for feeding in grouper cage culture, but its increasing cost, shortage of supply, variable quality and poor feed conversion ratios indicate that this form of feed may not be the best from either a nutritional or an economic point of view. However, groupers fed with bycatch (trash fish) in a study by Bombeo-Tuburan, Kanchanakhan and China (2001) fared significantly better in terms of final length and total production than when fed other diets (live tilapia, formulated diet).

A major problem is the limited supply of trash fish, so there is a need to develop a suitable diet for grow-out grouper production (Millamena, 2002). Fishery products, both in the form of low value trash fish or fishmeal, are presently the major sources of protein in the grow-out culture of most fish species and constitute up to 70 percent of their dietary composition. As the demand for fishmeal and fish oil for aquaculture increases, costs are expected to rise unless new sources (e.g. fish discards, krill, mesopelagics) can be economically exploited or substitutes for these marine products for inclusion in aquafeeds prove commercially applicable (New and Wijkstrom, 2002).

A dependable supply of cost-effective, non-marine, sources of alternative protein must be provided if fish farming is to remain profitable. Millamena (2002) conducted a feeding trial to evaluate the potential of replacing fishmeal with processed animal by-product meals, meat meal and blood meal, in practical diets for juvenile groupers (*Epinephelus coioides*). The study demonstrated that up to 80 percent of fishmeal protein can be replaced by processed meat and blood meal derived from terrestrial animals with no adverse effects on growth, survival, and food conversion ratio (FCR). From an economic standpoint, replacement of fishmeal with cheaper animal by-product meals in practical diets can alleviate the problem of low fishmeal availability and high costs. These processed by-products can be delivered in the Philippines, for example, at US$0.40/kg, less than half the price of most commercial fishmeals (US$1/kg). The effective use of meat meal-based diets for grouper grow-out also reduces the requirements for trash fish, another fishery resource that is extensively used (Millamena, 2002). Economic sensitivity analysis showed that a combination of improvements resulted in higher return-on-investment (ROI). However, these apparently favourable results must be balanced with the fact that some countries (e.g. in the EU) have banned the inclusion of all terrestrial meat-meal based products in fish feeds, due to fears concerning mad-cow disease (Ottolenghi *et al.*, 2004).

ENVIRONMENTAL IMPACTS OF THE JUVENILE GROUPER FISHERY

Mous *et al.* (2006) conducted a pilot study in Indonesia of artificial shelters (*gangos*), to determine the sizes and capture rates of species of interest to the live fish trade, and to determine the likely environmental footprint of a gango type of capture method. From the results of the 15-month study, they drew inferences regarding the sustainability of this fishing method and requirements of space, fish and materials for a viable grow-out operation. The results showed that gangos were unselective for either species or size. Only 1.4 percent of the total fish catch (by number) were target species, mainly the grouper *Epinephelus coioides*, and most were large enough (mean total length was 13.6 cm) to have bypassed the early high mortality phase. Moreover, there were large non-target catches that included many food fish species too small to be useful in catches. Assuming that a soak-time of 3 months results in an average catch per gango of 6.6 *E. coioides* (as was observed for this species in Terang Bay, the most productive of the four sites), yearly production per gango would amount to 26.4 fish. Even a small local grow-out industry with a capacity of 25 tonnes would require an annual supply of 80 000 fish, assuming a grow-out weight of 0.6 kilogram and 50 percent mortality from fingerling stage to market-ready product. This would require deployment of an estimated minimum of 3 000 gangos.

With such figures in mind, Mous *et al.* (2006) estimated of the space needed to accommodate sufficient gango deployment and suggested that a sizeable fish culture industry based on capture of fry, fingerlings and juveniles from the wild would have a large ecological footprint. For example, the 3 000 gangos estimated to support a

25 tonnes grow-out operation, would require approximately 300 000 m^2 (assuming that each gango requires a plot of 10 x 10 m) or 30 kilometres of coastline (assuming that gangos are deployed in a single line following the optimum depth contour). In other words, juvenile supply would require 1.2 hectares of shallow coastal waters for each tonne produced.

Given the large number and area of gangos needed for a viable operation, and that many groupers captured could probably have survived to reproduce, the ecological footprint of this approach could be substantial (Mous *et al.*, 2006). These results, and literature on other juvenile fisheries, suggest that CBA sources of seed such as gangos may often need management, have important links to other capture fishery sectors, and require careful evaluation of potential costs and benefits before introduction or development.

Support for grouper CBA is often based on the assumption that the natural morality of early juvenile grouper is very high, so that the fishery is not adding substantially to this natural mortality and therefore not affecting adult population size to any great extent. This assumption remains untested for grouper species. As Sadovy (2001b) points out, the critical question is how early do juvenile mortality rates decline to adult levels? If early mortality is high, then removal of some post-settlement fish for culture may have little impact on adult numbers, since the probability of survival of any individual fish is low. However, recent research suggests that the period of very high mortality occurs during and immediately after settlement, and that fish surviving more than a few days have a much higher chance of survival. Tupper (2007) estimated the cumulative mortality of early juvenile (2.5–5.0 cm TL) *Plectropomus areolatus* and *Epinephelus polyphekadion* in their preferred nursery habitats to be around 50–75 percent over the first 3 months post-settlement. Assuming an exponential rate of decline in mortality, the instantaneous mortality at 3 months post-settlement would be much lower than 50 percent. Indeed, mortality rates of post-settlement juveniles may not be substantially greater than adult mortality (estimated at 20–30 percent for most groupers, e.g. Posada and Appledoorn, 1996) and are likely much lower than the estimates of >90 percent mortality often suggested for newly settled reef fishes. If each individual has a 50 percent chance of surviving the first 3 months after settlement, then removal of large numbers of juveniles will almost certainly have an impact on adult population size. This could result in direct conflicts with the adult capture fishery and could accelerate overfishing of groupers.

In addition to problems of bycatch, wasteful mortality, and overfishing, cage and net culture can create other environmental problems, most notably point-source pollution which can have adverse effects on coastal waters, and particularly on coral reefs. For example, in 1994, researchers in Barbados noted complete bleaching and eventual death of coral patch reefs in the vicinity of a cage culture operation for dolphin fish (*Coryphaena hippurus*). Disease transfer is another problem exacerbated by the complex and extensive trade in live fish between Asian countries.

SOCIAL AND ECONOMIC IMPACTS OF GROUPER FARMING

Despite the growing importance of grouper aquaculture as both an alternative to wild caught grouper for the LRFT, and as an alternative livelihood for fishers engaged in destructive fishing practices, relatively little is known about the social and economic impacts of grouper farming, and the broader socio-economic context in which it takes place. Studies have focused on the trade of live reef fish which fuels the fishery for grouper and provides an incentive for grouper aquaculture.

The trade in live reef fish

The trade in live reef fish, whereby fish are transported live from the capture location to restaurants and supermarkets, began in China in the 1960s when a few marine species were to be found in the live fish markets of China Hong Kong SAR, and has expanded rapidly since the early 1990s. The preference for keeping fish alive until minutes before cooking and consumption has been popular for centuries in Chinese culture, and until recently this demand for live fish was supplied by locally caught species. A preferred species for consumption was the red grouper, *Epinephalus akaara*, until overfishing of both adults and later fingerlings for culture in China Hong Kong SAR waters led to severe depletion of local stocks, forcing fishermen and the LRFT industry further afield to seek out supplies to meet local demand for market size fish. In the mid-1970s fishing boats began to exploit Philippine waters, and later the islands of Indonesia, before moving on to the Pacific Islands (e.g. Papua New Guinea, the Solomon Islands), Australia's Great Barrier Reef, and the Maldives (Johannes and Riepen, 1995). Thailand is now also an important contributor to the LRFT. The trade supplies a luxury, niche market. Live reef fish are described as being "high-value-to-volume" and can fetch US$5 to US$180 per kilogram, considerably more than dead reef fish (Sadovy *et al.*, 2003). Highly valued species such as *Cheilinus undulatus*, or humphead wrasse, can fetch a price of up to US$200 per kilogram (Lau and Parry-Jones, 1999).

China Hong Kong SAR is the hub of the live reef fish trade, and the destination for much of the wild-caught and cultured grouper in the region. Approximately 60 percent of internationally traded live reef fish are exported to China Hong Kong SAR (Sadovy and Vincent, 2002), representing approximately 15 000 to 20 000 tonnes per year at a value of US$350 million (Muldoon and MacGilvray, 2004). Accurate volumes of trade for individual species are difficult to estimate, as exports are not disaggregated at the species level and much of the trade goes unreported (Sadovy *et al.*, 2003).

The market network linking farmers to consumers is relatively long and complex, frequently crossing international boundaries, with ownership changing repeatedly. Grouper farmers obtain fry fish from their own fish catch, purchase from local fry fishers, private or government hatcheries. It is common for fry fishers who do culture grouper to sell their catch to a middleman, who may support a group of ten to thirty fishers. The fry are then either sold locally to farmers for on-growing or transported directly to export centres for shipping to other countries in the region. Grouper from grow-out operations are also predominantly destined for the export market, although there is also a growing domestic market in many countries where grouper are becoming increasingly popular on the menus of local seafood restaurants throughout Southeast Asia.

Social impact of grouper fry fishing

The number of fishers exploiting the grouper fry resource is unknown, but estimates suggest that fry fishers in the Philippines may number in the tens of thousands (Sadovy, 2000). For these fishers, fry fishing represents one activity in a broader portfolio of activities on which they depend. Fry fishing is seasonal in nature and both fishers and non-fishers alike enter the fry fishery if market signals indicate a lucrative opportunity. Fishers may be engaged in the fishery on a full- or part-time basis, whilst also engaging in other fishing activities for the capture of food fish or fish for the aquarium trade (Sadovy, 2000). The capture of wild grouper fry is reported to make a significant economic contribution to the lives of coastal fishers (Sadovy, 2000). However, despite this apparent significance, few studies have attempted to assess the role of these wild fry fisheries in the livelihoods of coastal fishers. There is, therefore, a critical gap in our understanding of the precise nature of the contribution made by wild fry fisheries to coastal households, the economic and gender profile of fishers, and the way in which coastal fishers may be affected by developments in the grouper industry.

Some studies in the region do indicate that the capture of grouper fry may contribute substantially to household incomes. In Sulawesi, Indonesia, for example, fishers may catch in the region of 1 000–2 000 2.5 cm fry per fisher on daily basis during the peak season using scoop nets, with a value of US$300–600 (Haylor *et al.*, 2003). In Viet

Nam, income from grouper fry/fingerling harvest was reported to earn fishers as much as US$3 080 per year (Sadovy, 2000).

Grouper fry fishers do not represent a homogenous group in terms of social status. Fishing households, like most rural households, engage in a diverse range of activities of which fishing may be only one component. Similarly, fishing activities are also diverse with fishers using a variety of gears to target different species according to seasonality and the tides. Dependence upon fry fishing is therefore rare, if it exists at all, although the extent to which the income from fry capture contributes to the total household income will vary from household to household. The relatively high value of grouper fry compared to the rest of the fish catch may, therefore, represent an important income source. As one fisher in Viet Nam indicated, catching 5–10 grouper fry per day can equal the income from all the other fish harvested (Sadovy, 2000). Findings from a survey in Thailand suggest that, for the majority of households, fry fishing is a supplementary activity, often opportunistic, with fishers entering and leaving the fishery according to fry abundance and market signals. Fry fishing in southern Thailand complements the regular fishing activities of coastal fishers, whose principal target species, including shrimp, small pelagic species, are caught at different times of the lunar calendar. Fry fishing therefore allows fishers to supplement their fishing activities at a time when fishing would otherwise not be possible (Sheriff, 2004).

Social impacts of grouper aquaculture

Important synergies exist between grouper aquaculture and fry fishing, which blur the distinction between fry fishers and grouper farmers, and give added significance to the role of grouper fry in coastal livelihoods. In the absence of a reliable source of hatchery fry, and the preference of many farmers for wild caught fry even where hatchery fry is available, most grouper farmers rely upon wild-caught fry to stock their culture systems. Where adequate supplies of grouper fry are still available in the wild, many farmers fish for their own seed inputs which, as they are not purchased and require no cash outlay, are considered a "free" resource. This has important implications for the ability of resource poor households, with little access to financial capital, to take up grouper aquaculture.

Grouper aquaculture has been identified as an activity which can generate a relatively high return in comparison to many of activities available to coastal households (Hambrey, Tuan and Thuong, 2001). Many activities which generate a comparable return, including trading, ownership of plantations and shrimp culture are inaccessible to the majority of households due to the high levels of investment required to take up these activities. Grouper aquaculture can therefore be an important addition to household livelihoods, providing a means of savings to supplement the daily income generated by regular fishing activities (Sheriff, 2004).

As a solution to the problem of destructive fishing, aquaculture may not present the ideal alternative to fishing, as is frequently suggested. There is an assumption that aquaculture is an activity that is easily interchangeable with fishing as a livelihood activity, and that fishers are willing and able to give up fishing to take up a new and markedly different occupation. Studies suggest that fishing is deeply rooted in the lives and traditions of "fishing" communities and the identity of fishers. McGoodwin (2001) reports that fishing is regarded "not merely as a means of ensuring their livelihoods, but as an intrinsically rewarding activity in its own right – as a desirable and meaningful way of spending one's life…prompting many fishers to tenaciously adhere to the occupation and to continue fishing even after it has become economically unrewarding." In a study conducted by Pollnac, Pomeroy and Harkes (2001) in the Philippines, Indonesia and Malaysia, it was found that, in all three countries, fishers like their occupation and only a minority would change to another occupation, with a similar income, if it were available. In the Philippines, 95 percent of fishers surveyed reported that they would choose to become fishers again if they had to live their life over again. They also cited pleasurable aspects of the job as reasons for staying in the fishery, including the beauty of the sea and not having to work for a boss. Fishers in the three countries who would choose to leave the fishery were characterized by a higher level of education and a lower income from fishing. The results do not support the view that fishers are the poorest of the poor, as fishers cite income as one of the reasons for choosing not to change their occupation. The level of satisfaction with fishing as an occupation suggests that fishers will not necessarily change to an alternative occupation and leave the fishery (Pollnac, Pomeroy and Harkes, 2001). Furthermore, the role of fishing in households livelihoods differs markedly from the contribution made by aquaculture. Fishing provides a source of daily income which pays for the daily needs of the household. In contrast, fish culture has been identified as being of importance to the households ability to save money and thus to accumulate assets. Proposals to encourage fishers to leave the fishery by offering fish culture as an *alternative,* may therefore fail, as fish culture cannot meet the daily needs of the household. Aquaculture can, however, provide an important supplementary activity to support livelihood diversification in coastal communities, where few alternatives may exist (Sheriff, 2004).

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high-value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. High initial investment cost is frequently cited as the principal constraint to the uptake of grouper aquaculture. Approximate investment costs for a small-scale farm are in the region of US$1 470 in the Philippines and US$1 010 in Indonesia (Pomeroy, Parks and Balboa, 2006), US$516 in Viet Nam (Hambrey, Tuan and Thuong, 2001) and US$237 in Thailand (Sheriff, 2004). Financial analyses of grouper aquaculture have indicated that grouper rearing is financially feasible, although Pomeroy, Parks and Balboa (2006) found that the capital requirements of some aquaculture systems in the Philippines and Indonesia may be beyond the financial means of many small producers, specifically broodstock and nursery/hatchery systems (Table 18). However, capital costs for grow-out are substantially lower than the broodstock or nursery systems, and are within the financial means of many small producers (Pomeroy, Parks and Balboa, 2006) (Table 19). This figure excludes holding tanks, and therefore more accurately reflects reality. Fish are most frequently kept in holding tanks of a local fish trader within the community, and therefore represent a cost which will not often be incurred at the farm level. The total production costs per market size fish from grow-out, US$3.01 in the Philippines and US$3.18 in Indonesia for a 600 g fish, were found to be well below the average selling price at the time of the Pomeroy, Parks and Balboa (2006) study, which was US$6 in 2002. With the sale of market size fish able to generate this level of profit, it is not surprising to find that the annual enterprise budget show in Table 20 suggests that the cost of investment can be recouped relatively quickly. Pomeroy, Parks and Balboa (2006) conclude from their analysis that loans or other incentives to cover start-up costs could be repaid within the first or second year of production.

Despite these apparently high costs studies have shown that, with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. For example, one study in Thailand found that grouper culture was taken up by households from all wealth groups within a community in Satun province (Sheriff *et al.*, in press). Support from the Thai Department of Fisheries in the form of materials for cage construction and seabass seed allowed households to establish a small farm of two cages with which to initiate grouper culture. Grouper fry were supplied in small quantities from the farmers fish catch, and a share of the profits returned to a centralized revolving fund for the benefit of all households in the community.

TABLE 18
Total projected capital investment costs for grouper hatchery/nursery and broodstock operations, modelled for Indonesia and Philippines (in US$)

	Nursery/hatchery operations			Broodstock system	
	Philippines	Indonesia	Indonesia	Philippines	Indonesia
		(small size operation)	(medium size operation)		
Broodstock costs					
Male specimens				400	660
Female specimens				600	1 320
Sub-total				1 000	1 980
Land operations					
Land	6 500	728	4 850	6 500	4 850
Perimeter fencing	50	20	50	50	50
Tanks and reservoirs	11 900	1 110	8 760	6 100	3 080
Roofing, framing and siding	3 800	230	1 835	2 400	1 000
Building/structures	5 800	250	1 850	0	650
Plumbing	4 000	210	2 000	2 000	1 000
Electrical	3 500	135	1 700	2 000	1 000
Air blower	1 980	100	600	1 320	250
Sea- and freshwater pumps	2 600	315	1 800	1 700	900
Generator	2 000	0	450	2 000	450
Truck	0	0	14 000	0	0
Miscellaneous	1 000	160	900	200	150
Sub-total				**24 270**	**13 380**
Total capital investment	**43 130**	**3 258**	**38 795**	**25 270**	**15 360**

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

TABLE 19
Total projected capital investment costs for grow-out of grouper modelled for Indonesia and Philippines (in US$)

	Indonesia (*Cromileptes altivelis*)	Philippines (*Epinephalus coioides* and *E. malabaricus*)
Marine Operations		
Floating net cages	1 280	825
Boat	80	60
Water quality test equipment	70	80
Harvest equipment	40	45
Sub-total	**1 470**	**1 010**

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

TABLE 20
Summary of annual enterprise budgets over a single production cycle across grouper scenarios modelled for the Philippines (*Epinephalus* spp.; 12 month grow-out period) and Indonesia (*Cromileptes altivelis*; 18 month grow-out period)

	Philippines			Indonesia			
	Broodstock	Hatchery / nursery	Grow-out	Broodstock	Hatchery / nursery (medium)	Hatchery / nursery (small)	Grow-out
Variable costs[1]	13 128	15 895	4 786	8 160	24 325	3 435	8 363
Fixed costs[2]	4 053	7 713	2 299	2 662	8 235	668	2 108
Total expenses	17 181	23 608	7 085	10 882	32 710	4 103	10 471
Total income	23 503	45 045	14 400	83 784	106 270	12 505	20 250
Balance	**6 322**	**21 347**	**7 315**	**72 902**	**73 560**	**8 402**	**9 779**

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

[1] Eggs, fingerlings, feed, vitamins/medication, chemicals, electricity, labour and consultants, fuel and oil, marketing/packing/harvesting, supplies, repairs.

[2] Depreciation of fixed assets, interest payments.

The absence of large-scale production of grouper fry has ensured that production is kept primarily in the hands of small-scale, individual family owned operations (Hambrey *et al.*, 2001; Sadovy, 2000; Sheriff, 2004), however some systems involve a large number of cages and off-shore systems are being tested in countries including Malaysia and Viet Nam (Kongkeo and Philipps, 2001). On-going research efforts are focusing on the hatchery production of the most vulnerable and commercially important grouper species in an attempt to reduce pressure on wild stocks. Yet there may be significant socio-economic impacts if hatchery production becomes commercially viable on a large-scale, and may threaten the livelihoods of both fry fishers and small scale grouper farmers. Taiwan Province of China is one of few countries to have a successful hatchery industry and may provide some insight into the potential impacts of hatchery produced grouper, where production has led to a marked effect on demand for grouper fry and a subsequent decline in seed prices. A reduction in the value of grouper is anticipated by exporters and importers as a result of increased production (Sadovy, 2001a). However, small-scale hatchery production of grouper has been found to be a viable livelihood option providing employment opportunities and rural livelihood diversification (Siar, Johnston and Sim, 2002). In Bali, where many such hatcheries have been established, milkfish fry production has provided the basis for diversification into grouper fry, and therefore provides a particularly relevant model for transfer to countries like the Philippines. However, uncertainties remain as to the acceptability of hatchery produced grouper fry to grouper farmers and the likely livelihood impact of hatchery production on fry fishers and the value of cultured grouper.

Gender roles in the grouper fry fishery and aquaculture

The specific role of women within the grouper fry capture fishery and trade network is little understood. Within the fisheries sector, women often play an important role in post-harvest activities, which are absent from the live fish trade. However, women frequently take responsibility for trade and financial matters, and in countries such as Thailand, it is not unusual to find that the main fish and fry trader within the community is female, although fish trading beyond the community is more frequently the domain of men (Sheriff, personal communication). Grouper culture can provide perhaps the most significant opportunities for women, who are often responsible for maintaining aquaculture operations on a daily basis (Haylor *et al.*, 2003). The requirement for trash fish is high in grouper culture, and the preparation of trash fish for feeding is frequently done by women (Sheriff, 2004). Experience in Indonesia has shown that women may also find employment in the small-scale hatchery industry, providing labour as temporary workers for the counting and packaging of milkfish fry (earning in the region of US$0.33 per 5 000 fry counted), or as brokers in the fry marketing chain (Siar, Johnston and Sim, 2002). Similar work in a grouper hatchery grading grouper fry may earn women US$6.66 per day. The work is however, extremely hard, according to one hatchery owner (Siar, Johnston and Sim, 2002).

MANAGING CAPTURE-BASED AQUACULTURE OF GROUPER

The management of capture-based farmed groupers is complicated by several problems, including shortage of capture-based seed, disease transfer resulting from international trade in seed, high mortality rates in capture and culture, overfishing of grouper adults, etc. (Ottolenghi *et al.*, 2004). Groupers are top predators, sedentary in character and strongly territorial, typically long-lived and slow growing and many assemble in large numbers to spawn. These characteristics contribute to the ease with which over-exploitation may occur, and is engendered by the Live Reef Fish Trade (LRFT). This has already led to calls to include many of the target species in Appendix II or III of the Convention on International Trade in Endangered Species (CITES) (Lau and Parry-Jones, 1999). The Nature Conservancy (TNC) has developed a regional strategy in the Asia-Pacific that focuses on developing and applying regional models to sustainable fisheries. Many different approaches have been taken to reduce exploitation, e.g. the Bahamian government has recently approved the establishment of five no-take marine reserves. All of these sites contain known Nassau grouper (*Epinephelus striatus*) spawning aggregations. Although stocks of Nassau grouper in the Bahamas appear to be healthy, these closures (coupled with other research activities) are being implemented to ensure that conservative management measures are taken, as a precaution against stock collapses such as those that have occurred in other locations that once held stocks of this species (Johannes, 2000). In Micronesia, Palau was among the first nations in the world to protect their grouper spawning aggregations, enforcing a seasonal closure on the Ngerumekaol (Ulong Channel) aggregation site in 1976, then creating permanent no-take marine reserves at Ngerumekaol and Ebiil (another aggregation site) in 1999. Pohnpei State in the Federated States of Micronesia has also declared permanent no-take zones around its grouper spawning aggregations (Rhodes and Tupper, 2007). Both Palau and Pohnpei have closed their grouper fisheries during the reproductive season and have limited or banned export of groupers and other species involved in the live reef fish trade.

Other regulations should be developed to control the harvest of grouper seed. The availability of capture-based grouper seed is often insufficient and unreliable (both in quality and quantity) to meet demand; low production in farming is mainly attributed to lack of seed supply (Chao and Chou, 1999; Yashiro, Vatanakul and Panichsuke, 2002; Agbayani, 2002). Disease problems due to the high transfer stress can cause high mortality rates in capture and culture. Sadovy (2000) has compiled information on the status of regulations on grouper seed capture and exports that concern capture-based aquaculture (Table 21).

A survey of CBA in Southeast Asia found that while the quantity of seed caught was significant, the production level was very low (Sadovy, 2000). The major causes contributing to this massive mortality are destructive fishing practices and gears, poor post-harvest handling, poor farming practices and conditions, and a generalized lack of experience or knowledge. This review indicated that there is a substantial fishery, and demand, for fish in the 5–10 cm range, but that the removal of this seed could have serious consequences for the future of both adult stocks and the contribution of these adults to the future of the seed fishery itself. Given the likelihood that there will be a significant increase in natural mortality for the smallest settling fish, several researchers have already proposed that fisheries for very early post-settlement (or even pre-settlement) seed is a way of gaining benefit from a resource that does not affect its long-term sustainability.

It is necessary to consider further initiatives to attain a more sustainable use of grouper stocks and greater socio-economic benefits from grouper capture-based aquaculture. One possible approach for grouper management is, as Sadovy (2000) suggests, the establishment of nursery areas where the capture fishery and culture operations occur. Another possibility is to protect key seed settlement areas and nursery habitats, such as mangrove areas, coral rubble and sea-grass environments in river mouths and estuaries, and to ensure seed production by safeguarding spawning adults. Marine protected areas (MPAs) should incorporate key settlement and nursery areas, but to date, there are few (if any) MPAs protecting grouper nursery habitat (Tupper, 2007).

Positive steps to address many of these issues are being taken by the Network of Aquaculture Centres in Asia and the Pacific (NACA) and its partners, the Asia-Pacific Economic Cooperation (APEC), the South-East Asian Fisheries Development Center (SEAFDEC), the Australian Centre for International Agricultural Research (ACIAR), and the WorldFish Center (formerly known as ICLARM), etc. In 1998 the Asia-Pacific Grouper Network (APGN) was established; this organization addresses aquaculture development, in order to:

- reduce the current reliance on capture-based “seed” for aquaculture, as the capture of wild juveniles is sometimes carried out using destructive fishing techniques that can have significant impact on the long-term status of the stock;

TABLE 21
Southeast Asia national regulations

Locality	Regulation
China	Limits the number of grouper "seed" fishers and the quantities of grouper "seed" captured A licence is needed for transporting marine "seeds" and their export is prohibited There is a management regulation of Guangdong Province for the cultivation of aquatic products in the shallow sea intertidal zone, which applies to those engaged in marine cultivation
China Hong Kong SAR	Culturists must be licensed and operate in one of 26 gazetted culture zones There are no regulations that apply to the capture of grouper "seeds" or their import or export
Indonesia	There is no management of seed resources
Malaysia	Federal legislation prohibits the use of cyanide for fishing In East Malaysia there are no special regulations for grouper seed capture. Some regulations may act indirectly, for example some gears that are made of trawl net are subject to trawl mesh size control. Grouper seeds cannot be imported for culture In West Malaysia the fishing of "seeds" is not allowed during November and December; it is only permitted during the peak season from January to April. No export of seeds smaller than 15 cm is permitted
Philippines	It is illegal to use cyanide or any other poisonous substance for fishing The scissor net is illegal Fyke net have been banned The Fisheries Code of 1998 (Republic Act 8550) prohibits the export of "seed" of milkfish and prawn but its application to grouper is not clear. This Code regulates gear/structures and operational zones for fish capture and culture Transportation and export of fish and fisheries products requires permits from the Quarantine section, including a health certificate from the Fish Health section of Bureau of Fisheries and Aquatic Resources (BFAR)
Taiwan PC	In Penghu Island, fishers are not permitted to catch any grouper seed of <6 cm The use of cyanide for fishing is illegal
Thailand	The use of push nets and fyke nets is limited. Push nets and trawlers should not be used within 3 km of the shore and the mesh size of trawlers should be ≥2.5 cm.
Viet Nam	Government regulations prohibit export of groupers <500 g (ex Ministry of Fisheries) There is no limit on export volumes. For export a health certificate from a provincial office, Fisheries Resources and Environment Conservation Sub-Department is needed, and requirements of the importing country satisfied

Source: Sadovy, 2000, as reprinted in Ottolenghi *et al.*, 2004.

- provide an alternative source of income/employment for coastal populations currently engaging in destructive fishing practices;
- protect endangered reef fish from the pressures of illegal fishing practices, through the development of sustainable aquaculture; and
- develop new aquaculture livelihood options and investments that will generate economic benefits for a diversity of stakeholders and employees.

Since 1996, all the above mentioned organizations have conducted workshops, with the aim of establishing a regional mechanism for research cooperation that supports the sustainable development of capture-based aquaculture in the Asian region. Emphasis has been placed on technology transfer and management strategies for the benefit of farmers and coastal populations (Ottolenghi *et al.*, 2004).

CONCLUSIONS

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high-value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. Despite high initial investment costs, studies have shown that with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. However, based on the information reviewed in this report, capture-based aquaculture may not be the best means to ensure a steady and sustainable supply of grouper for either the live or "non-live" fish trades. This is due to a number of problems including low availability of seed, destructive and wasteful seed collection techniques, removal of large numbers of early life history stages with subsequent impacts on adult populations and conflicts with capture fisheries, and pollution and disease resulting from culture operations.

The obvious solution to some of the problems of CBA is to develop closed-cycle hatchery rearing for all grouper species. Important advances in full-cycle culture have been made for several species, particularly in Taiwan Province of China, and full-cycle culture appears financially feasible given a large enough capital investment. However, given the financial means of most grouper culturists, and the difficulty in rearing most grouper species, it remains unlikely that many of these species will be hatchery-reared in the near future. It is also likely that hatchery production would undermine the potential contribution of grouper culture in the livelihoods of the poor. Production would most likely be taken out of the hands of small-scale producers. An increase in production if hatchery fry is available would also lead to increased supply and a likely drop in value, and lower profits. The market value of grouper is driven by its relative rarity. On the other hand, poorer farmers would probably continue to fish for grouper fry as they cannot afford to buy fry, and wild capture makes grouper culture less risky and more accessible. In the meantime, steps must be taken to improve the management of both CBA and capture fisheries for grouper. Some countries, such as Palau, have taken strong measures to protect their reef fish populations, including the closure of spawning seasons and spawning aggregation sites, bans on the export of grouper and other vulnerable species, and even complete moratoria on fishing for species in an obvious state of decline (e.g. humphead wrasse, *Cheilinus undulates*, and bumphead parrotfish, *Bolbometopon muricatum*). This has effectively stopped the live reef fish trade in Palau. In addition, the government of Palau, in cooperation with the governments of the US and Japan, has developed viable full-cycle culture for at least one commercially important grouper (*Epinephelus fuscoguttatus*), and experimentation continues with other species.

Similar to export bans on adult grouper fisheries, Sadovy (2001b) suggested that all export of grouper seed should be banned and that grouper should be cultured to market size within their own country. This would allow for more stringent management of grouper CBA, while reducing the transmission of disease via exported seed. Reduction or elimination of the more wasteful and destructive seed collection techniques (e.g. fyke nets and scissor nets) is another appropriate step. Lastly, both CBA and capture fisheries should promote the application of the precautionary principle and adopt the FAO international Code of Conduct for Responsible Fisheries (CCRF).

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