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.

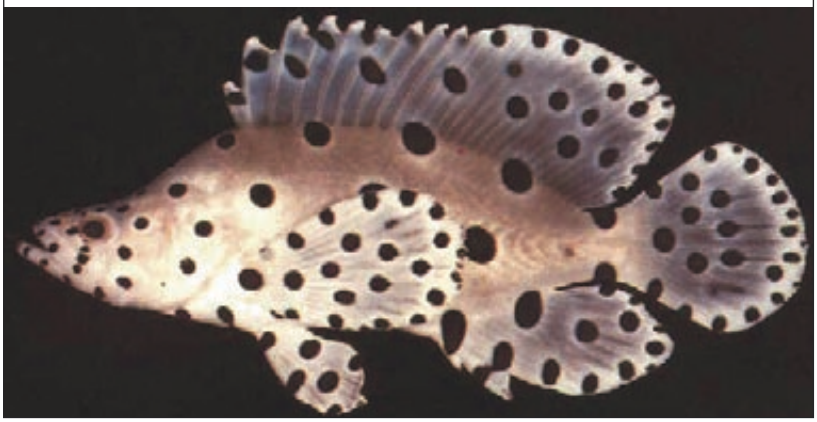
Juveniles and adults of some grouper species live in coastal or lagoonal waters and estuaries, while others prefer the cleaner waters of offshore reefs. Their eggs are single, non-adhesive, and buoyant at normal salinities. The larvae of most species spend about 30–50 days as planktonic larvae (Colin, 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*)



COURTESY OF J.E. RANDALL

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*)

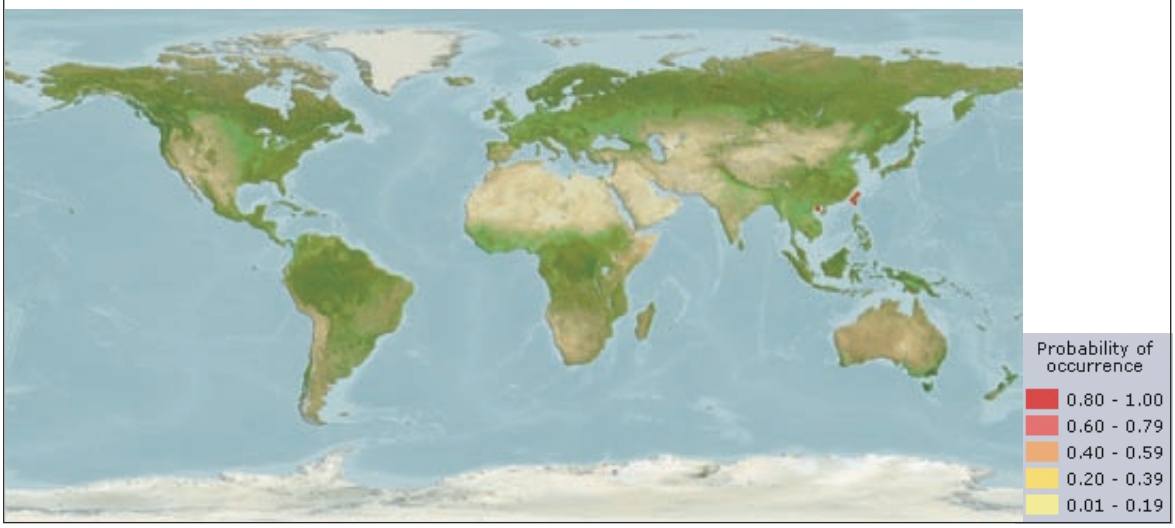
COURTESY OF A. CORNISH

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*)

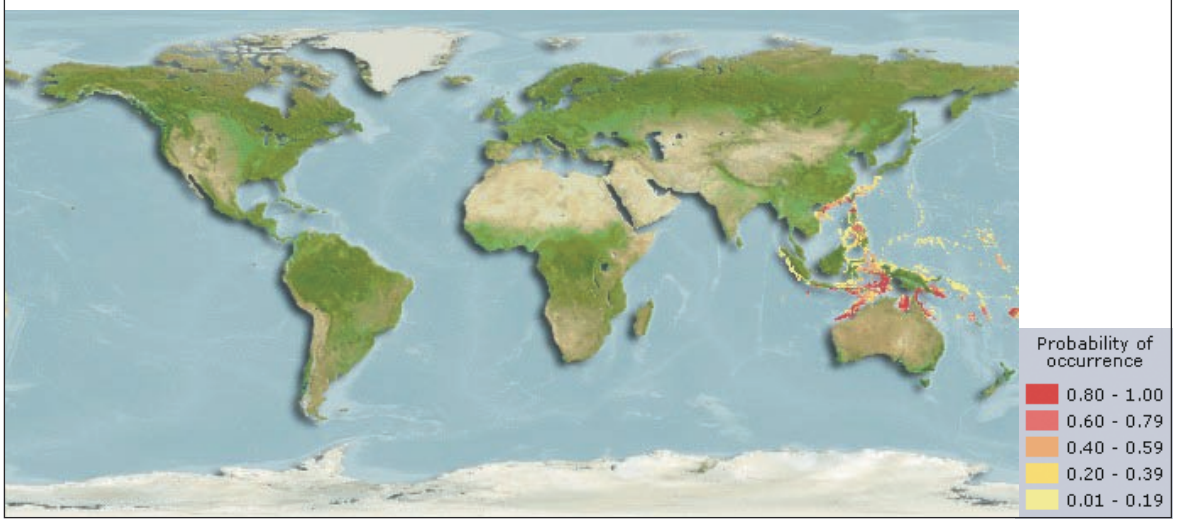
COURTESY OF CSIRO

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*)

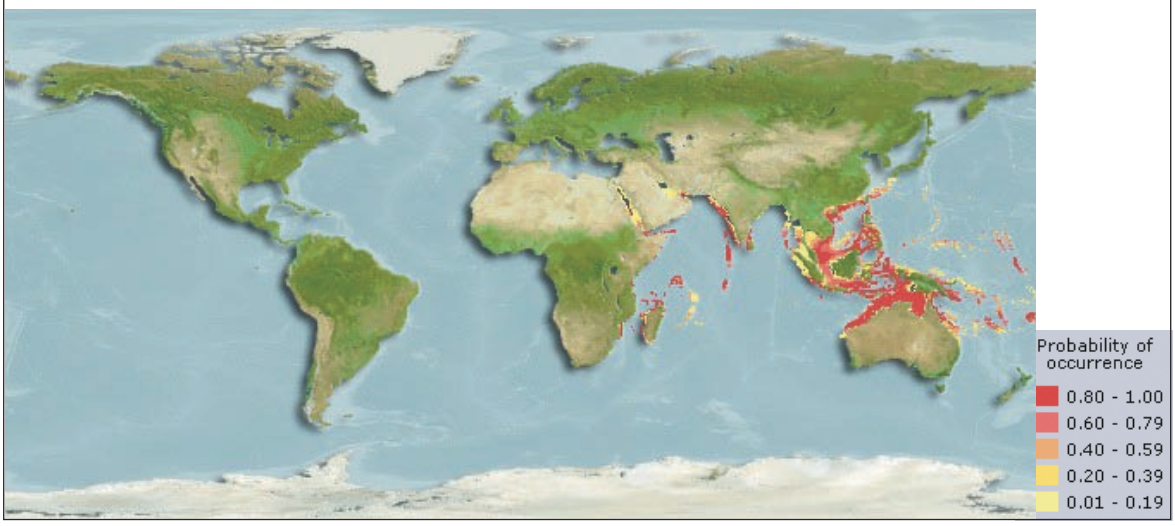
COURTESY OF J.E. RANDALL

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.

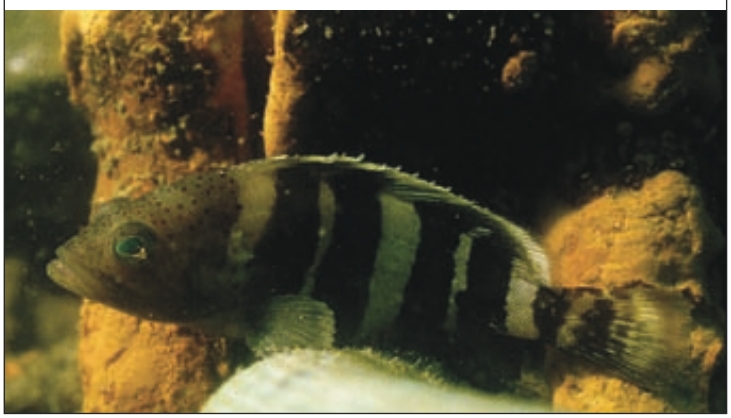
Source: Modified from FishBase (Froese and Pauly, 2007).

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



Epinephelus awoara (Temminck & Sclegel 1842)

FIGURE 9
Yellow grouper (*Epinephelus awoara*)



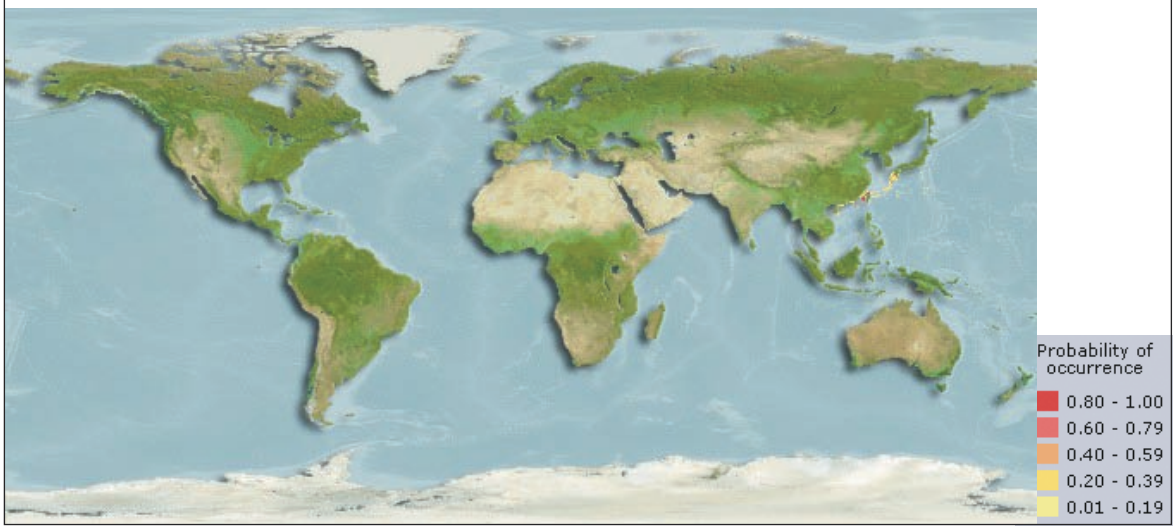
COURTESY OF D.C. COOK

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*)

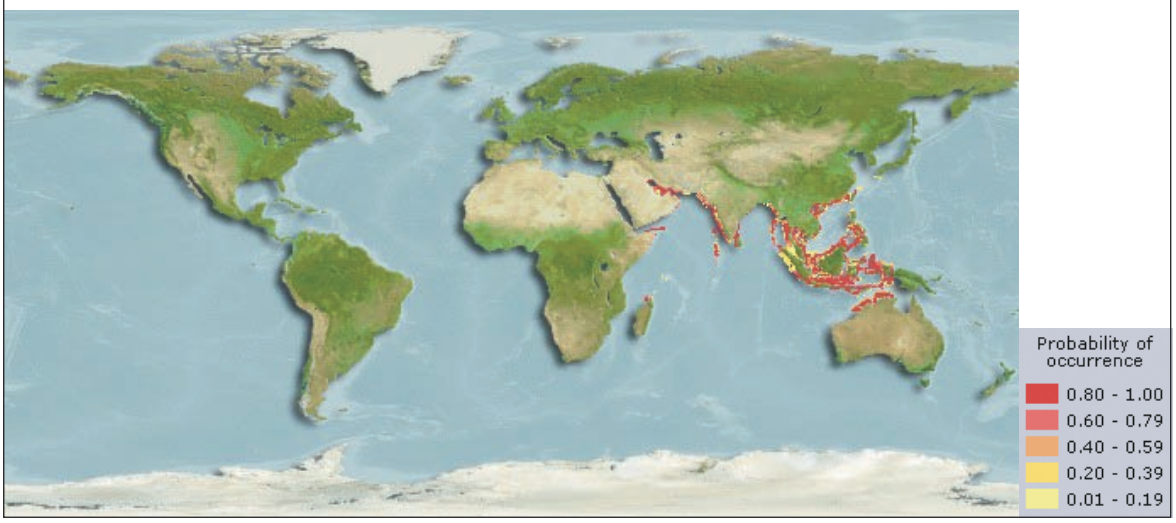
COURTESY OF J.E. RANDALL

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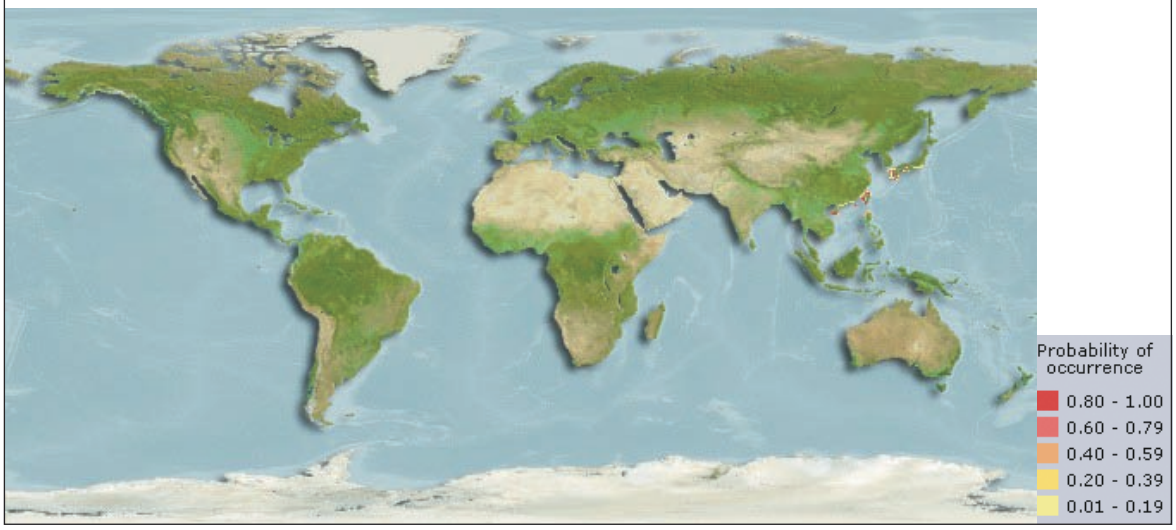
TABLE 7
Characteristics of the longtooth grouper, *Epinephelus bruneus*

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*)

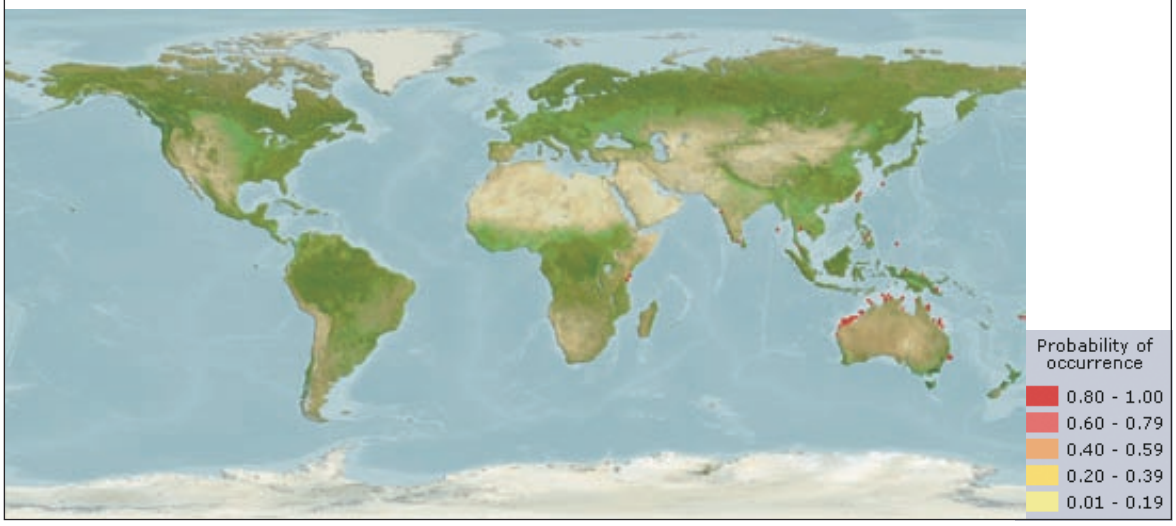
COURTESY OF D.C. COOK

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.

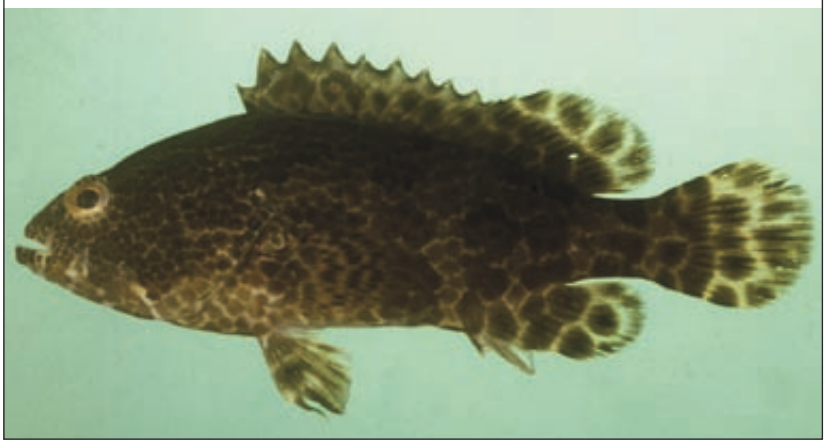
Source: Modified from FishBase (Froese and Pauly, 2007).

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



Epinephelus fuscoguttatus (Forsskål, 1775)

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



COURTESY OF J.E. RANDALL

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)