Chapter 8
Fishery and Biological Implications of Fishing Spawning Aggregations, and the Social and Economic Importance of Aggregating Fishes

Yvonne Sadovy de Mitcheson and Brad Erisman

Abstract This chapter explores the fishery and biological implications of exploiting aggregating marine fishes, their general importance to subsistence, commercial, and recreational fisheries and the possible consequences of losing them. We synthesize and examine empirical data from a wide range of taxa to determine whether, when and why fish spawning aggregations need to be targets of management. We examine the socioeconomic importance, costs and benefits of exploiting reef fish aggregations for both extractive and non-extractive (e.g. tourism and reproductive output) purposes. We provide recommendations and guidance for future research, education, management and conservation planning for aggregating species.

8.1 Introduction

This chapter explores the fishery and biological implications of exploiting aggregating marine fishes, their general importance to subsistence, commercial, and recreational fisheries and the possible consequences of losing them. We synthesize and examine empirical data from a wide diversity of species range of taxa to determine whether, when and why fish spawning aggregations need to be targets of management. Although we focus on reef fishes, we extensively use relevant or important examples from non-reef species, where informative, because many share the same problems of perception and lack of management; particularly illustrative examples

Y. Sadovy de Mitcheson (✉)
Division of Ecology & Biodiversity, University of Hong Kong, Pok Fu Lam Road, Hong Kong, China
e-mail: yjsadovy@hku.hk

B. Erisman
Marine Biology Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0202, USA
e-mail: braderisman@gmail.com

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are given in more detail. We examine the socioeconomic importance, costs and benefits of exploiting reef fish aggregations for both extractive and non-extractive (e.g. tourism and reproductive output) purposes. Against this background, we provide recommendations and guidance for future research, education, management and conservation for aggregating species. We use the definition of spawning aggregation (transient and resident) as elaborated in Chap. 1.

Fishes that aggregate to spawn form an important component of marine fisheries and ecosystems globally. While most such species are caught throughout the year, it is commonly during the spawning season that landings volumes are greatest. Such aggregations naturally offer a welcome opportunity for large catches and easy earnings often representing a seasonal bounty to be shared by whole communities. They are targeted for recreational and tourist fishing charters, or may be important for cultural events. While most aggregations are exploited for fish flesh, for some species the more valuable target might be ripe gonads or swimbladders (Fig. 8.1). In some species the millions of young produced briefly each year by the concentrated spawning of hundreds to thousands of assembled adults support capture-based aquaculture (CBA) for which large numbers of newly settling or settled juveniles are collected *en masse* and grown out in captivity prior to sale. For these species, aggregations are the only known time that reproduction occurs and are thus important for maintaining their populations and the fisheries these support.

Unfortunately, many fishes that form spawning aggregations have undergone marked declines in their fisheries and these reproductive events are increasingly targeted (Sect. 8.2). Numerous documented examples, ranging from reefs to estuarine environments (Table 8.1), to the pelagic realm and deepwater seamounts, demonstrate unequivocally that aggregations can be substantially reduced by excess fishing effort over just a few spawning seasons leading to collapse of the fisheries they sustain, with important biological, social and economic implications.

Despite widespread declines globally, spawning aggregations of most species that form them are typically unmanaged. Among key unanswered questions that may account for such lack of attention, are (1) whether aggregations themselves need to be a focus of management as opposed to applying more conventional management (such as annual quotas or gear controls) to the fish populations of interest (Chap. 11); (2) whether reduced or extirpated aggregation sites can recover following management intervention and how long might be needed for recovery; and (3) the importance of healthy aggregations to reproduction, and hence the implications of aggregation declines and losses for harvested species. The strong appeal of aggregations as targets for fishing, their importance in many seasonal fisheries, the apparent abundance when aggregation catches are witnessed, and general lack of data on catches, together with the three above noted factors, make their management particularly challenging.

The preservation of sufficient spawning (reproductive) biomass in exploited populations is a core guiding principle in fisheries science for ensuring sustainable resource use. However, how this principle is best applied to aggregating species is unclear for two reasons. First, the extent to which declining trends in fisheries of aggregating species are due to exploitation of aggregations *per se* is uncertain: many

Fig. 8.1 Catches from spawning migrations or aggregations are valued for (**a**) ripe gonads (unknown mullet species) sold in Taipei market, Taiwan (Photo: Yvonne Sadovy de Mitcheson), (**b**) grouper flesh (*Epinephelus fuscoguttatus*) in Fiji (Photo: Randy Thaman), (**c**) croaker swimbladders (*Cynoscion othonopterus*) in Mexico (Photo: © Ismael Mascarenas)

aggregations, for example, occur in fish species that are naturally vulnerable to unmanaged fishing due to other life history attributes, such as longevity and late sexual maturation (Reynolds et al. 2005). Additionally, most species are also exploited during non-aggregation periods. Second, the potential impact of removing or disturbing ripe adults from aggregations prior to spawning is not known. In an attempt to better understand the implications of fishing on aggregations, and identify key data gaps, we explore the biological, social, and economic implications of

Table 8.1 Commercial examples of fisheries on aggregating species fished at aggregations – reef fishes and other examples

Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
Nassau grouper *Epinephelus striatus*	Epinephelidae	Handline, longline, fish traps, speargun, gillnet	Caribbean-wide	One third of aggregations have been eliminated or reduced to negligible numbers. Disappearances have been documented in the Bahamas, Florida USA, Puerto Rico, US Virgin Islands, Honduras, Cuba, Belize, and Mexico	Sadovy and Eklund (1999), Chap. 12.6
Nassau grouper *Epinephelus striatus*	Epinephelidae	Handlines, spearguns, gill nets	Mahahual, Quintana Roo, Mexico	Aggregations of up to 15,000 fish formed each year at the same site, but due to increased fishing pressure in the 1990s, aggregations have not formed since 1996. Management not enforced	Aguilar-Perera (2007), Chap. 12.6
Nassau grouper *Epinephelus striatus*	Epinephelidae	Fish traps	Cuba	Targeted almost exclusively during aggregation periods; 20 of 21 historical aggregation sites no longer form. Management measures increasing but recovery not recorded	Claro et al. (2009), Chap. 12.6
Nassau grouper *Epinephelus striatus*	Epinephelidae	Handline, speargun, fish traps	Belize	Eighty percent decline in last 25 years (15,000 down to 3,000 fish) in aggregation size at Glover's Reef; Only 2 of 9 known aggregation sites remained by 2001; reduced from 30,000 to 1-5,000 fish. All known aggregation sites underwent dramatic declines in the abundance of spawning fish over the last 2 decades. Fishing particularly intense on spawning aggregations. Current aggregation protection does not appear to be restoring this species and a minimum capture size was recently introduced	Sala et al. (2001), Carter et al. (1994), Heyman and Requena (2002), Janet Gibson 2010, Chap. 12.6

Nassau grouper *Epinephelus striatus*	Epinephelidae	Handlines, traps, spearguns	Bermuda	Fished exclusively during aggregation periods. Commercial landings dropped from 75,000 tons in 1975 to less than 10,000 tonnes in 1981. The four known historical aggregation sites have ceased to form	Bannerot et al. (1987), Luckhurst (1996), Chap. 12.6
Goliath grouper *Epinephelus itajara*	Epinephelidae	Hook and line; spearfishing, trawl and longline bycatch	Gulf of Mexico	Aggregations of 100–150 fish on deepwater wrecks declined to 0–10 fish by 1989	Sadovy and Eklund (1999), Chap. 12.4
Goliath grouper *Epinephelus itajara*	Epinephelidae	Hook and line, spearfishing, trawl and longline bycatch	Florida USA	Fishery closed in 1990 due to rapid declines in catch and CPUE. Aggregations of several dozen fish were common off the East Coast of Florida in the 1950s and 1960s but were not observed anywhere in the 1990s. The population increased after the closure and the species is no longer considered to be of concern in US waters. A sevenfold decrease in the CPUE of Goliath grouper occurred between 1965 and 1969 in south Florida sport-fishery	Sadovy and Eklund (1999), McClenachan (2009), Chap. 12.4
Goliath grouper *Epinephelus itajara*	Epinephelidae	Hook and line, spearfishing,	Yucatan Peninsula, Mexico	Surveys from 2004 to 2006 revealed that Goliath grouper represent a negligible commercial fishery in the region. The absence of landed fish is attributed to widespread overfishing of this species from its spawning aggregations	Aguilar-Perera et al. (2009), Chap. 12.4
Goliath grouper *Epinephelus itajara*	Epinephelidae	Handlines, spearguns, traps,setlines, longlines, and drumlins	Belize	Adults are now rarely caught and the commercial fishery is dominated by juveniles (90% of catch)	Graham et al. (2009), Chap. 12.4

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Table 8.1 (continued)

Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
Pacific goliath grouper *Epinephelus quinque fasciatus* (= *E. itajara*)	Epinephelidae	Spearguns	Gulf of California, Mexico	Landings dropped from 750 mt to less than 10 tonnes between 1980 and 1988. Aggregations have not been observed since 1995. Historically, fish were harvested almost exclusively during aggregations. However, in recent years spearfishers removed solitary fish throughout the year	Kira (1999) and Sala et al. (2004)
Gag grouper *Mycteroperca microlepis*	Epinephelidae	Trawl	Florida USA	Many aggregations disappeared between the1970s and 1980s; fished during and following spawning aggregations; Sex ratios shifted from 6:1 females to males in the 1970s under light fishing pressure to 30:1 in the 1990s; Commercial sales ban during spawning season implemented in 2000; In 2009 final rule outlines measures for recreational bag limits, commercial quotas, and closed season for all fishing from January to April for shallow water groupers (gag, black, red, scamp, red hind, rock hind, coney, graysby, yellowfin, yellowmouth, tiger). Dehooking tools required as necessary	Coleman et al. (1996), Koenig et al. (2000), Southeast Fishery Bulletin 2009 National Marine Fishery Service, USA, Chap. 12.7
Scamp *Mycteroperca phenax*	Epinephelidae	Trawl	Florida USA	Declines in landings and average size of landed fish; Percentage of large males decreased from 34% to 21%, median length decreased from 610 to 570 mm TL, and the percentage of fish 10 years or older decreased from 17% to 7% between 1979 and 1997; aggregations protected by recreational and commercial harvest ban during spawning season of shallow water groupers in 2009	Coleman et al. (1996), Harris et al. (2002); Southeast Fishery Bulletin 2009 National Marine Fishery Service, USA

Tiger grouper *Mycteroperca tigris*	Epinephelidae	Fish trap, spearfishing, handline	Puerto Rico	Commercial landings from aggregation site off Vieques Island dropped from 5 tonnes in 1995 to 2 mt in 1998 (60% decline). Sex-selective spearing focused on males to protect eggs. Site not protected despite declines	Matos-Caraballo et al. (2006) and Sadovy et al. (1994a, b)
Red Hind *Epinephelus guttatus*	Epinephelidae	Fish trap, spearfishing, handline	US Virgin Islands	Reduction in catch, skewed sex ratios (15 females:1 male), reduced size of aggregating fish between the 1970s and 1990s; fished primarily during aggregations; closure of the aggregation fishery resulted in increase in size of fish, shift in sex ratio (4:1) and increased size of landed fish on fishing grounds outside protected site. Average density and biomass of spawning fish increased by 60% in five years, and maximum density doubled	Beets and Friedlander (1999), Nemeth (2005), Chap. 12.3
Mutton snapper *Lutjanus analis*	Lutjanidae	–	Belize	Commercial fishers target aggregations in spring months. Major declines in CPUE (59%), mean landings per boat (22%), and median fish size reported over the last decade. Widespread population declines due to overfishing of aggregations reported as early as the 1940s. There is little effective protection	Graham et al. (2008), Rachel Graham 2010
Camouflage grouper *Epinephelus polyphekadion*	Epinephelidae	Hook and line, spear	Fiji	The species is intensively fished on a number of spawning aggregations. According to interviews, CPUE decreased significantly at four sites from about 300 kg in the 1990s to 100 kg in 2002-3 per trip. Some aggregation sites are no longer fished because numbers have declined substantially. The government programme to open ice plants in more remote areas could encourage aggregation fishing and legislation is in draft form to protect spawning aggregations of groupers	YS, unpublished data, Chap. 12.5

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Table 8.1 (continued)

Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
Camouflage grouper, *Epinephelus polyphekadion,* brown-marbled grouper, *E. fuscoguttatus* and squaretail coralgrouper *Plectropomus areolatus*	Epinephelidae	Mainly hook and line	Solomon Islands, Western Province	These three species often aggregate together and are targeted for the live reef food fish export trade. The live reef fish trade started in 1994 with aggregations heavily targeted. Interviews suggested that after about two years most fishers noted declines in sizes of fish and numbers caught. There was also concern that ripe females taken for the live trade had high mortality rates. The export business stopped due to such concerns but restarted later	Johannes and Lam (1999), Chap. 12.2, 12.5, 12.8
Camouflage grouper, *Epinephelus polyphekadion,* brown-marbled grouper, *E. fuscoguttatus* and squaretail coralgrouper *P. areolatus*	Epinephelidae	Spear, hook and line	Palau, western Pacific	Several aggregations with these three species have been heavily exploited in central and southern Palau since at least the mid 1900s. Interviews with patriarch fishers suggest that landings have dropped significantly from over 1 tonne per trip to less than 100 kg on aggregations. The aggregations are protected from April to July each year when they cannot be fished or marketed but aggregating still occurs in August; there is little enforcement and substantial poaching	Sadovy (2007), YSM personal observation, Chaps. 12.2, 12.5, 12.8

Brown-marbled grouper and squaretail coralgrouper *Epinephelus fuscoguttatus* and *Plectropomus areolatus*	Epinephelidae	Spearfishing, hook and line	Southern Manus, PNG.	Fisher knowledge indicated declines in aggregations and in 2004 led the community to institute a lunar-based ban on spearfishing and commercial fishing at the aggregation site in the10 days leading up to and including the new moon in every month of the year. Only subsistence hook and line fishing was allowed. In early 2007 when the results of monitoring indicated that aggregation numbers had not improved a 1 year ban on all fishing on the site was introduced in the 10 days of each month of the year during which aggregations formed	Hamilton et al. (2004), Chaps. 12.2, 12.8
Gulf grouper *Mycteroperca jordani*	Epinephelidae	Gill nets, hook and line, spearguns	Gulf of California, Mexico	Comprised 45% of finfish production of Baja California Sur in 1960, but dropped to 6% by 1972 and to <1% by 2004. There has been a tenfold reduction in daily landings and CPUE between 1950s and 2000s, and entire fishery is comprised of juvenile fish. In 1960s, a fleet of six boats would land up to 63 tonnes/month from one site during peak aggregation season. Recent underwater surveys reveal a population of 3 adult Gulf grouper at the site. No targeted management related to protection of aggregations; no commercial limits or restrictions; daily catch limit for recreational fishers is not clear and not enforced	Saenz-Arroyo et al. (2005), Sala et al. (2003), Aburto-Oropeza et al. (2008)

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Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
Leopard grouper *Mycteroperca rosacea*	Epinephelidae	Gill nets, speargun, hook and line	Gulf of California, Mexico	The most commercially important grouper in terms of landings and market value in the region. Increased fishing pressure on feeding and breeding aggregations correlated with widespread declines in landings and average size of landed fish. No targeted management related to protection of aggregations; no commercial limits or restrictions; daily catch limit for recreational fishers is not clear and not enforced	Sala et al. (2003, 2004), Aburto-Oropeza et al. (2008)
Leopard coralgrouper *Plectropomus leopardus*	Epinephelidae	Hook and line	Australia	*P. leopardus* is the most commercially important of several coral trout species in Australia. It is nowadays mainly taken for the high value live reef food fish export trade. In the last 20 years, annual commercial landings on the Great Barrier Reef (GBR) varied between 900 and 2,500 mt and the relatively small spawning aggregations are apparently not a specific fishing target. However, collapse of one spawning site was attributed to fishing. Management is by minimum sizes and short term seasonal closures at spawning time	Chap. 12.9

Squaretail coralgrouper *Plectropomus areolatus*	Epinephelidae	Hook and line	Kiribati, western Pacific	In parts of Kiribati, targeting spawning aggregations was traditionally practiced that became intensive in the 1980s when an Outer island Fisheries Project started to buy fish from the outer islands to sell in Tarawa, the capital. At the peak season, an estimated catch of 2 mt of fish (about 1,200 individuals) per day was normal. Underwater surveys showed that mean densities and sizes in the area declined from 0.13 individuals per 100 sq.m and a mean total length (TL) of 40 cm to 0.04 individuals per 100 sq.m and mean TL of 33 cm by 2004	Being Yeeting 2009, Chap. 12.8
Grey mackerel *Scomberomorus semifasciatus*	Scombridae	Gill net	Australia	This fishery historically concentrated on a peak spawning aggregation time and location. Since 1988 about 65% of the annual catch is taken in October from a single spawning site. While the fishery-dependent CPUE remains stable, this may be a case of hyperstability because anecdotal information suggests that the aggregation used to be much larger and that there were once similar aggregations throughout the GBR, which have now ceased to exist or have diminished substantially. In 2008, no grey mackerel schools were found at all and landings have fallen markedly in the last few years. In 2009 size limits and total allowable catch was introduced in Queensland east	Martin Russell David Cook, personal observations 2010

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Table 8.1 (continued)

Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
Dusky rabbitfish *Siganus fuscescens*	Siganidae	Throw-nets (mainly), throw spears, surround nets, and spear guns while night fishing with flashlights	Palau	In Palau at least 38 locations are known as pre-spawning aggregation sites for this species. Fishermen position themselves along the migration path as the fish head to the outer reef and fish with throw nets. In the early 1990s fishers became concerned about the declines in the number and sizes of the sites and production has declined. The reasons for declines are not clear but heavy fishing of spawning migrations is very likely an important factor. In 1994 legislation ("Marine Protection Act") banned fishing for *S. fuscescens* from March 1 to May 31 during the supposed peak spawning season but in 2006 the period was reduced to 2 months to allow increase in landings. Despite protection, commercial landings are still reported throughout the March-May closed season	Chap. 12.22
Milkfish *Chanos chanos*	Channidae	Corralling of fish using superlights and dynamite	Philippines, central, Mactan Island	The species is heavily fished as adults during migrations in the spawning season each April for 1–3 weeks when many vessels come to Mactan Island to join local fishers to catch the fish, as well as caught during the settlement stage; 'bangus' fry have long been taken for mariculture growout. CPUE of bangus have declined markedly in the last two decades according to interviews. Philippines Fisheries Code of 1998 could provide some protection but is not enforced. Declines in bangus numbers could partly be due to heavy aggregation fishing	Amores (2003) report in www.SCRFA.org

Flathead grey mullet *Mugil cephalus*	Mugilidae	Hook and line and a wide range of net types; commercially gill and cast nets	Florida Gulf Coast, USA	Large numbers of mullet are taken during the migration to spawning grounds offshore. These fish are prized for their flesh and their roe is part of a large international trade. The Flathead grey mullet is marketed fresh, dried, salted, and frozen with the roe sold fresh or smoked. It is a very important commercial fish in many other parts of the world. During the autumn and winter months, adult mullet migrate far offshore in large aggregations to spawn. A net ban has been in effect in the state of Florida since 1995. Prior to the net ban amendment, mullet were severely overfished throughout the state. Currently, mullet are on the road to full recovery	http://www.flmnh.ufl.edu/fish/gallery/descript/stripedmullet/stripedmullet.html
Other examples					
Giant seabass *Stereolepis gigas*	Polyprionidae	Hook and line, spearfishing; gill net; longline	Baja California, Mexico and Southern California, USA	Commercial landings peaked at about 360 mt in the 1940s, dropped below about 90 mt in 1964, and collapsed by 1980s; recreational fishery went from 800 fish/year to less than 20 per year in 1980s; fished primarily during summer spawning aggregations that formed in kelp beds. No targeted management of aggregations, commercial limits or restrictions; daily catch limit for recreational fishers not clear and not enforced	Domeier (2001), Pondella and Allen (2008)

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Table 8.1 (continued)

Species (common and latin) names	Family	Gear types	Country/Region	Fishery history, management, and conservation status	References
White seabass *Atractoscion nobilis*	Sciaenidae	Gill nets	Southern California USA	Commercial landings fluctuated between 100 and 400 tonnes/year until the 1980s when landings plummeted by 90% by the 1980s. Commercial fisheries targeted spawning aggregations that formed from March to July; Commercial fishing ban during first half of spawning season (March to May), banning of nearshore gillnets (within 3 miles of coast), and 1 fish per day recreational limits implemented to protect spawning aggregations	Allen et al. (2007), Pondella and Allen (2008)
Gulf corvina *Cynoscion othonopterus*	Sciaenidae	Gill nets	Mouth of Colorado River Delta, northern Gulf of California, Mexico	Aggregation fishery is main source of income for the nearby town of Santa Clara for 2 months each year and involves the entire community. Generates 3,000 to 4,000 tonnes and c. $1 million USD in revenue from February to April each year and is main source of fish for the Easter Season in Mexico. Spawning aggregation site protected via a no fishing zone, but is not consistently enforced	Roman-Rodriguez (2000), Brad Erisman, upublished data
Totoaba *Totoaba macdonaldi*	Sciaenidae	Gill nets	Northern Gulf of California, Mexico	Commercial landings dropped from 2,500 tonnes in 1942 to 59 tonnes in 1975 when fishery closed; stocks have not recovered; fishery targeted winter/spring spawning aggregations that form near the mouth of the Colorado River Delta and fish migrating along coast to reach spawning sites. Listed on CITES Appendix I in 1975	Lercari and Chavez (2007); Cisneros-Mata et al. (1995)

Giant yellow croaker *Bahaba taipingensis*	Sciaenidae	Gill nets	Estuaries of Hong Kong and southern Mainland China.	Targeted mainly on seasonal aggregations in estuaries for its highly valuable swimbladder. The species is likely to be close to extinction and the rare catch nowadays of a single large individual often makes news headlines. Landings plummeted in the middle of the twentieth century. Endangered on the IUCN Red List	Sadovy and Cheung (2003)
Large yellow croaker *Larimichthyes crocea*	Sciaenidae	Trawl-dragged seine nets	Estuarine and offshore areas, mainly of Mainland China and Hong Kong	Once a very important fishery in coastal China and heavily fished since the 1950s with little effective management. Heavily fished during the spawning seasons and in deeper overwintering areas. Marked declines occurred in the 1980s and catches of wild fish are now uncommon	Liu and Sadovy (2008)

their exploitation. Specifically, we need to know: (1) the degree to which a fishery depends on aggregation catches and how the increased ease of capture at such times can promote overfishing; (2) the extent to which the subtleties of mating behaviour and other reproductive parameters are or might be affected by fishing activities on aggregations, (3) the social and economic challenges and implications of managing, versus losing, aggregations, and (4) the contribution of healthy aggregations to the overall productivity of the fishery.

Determining the appropriate management approaches for aggregating species is important because of the obvious appeal and attraction of fishing them, especially if this is a traditional or highly lucrative activity. The historical absence of controls on aggregation-fishing or collective experience of marked declines, however, makes their management uniquely challenging, as we shall illustrate. The need for steady market supplies may make a seasonal break in fishing, as could occur with management, unpopular. Combine these factors with the prevailing lack of information on the specific biological and economic impacts of fishing on aggregations *per se* and it becomes easier to appreciate why so few are adequately managed and protected. Even conservation-focused measures, such as marine protected areas, do not routinely consider aggregation protection except when species are already threatened with extinction and thus merit conservative management. It has also become clear that public perspectives and education about aggregations require considerably more attention.

8.2 Types of Extractive Exploitation

Many fish species taken in coastal fisheries of the tropics and subtropics, whether for subsistence, recreational, cultural or commercial purposes, aggregate at predictable times and places to spawn. Not all aggregating species are fished at their spawning aggregations, however. Some, like certain rabbitfishes (Siganidae), mullets (Mugilidae) and bonefishes (Albulidae) are specifically targeted during spawning migrations. Intensive fisheries for CBA on the massive larval settlement pulses of certain mullet, grouper (Serranidae), milkfish (Channidae) or rabbitfish species are partly possible due to aggregation-spawning.

This section provides a general overview of the subsistence, recreational and commercial uses of spawning aggregations with indications of management (covered more in Chap. 11) and landings trends. While some smaller aggregating species, like the blacktail snapper, *Lutjanus fulvus* (Chap. 12.10), are not specifically targeted (and therefore do not currently represent management challenges) we particularly focus on those species targeted heavily at or travelling to their aggregations, rather than on aggregating species in general, because: (1) aggregations or pre-spawning migrations of ripe fish are particularly vulnerable to overfishing and often make up a significant proportion of the annual catch; (2) aggregations or pre-spawning migrations are increasingly a specific target for fishing and can be very valuable; and (3) managing aggregation-fishing and conserving aggregations pose a unique challenge, both for conventional management as well as for marine protected area designation.

8.2.1 Subsistence and Traditional Fisheries

Native fishers have a long history of exploiting aggregating species for subsistence and cultural purposes. In the Pacific, subsistence use is best known from anecdotal accounts and a growing number of published studies based on fisher interviews (e.g. Johannes 1981; Hamilton 2005a, b; Sadovy 2007). Indeed, an annual cycle of seasonally plentiful resources typifies fisheries in many places with fishing pressure concentrated sequentially on different species for brief periods (Johannes 1981; Hickey 2006). In Niue and Fiji, Pacific, goatfish (Mullidae) are seasonally plentiful with eggs and associated with specific community activities (Vunisea 2005, Loraini Sivo personal communication 2010). Accounts of subsistence use in the Caribbean include the Nassau grouper, *Epinephelus striatus*, in southwestern Puerto Rico, which was once caught in massive numbers while aggregating and then salted to last for many months thereafter (Sadovy 1993).

Species that predictably migrate in large numbers close to shore *en route* to spawning areas, such as mullet, rabbitfish and bonefish, are often important for seasonal fishery events in which whole communities take part. In Manus, Papua New Guinea, the mullet *Crenimugil crenilabris* was regularly targeted for its roe and flesh. Communities gather during its pre-spawning migrations and catch large numbers using gill and hand nets, even dynamite (Hamilton 2003, 2005a, b). In Tarawa, Kiribati, bonefish have been heavily fished by gill nets on their spawning runs and of several runs, all but one yielded smaller and fewer fish between 1977 and the late 1990s. These changes were attributed to fishing and causeway construction that impeded coastal migrations (Johannes and Yeeting 2000). Regulations introduced in 1994 prohibited fishing during the 3 days before and after the full moon migration period and restricted fishing methods; some recovery in numbers was noted and there is now both recreational and subsistence use of the species (Being Yeeting personal communication 2009).

Much subsistence fishing of aggregations nowadays involves a commercial component and the line between the two activities is increasingly blurred. While subsistence fishing is often poorly documented, and volumes, species and other purely subsistence fishing activities are rarely well understood, indications are that catches can be substantial (Sect. 8.2.1). In one study in Fiji, for example, many major species for both subsistence and commercial use are fished from aggregations. In Pohnpei, Micronesia, subsistence fishing of aggregations is largely ignored by local legislation, which focuses primarily on commercial fishing. However, the removal of reproductively active fish for subsistence may equal or even exceed that of commercial catches (Rhodes et al. 2005). In Palau, subsistence fishers have shifted to more modern, typically less selective, fishing gears and practices, with heavy illegal use of SCUBA and spearing, including on aggregations. The many fast boats that now exist in the country enable fishing to occur throughout the Palauan archipelago, and exploitation is shifting from a focus on subsistence and 'custom' (traditional use) to commercial use, including for the tourism sector. While the fishery is no longer regularly monitored, many aggregations of squaretail coralgrouper, *P. areolatus,* brown-marbled grouper, *E. fuscoguttatus,* camouflage grouper, *E. polyphekadion*, bluespine unicornfish, *Naso unicornis,* twin-spot snapper, *Lutjanus bohar,* and long-face emperor, *Lethrinus olivaceus*, long used for subsistence, have declined over the last decade or so according to fisher perceptions (Johannes 1981; Sadovy 2007).

8.2.2 Recreational and Sport Fisheries

Recreational fishing on spawning aggregations and migrations in tropical and subtropical coastal species is attracting management attention because of associated high economic value and growing popularity. Examples come from Australia, the Pacific and Indian Oceans, and the Caribbean. Some of the fishes involved are considered good eating fish, like seabreams (Sparidae) and croakers (Sciaenidae), while others, such as tarpon or bonefish, are mostly valued for their sport appeal and fighting ability. Recreational fishing tends to involve selective gears such as hook and line and speargun and may involve tag (or capture) and release.

Relatively well-studied coastal recreational fisheries occur in Australia and the USA. In western Australia, there is high recreational interest in the silver seabream (snapper or silver bream) (Sparidae; *Pagrus auratus* = *Chrysophrys aurata*, Chap. 12.12), mulloway and black jewfish (Sciaenidae: *Argyrosomus hololepidotus* and *Protonibea diacanthus*), and in dhufish (Glaucosomatidae: *Glaucosoma hebraicum*), among other species, much of it involving catch and release. In Shark Bay, for example, a major recreational fishery on the silver seabream occurs in winter, when sea conditions are most conducive to fishing from small boats and the fish aggregate to spawn. By the mid-1990s, there was serious concern that recreational catches for this species had reached unsustainable levels, largely due to aggregation-fishing (Marshall and Moore 2000). In 2003, a total allowable catch, and other management measures, was agreed for each snapper stock, an unusual situation for such a small and mostly recreational fishery in Australia (Chap. 12.12). The black jewfish in Australia's Northern Territory is also taken by several fishing sectors but predominantly by recreational fishermen with heavy targeting of aggregations (Phelan et al. 2008). Dhufish and mulloway are highly regarded recreationally but long-lived and fished on aggregations with concerns about overfishing for both species (Mackie et al. 2009).

In parts of the Caribbean and SE USA, tarpon, *Megalops atlanticus*, is highly valued recreationally and taken in large numbers during pre- or post-spawning migrations. The fisheries are now heavily regulated because of marked declines noted in the past from overfishing and loss of habitat, with commercial take no longer permitted in Florida. Nowadays, the tarpon fishery in the region is largely one of tag and release (http://www.tarbone.org/about-btt/then-and-now.html) and among the most lucrative fisheries in the state of Florida.

Recreational fisheries that involve aggregating species occur in many parts of the Pacific. In Kiribati, for example, bonefish, *Albula vulpes*, is taken for subsistence (see above) and, since the early 1980s, as part of a high-value fishery. For many years, its spawning migrations were subjected to fishing, but due to strong support from the tourism sector and interest in long-term sustainability, fishing is now

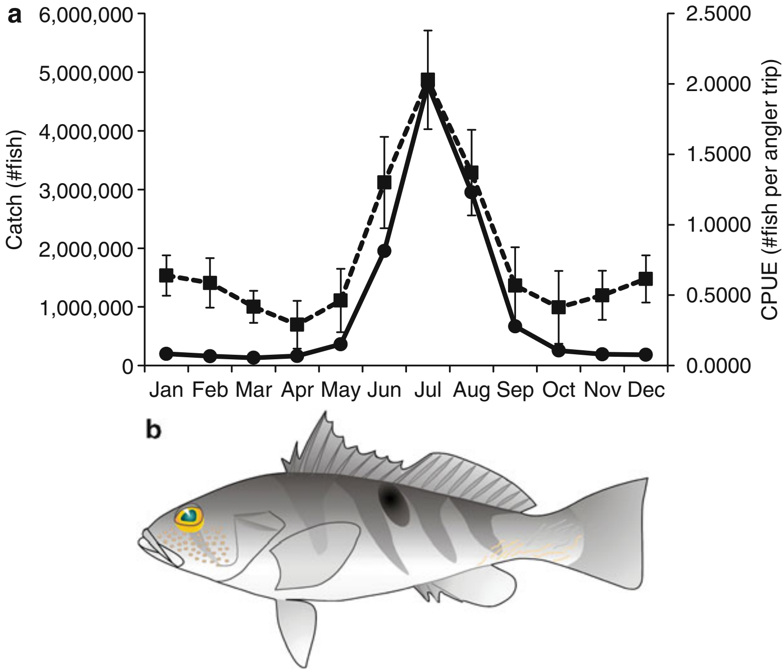

Fig. 8.2 (**a**, **b**) Barred Sand Bass, *Paralabrax nebulifer*, have consistently ranked as one of the top two recreational fisheries of Southern California for more than three decades (Love et al. 1996; Dotson and Charter 2003). The species forms massive spawning aggregations over offshore sand-flats from May to August, with a peak in July (Turner et al. 1969; Love et al. 1996). While all commercial catch has been banned since WWII, its aggregations are not managed. However, the recreational fishery is managed by a 12-inch minimum size limit and a 10-fish per day bag limit (combined daily limit for the 3 *Paralabrax* spp. that co-occur). Catch-*circle* and *solid line* (Drawing: © Larry Allen)

prohibited during spawning times (Being Yeeting personal communication 2009). Where this recreational fishery developed, there were conflicts with locals wanting to maintain it as a food source. However, after public consultation, more than 90% of the community agreed that it was a worthwhile resource to protect and use as a basis for tourism. In the Gulf of California, the endemic Gulf grouper, *Mycteroperca jordani*, is a prized target of recreational anglers and spearfishers, and sportfishing tournaments are still held during the spawning season despite dwindling numbers of fish (Sala et al. 2003; Saenz-Arroyo et al. 2005, BE personal observation). Kelp Bass (*Paralabrax clathratus*) and Barred Sand Bass (*P. nebulifer*) have consistently ranked top among species targeted by recreational fisheries of southern California, USA, over the past three decades (Dotson and Charter 2003), with 70–80% of annual landings and the highest fishing effort occurring during the summer months when both species form spawning aggregations. Although banned from commercial harvest, no specific management of aggregation sites or periods exist for the recreational fishery of either species, and landings of both have declined significantly over the last 5–10 years (Fig. 8.2).

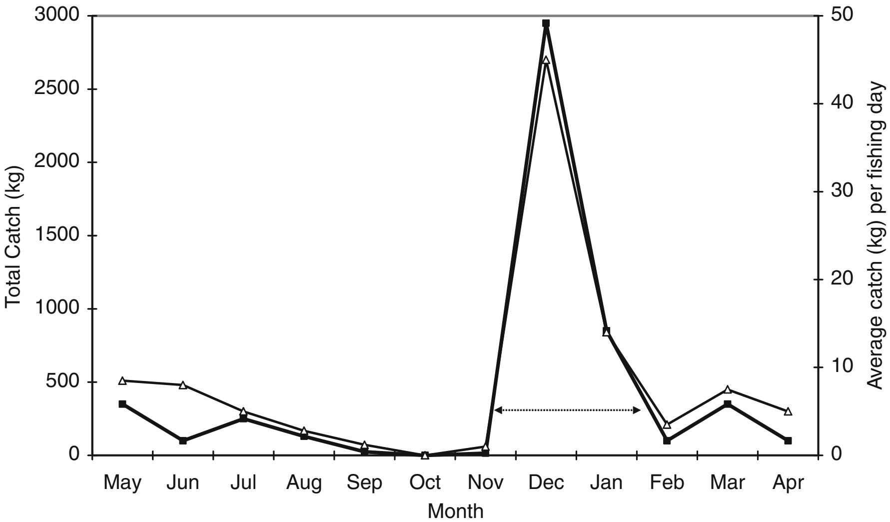

Fig. 8.3 Catch trends (total and average) in *E. fuscoguttatus* in eastern Australia show clear peaks during the limited spawning season (indicated by *horizontal line*) (Pears et al. 2007, Chap. 12.2)

8.2.3 Commercial Fisheries

Spawning aggregations are increasingly the target of commercial fisheries, using a wide range of gears and for both local and international markets. Many such fisheries are lucrative, yet few are managed and many show evidence of declines probably associated with aggregation-fishing (Sadovy de Mitcheson et al. 2008, Table 8.1). Species range from those taken exclusively at aggregations, either live or dead, for their flesh to those taken for their roe or swimbladder. Inshore coastal migrations of rabbitfishes, tarpon and mullets have also long attracted seasonal fishing operations, because they are highly predictable and many have declined or no longer form. Some species are mainly or exclusively taken in significant numbers when they aggregate, such as the brown-marbled grouper in Australia (Chap. 12.2) (Fig. 8.3) and Palau, and several deepwater species, such as orange roughy, *Hoplostethus atlanticus.* In the southern Gulf of California in Mexico, of the ten top commercially important reef fishes in terms of landings, eight are aggregation-spawners (Erisman et al. 2010; Figs. 8.4 and 8.5). Commercial fishing gears range from bottom trawls, purse seines and gill nets to hook and line, fish traps, spearguns with or without the use of compressed air diving, and even explosives and cyanide (Sect. 8.3).

In extreme cases species are threatened with extinction by commercial aggregation-fishing. The giant yellow croaker (Chinese bahaba), *Bahaba taipingensis*, a southern China endemic, and the totoaba, *Totoaba macdonaldi*, a similarly large croaker endemic to the Gulf of California, had fisheries targeting both principally for their high-value swimbladders. The large yellow croaker, *Larimichthyes (=Pseudosciaena) crocea*, is now considered to be endangered (Wang et al. 2009) and the totoaba was

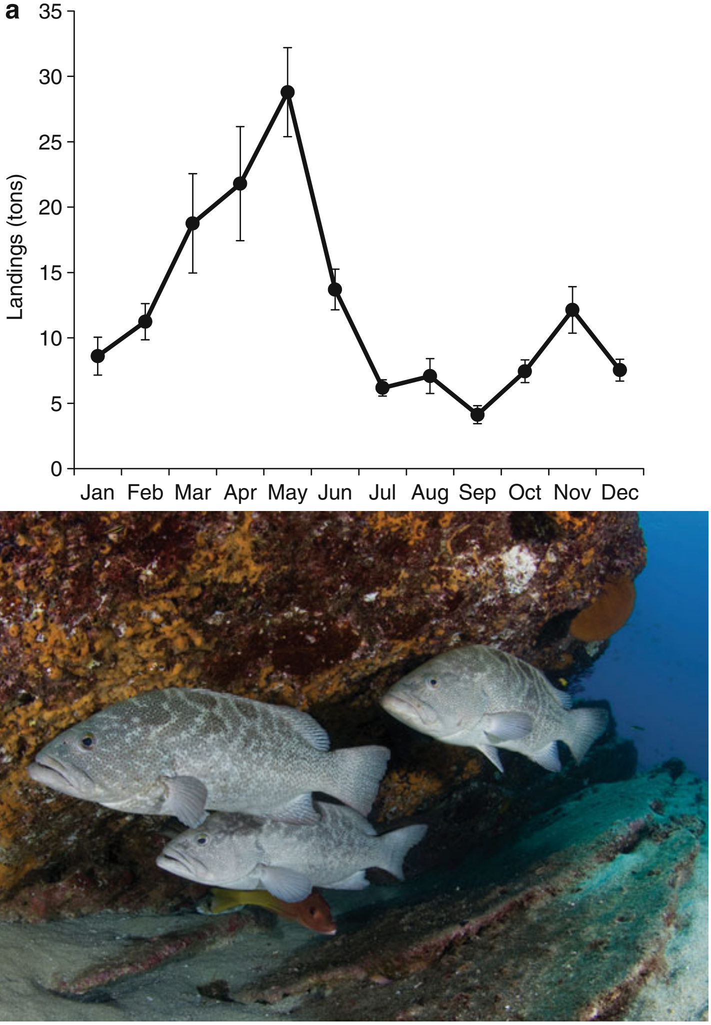

Fig. 8.4 (**a**, **b**) Leopard grouper, *Mycteroperca rosacea*, spawn within aggregations from March to June in the southern Gulf of California, Mexico (Erisman et al. 2007), with peak spawning in April–May. Commercial fishers target aggregations using gill nets, nighttime spearfishing and hookah, and hook and line. Data show mean monthly commercial landings for 1999–2007 (mean and SE) (Photo: © Octavio Aburto/iLCP)

the first marine fish listing on a CITES (Convention on International Trade in Endangered Species) Appendix I in 1975 (Musick et al. 2000). Many of the larger species of groupers (Serranidae) are threatened primarily because of overfishing, especially when focused on aggregations (Tuuli 2010; Sect. 8.3.1).

Seasonal concentrations of spawning adults can form the basis for specialised fisheries. For example, herring, such as the Pacific herring, *Clupea pallesi*, eggs are

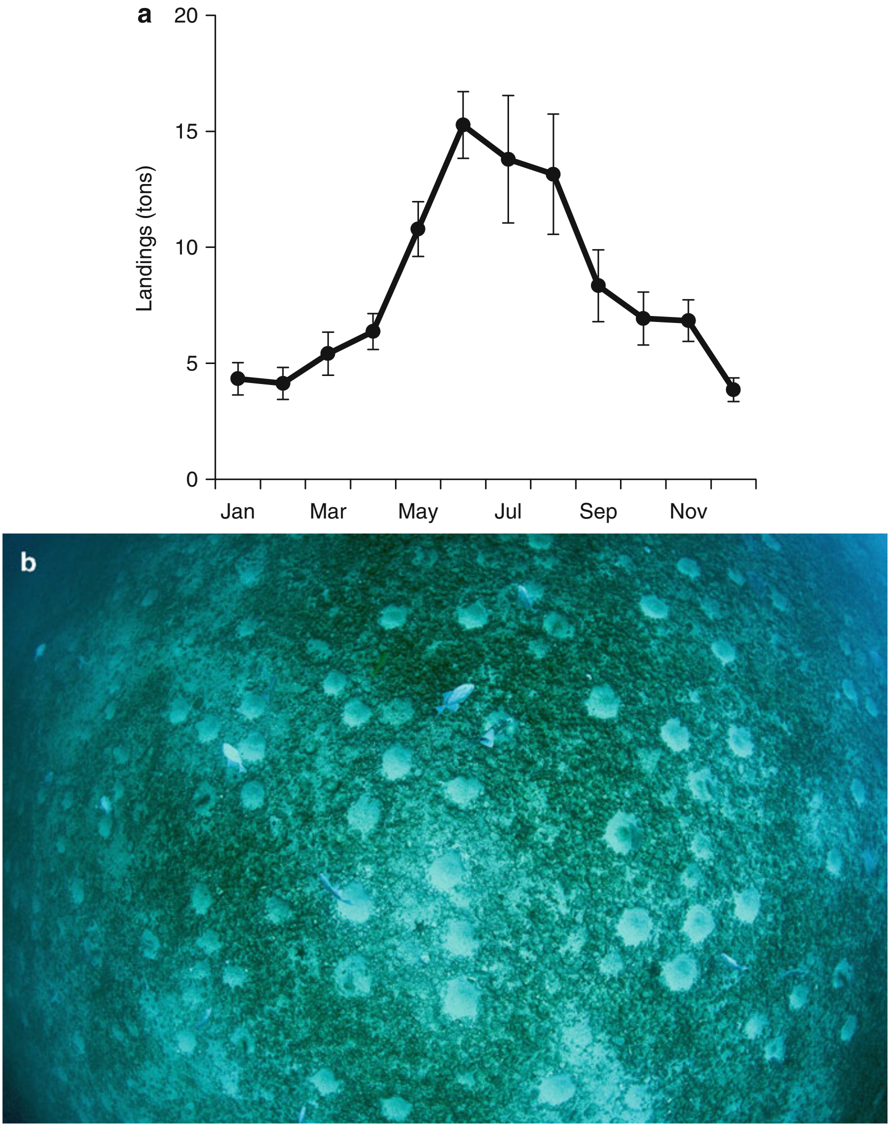

Fig. 8.5 (**a**, **b**) Finescale triggerfish, *Balistes polylepis*, aggregate to spawn and nest (*light circles* in photo) from May to September in the southern Gulf of California, Mexico (Sanchez-Velasco et al. 2009, BE personal observation). Commercial fishers target these aggregations by nighttime hookah fishing and gillnets. Data show that commercial landings for 1999–2007 (mean and SE) peak during this period (Photo: © Octavio Aburto/iLCP)

valued in a lucrative United States export market for herring roe, and for 'kazunoko kombu' (roe-on-kelp), a delicacy in Japan. In San Francisco Bay, California giant kelp is suspended in the spawning area of the species as spawning substrate, then prepared and exported to Japan. Several important fisheries target the enormous larval pulses that result from the large spawning events associated with aggregations for capture based aquaculture (CBA). Reef-associated fishes used for CBA include certain rabbitfishes, mullets, milkfish and groupers for which seasonal fisheries on post-settlement phase fish target the massive and concentrated numbers of settling recruits (Lovatelli and Holthus 2008). As one example, over a few months of the year in many Pacific islands the young of several species of rabbitfish, barely 2 months old, regularly recruit as a massive balls of tiny fish on shallow seagrass areas, mangroves, reef flats or beach areas. They are collected in their millions by push nets, cast nets, seine nets, and lift nets and grown to market size under captive conditions. They are so abundant that they have been referred to as 'endless' (Teitelbaum et al. 2008).

Over the last two decades, a particularly valuable fishery for living reef fish, destined for the Chinese seafood market and known as the live reef food fish trade (LRFT), has placed pressure on grouper populations in parts of the Indo-Pacific (Sadovy et al. 2003). The apparently insatiable consumer demand for these fishes drives an intensive fishery to fill air and sea consignments on a frequent and regular basis from many source countries. Aggregations are obvious targets for several of the preferred species, particularly brown-marbled grouper, camouflage grouper and squaretail coralgrouper, that form them, leading to declines in catches in the Solomon Islands, Papua New Guinea, Palau and the Seychelles (Johannes and Riepen 1995, Hamilton and Matawai 2006; Aumeeruddy and Robinson 2006). In Papua New Guinea (PNG) a Hong-Kong based trial LRFT operation claimed that it was not economically viable if it could not target aggregations and the operation ceased when aggregation fishing was not permitted (Leban Gisawa, PNG fisheries 2008). Fiji became involved in the LRFT in the late 1990s but stipulated no fishing during spawning or aggregation periods (Ledua Ovasisi, Fiji Fisheries, 2008). Aside from the large numbers of live fish removed from aggregations, which can represent a high proportion of assembled fish, catches of fully ripe females can lead to significant wastage because gravid fish tend to undergo high mortality shortly after capture.

8.3 Fishery Implications of Fishing Spawning Aggregations

A major challenge is to determine the extent to which exploitation of spawning aggregations contributes to declines in marine fish populations. Few of the 15,500 known marine fish species have both the necessary biology and fishery information for such detailed assessment. Nonetheless, this task is critically important from a management perspective, since many of the world's major fisheries support or once supported aggregation-fishing. The massive landings that once characterized many highly productive fisheries involved seasonal gatherings of fish at magnitudes far greater than are seen today (Roberts 2007). Presumably, aggregation-spawning evolved, for whatever proximate reason, because, ultimately, it resulted in greater reproductive success compared to a non-aggregating habit. Unfortunately, the very biological characteristic, aggregation-spawning, that evidently contributes to making such species so productive may also prove to be their 'Achilles Heel' when

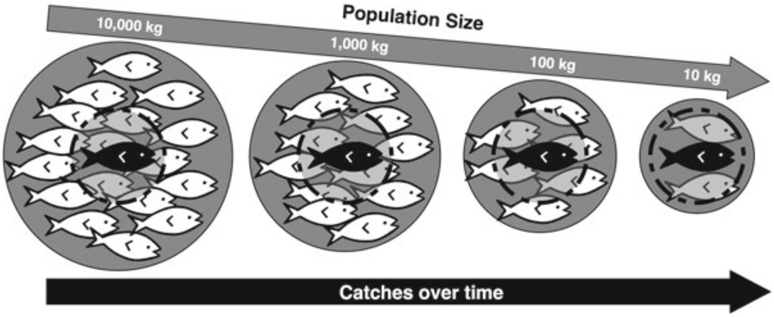

Fig. 8.6 Hyperstability refers to a phenomenon in which an observed index of stock abundance (e.g. catch per unit of effort or CPUE) remains stable (represented by *black fish in dotted circle*) while the abundance (population size) of the stock in question is actually declining (*black arrow* denotes past to the *left* and now to the *right*). The figure represents how CPUE can remain stable over time even as total fish numbers (*white fish and grey arrow*) are declining because fish are still aggregating to spawn; this will occur when the fishing effort is not so high that it removes all the fish at once but gives the illusion that fish numbers are not changing (Drawing: Octavio Aburto)

exploitation is uncontrolled. That is to say, those species that have evolved to spawn in massive aggregations may have done so because it is a particularly successful reproductive strategy, but however, the habit makes them very susceptible to overfishing.

To understand the impact of fishing on spawning also aggregations, two factors must be considered, the high catchability of fish while gathered for spawning, and the possible *direct* and *indirect* effects of fishing on aggregated and reproductively active fish. Aggregating behaviour can make fish particularly easy to catch (i.e. high catchability and hyperstability) during the spawning season yet very difficult to monitor (Fig. 8.6, Chap. 11) or manage relative to non-aggregating species. Exploitation of aggregated fish may directly or indirectly compromise reproductive function or output by disrupting the mating process or due to possible Allee effects (see Sect. 8.4.2) at low population levels. While standard fishery modelling approaches incorporate sex ratios, fecundity and spawning biomass into stock assessments, they typically do not factor in subtleties of reproductive biology (Hilborn and Walters 1992; Vincent and Sadovy 1998). Yet literature on other vertebrate taxa clearly shows that details of social and reproductive behaviour can be important components in the management of wild populations (Caro 1998). We explore each of these points.

Although aggregations may be subjected to intense fishing pressure, it is typically difficult to determine whether aggregation fishing is a major causative factor of population declines because most species with this habit are also fished outside of aggregations. This is a major impediment to promoting the need for the specific management of aggregations. An alternative explanation could be that a general failure to manage these fisheries throughout the year is the major cause of any declines noted, rather than aggregation-fishing *per se*. To tease apart these possible explanations, we consider the extent to which unmanaged exploitation (extrinsic factor) of aggregations could be a specific driver of population declines (see Sect. 8.3.1) and examine the role of fishing technology (Sect. 8.3.2). In Sect. 8.4 we go on to explore the possible biological (intrinsic) factors affecting responses to aggregation fishing. We then consider whether aggregations in general, or perhaps certain types of aggregations, need specific management attention, and address management options.

8.3.1 Specific Effects of Aggregation Versus Non-aggregation Fishing

In the management of aggregating species, understanding the specific impacts of fishing their aggregations, as distinct from the overall impacts of total fishing pressure on the target population throughout the year is important, albeit challenging. Natural resource managers must decide where funds and capacity are best directed, what kind of management is most appropriate and socially acceptable, and the economic implications for fishing communities of actions such as aggregation closures, or, conversely, their losses. Since detailed fishery and biological information is unavailable for most exploited reef fishes, and because few datasets allow for in-depth examination of their fisheries, teasing out cause and effect of aggregation versus non-aggregation fishing is problematic. The challenge is further compounded by the fact that other life-history characteristics, such as longevity or late sexual maturation, can strongly influence responses to fishing, and many aggregating species exhibit these characteristics (Reynolds et al. 2005). Moreover, making comparisons across very different taxa is complicated by phylogenetic differences, while analyses that treat species values as statistically independent points are questionable because closely related species may share traits through common descent rather than through independent evolution (Felsenstein 1985).

At least four approaches allow examination of possible fishery implications of fishing spawning aggregations. The first is to use information qualitatively across a wide taxonomic range of species and determine whether those in which aggregations are specifically targeted have shown the most marked changes. The second is to compare the fisheries status of several aggregating species within a single multi-species fishery, in which all species are exposed to similar fishing profiles and show general biological similarities yet exhibit different degrees of aggregating behaviour and extent of targeting of aggregations. A third approach, and one that addresses phylogenetic issues, is to select a single lineage that has both aggregating and non-aggregating species and examine fishery or conservation status by species. The fourth involves a comparison of the fishing history of a single aggregating species among locations or populations, ranging from situations where its aggregations are targeted and make a significant contribution to annual landings to those where aggregations contribute little to the overall fishery. While none of these four approaches entirely avoids possible confounding factors of life history differences, relatedness or the relative importance of non-aggregation fishing, examining the question from different perspectives at least provides a semi-quantitative means of evaluating the importance of aggregation-exploitation *per se* on fisheries. It also helps to identify the kinds of information needed in the future to address the question in more detail.

8.3.1.1 Approach One – Spawning Aggregation-Fishing as a Possible Threat Factor Across Taxa

Many aggregating species produce higher catch per unit of effort (CPUE) or higher percentages of annual landings when taken from aggregations than during other times of the year. Indeed, many of those species that have suffered serious declines or are otherwise considered to be of conservation concern, such as those listed as threatened under International Union for Conservation of Nature (IUCN) criteria, or depleted by FAO, are mainly or exclusively fished during aggregation periods.

The FAO database of world fisheries for 2004 indicates that of stocks for which information is available (c. 441 stocks), 52% are fully exploited and a further 24% overexploited or depleted (FAO 2005). Of the latter group many involve exploitation of spawning aggregations. Examples include European plaice *Pleuronectes platessa,* Atlantic cod*, Gadus morhua,* haddock, *Melanogrammus aeglefinus*, Atlantic herring*, Clupea harengus,* whiting*, Merlangius merlangus,* Argentine hake*, Merluccius hubbsi,* Geelbeck croaker*, Atractoscion aequidens,* Red steenbras *Petrus rupestris,*, icefish*, Champsocephalus spp.* Atlantic bonito*, Sarda sarda*, Atlantic halibut, *Hippoglossus hippoglossus*, and Pacific halibut *Hippoglossus stenolepis* (King 1985; Smale 1988; Griffiths and Hecht 1995; Smedbol and Wroblewski 1997; Hutchings et al. 1999; Parkes 2000; Hoarau et al. 2005; Pajaro et al. 2005; Zengin and Cincer 2006; Loher and Seitz 2008; Tobin et al. 2010). Particularly noteworthy are species like the Atlantic and southern bluefin tunas, *Thunnus thynnus* and *T. maccoyii*. These two tunas show aggregating behaviour (Farley and Davis 1998; Fromentin and Powers 2005) that appears to be more concentrated than for any other pelagic fishes and both have undergone some of the most marked declines among pelagic species, with heavy fishing focused on their aggregations. Other examples are provided below in the sections on groupers, South African sea breams (Sparidae) and croakers. Among reef fishes, species of many taxa typically form aggregations, and 60% of known tropical aggregations have undergone declines (Sadovy de Mitcheson et al. 2008).

Fuzzy logic (a form of mathematical logic in which truth can assume a continuum of values between 0 and 1) is one approach to explore possible factors associated with intrinsic extinction vulnerability to fishing. Many aggregating species have other characteristics, in addition to concentrated spawning, associated with high vulnerability to fishing or threat factors, such as large body size and longevity (e.g., Reynolds et al. 2005). For reef fishes in Fiji, Cheung et al. (2005) considered maximum body size, natural mortality and spawning aggregations, among other variables, and found, using fuzzy logic, that the incorporation of aggregations in this novel analysis greatly increased the goodness-of-fit between the estimated vulnerabilities and the empirical population trends, suggesting that aggregating species are more threatened, regardless of other characteristics, all else being equal. In a global analysis of more than 14,000 species that used a similar fuzzy logic approach, seamount aggregating fishes were shown to have a higher intrinsic vulnerability to fishing in comparison with other groups of commercially exploited marine fishes, due to a suite of life history characteristics such as long lifespan, late sexual maturation, slow growth, and low natural mortality (Morato et al. 2004).

8.3.1.2 Approach Two – Single Fishery, Multiple Species That Vary in Duration and Predictability of Aggregations

An unusually detailed and long-term fishery database from Cuba for six commercially important aggregating snappers (cubera snapper, *Lutjanus cyanopterus,* mutton snapper, *L. analis,* grey snapper, *L.griseus,* lane snapper, *L. synagris,* yellowtail snapper, *Ocyurus chrysurus*, and the Nassau grouper) was examined for species-specific trends (Claro et al. 2009). The species are reported to all share similar coastal water habitats, be part of the same multi-species fishery, have all been exposed to similar social, economic and management factors over a 45-year period, and evidently show different intensity of aggregation behaviour in relation to reproduction. They are also among the larger and longest-lived species in the fishery. In all six species, more than 50% of annual landings were taken during the spawning season, and all declined over time. Although cause and effect cannot be established, aggregation predictability and targeted fishing were likely major factors in declines, because the most marked declines occurred among those species that exhibit the briefest (fewest months) and most highly predictable (fish highly concentrated at relatively few sites) aggregations (Fig. 8.7). Marked declines were also observed in mullets, which are often targeted on or moving to spawning aggregations in Cuba. Other groups of fishes (jacks-Carangidae, mojarras-Gerreidae, and grunts-Haemulidae), not knowingly targeted in association with aggregations, involved in the same multi-species fishery have evidently not undergone similar declines (Claro et al. 2009).

8.3.1.3 Approach Three – Spawning Aggregations Within a Single Taxon

This approach compares trends within three very different taxonomic groups, groupers, sea breams and croakers, each taxon with both aggregating and non-aggregating species. The groupers (Family Epinephelidae, subfamily Epinephelinae) were recently assessed for conservation status according to IUCN Red List categories and criteria; threatened (T), near threatened (NT), least concern (LC) and data deficient (DD). The rich sea bream assemblage of South Africa has a relatively well documented fishery history, while many large croakers are fished on their aggregations with declines noted in some.

A comparative analysis of 163 groupers indicates that, among species of known reproductive strategy, spawning aggregation formation is associated with higher extinction risk (Fig. 8.8); in all cases aggregations are exploited. Since larger species

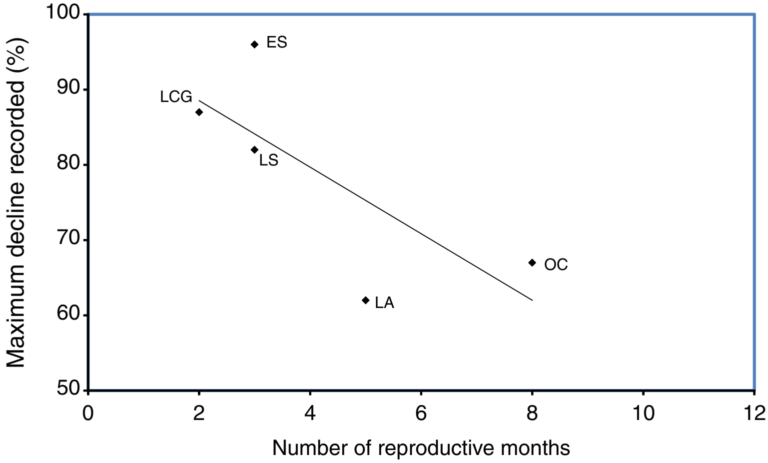

Fig. 8.7 Six commercially important coral reef species (two lumped), of maximum body sizes of 50 cm or more, taken in the coastal multi-species fishery in Cuba from a 45-year dataset with monthly landings data resolution. Y-axis indicates the largest overall drop within the 45-year period examined expressed for the 6 species according to the number of months that each species is known to be reproductive months. The trend shows greatest declines in those species that have the shortest and generally more concentrated spawning period ($r = -0.74$). *Lutjanus cyanopterus* and *L. griseus* data are lumped (LCG) *Epinephelus striatus* (ES), *L. synagris* (LS), *L. anali*s (LA), *Ocyurus chrysurus* (OC) (Claro et al. 2009)

in a taxon are more likely to spawn in aggregations than related smaller ones (Domeier and Colin 1997, Chap. 4) body size is potentially a confounding factor and further consideration is warranted; nonetheless, the data tend to support the conclusion that aggregating species are more vulnerable. For example, comparing similar-sized and sympatric species pairs in the western Atlantic (red grouper, *Epinephelus morio*-near threatened, no indication of strong aggregating habit, paired with Nassau grouper–threatened, transient aggregator, hundreds to tens of thousands of fish in an aggregation) and Indo-Pacific (leopard coralgrouper, *Plectropomus leopardus*–near threatened, resident aggregator, tens to a few hundred fish at a single aggregation paired with squaretail coralgrouper-threatened, transient aggregator, hundreds to thousands of fish at a single aggregation) suggests that declines in populations, as judged by landings trends in the fishery over time, have been greatest in transient species that aggregate at the fewest known sites and most predictably. This is clearly suggested by marked declines in Nassau grouper and squaretail coralgrouper and is consistent with the general and perhaps intuitive observation that, all else being equal, transient spawners are likely to be more susceptible to overfishing than resident spawners.

Of 42 species of sea bream (family Sparidae) found in South African waters (30 are endemic) the ‘seventy-four’, *Polysteganus undulosus*, has undergone the greatest overall declines in this comparatively well-monitored coastal fishery. It is one of the only sea breams in the region, of the 42 present, that was once fished intensively at specific spawning aggregation sites. In the early 1900s the species

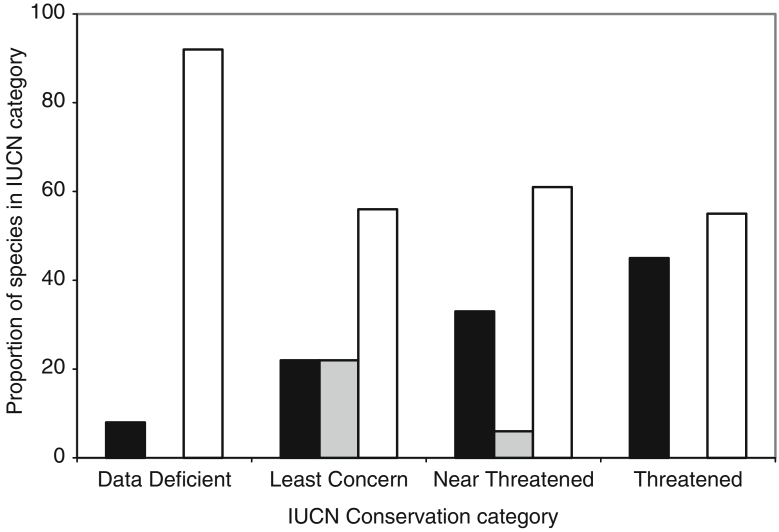

Fig. 8.8 Conservation status of 163 groupers of the family Epinephelidae according to IUCN Red List criteria (www.iucnredlist.org), data deficient, least concern, near-threatened and threatened. For each conservation category the numbers of species known to aggregate (*black bar*) known not to aggregate (*grey bar*) and of unknown reproductive strategy (*white bar*) are represented as a proportion of the category. The graph suggests that those species known to aggregate are more likely to be threatened or near-threatened (Craig et al. 2011; Sadovy de Mitcheson et al. in press)

contributed over 50% of landed catch from line-boats out of Durban harbour (Garratt 1996; Penney et al. 1999). By the late 1960s, catches in the main fishing area, KwaZulu-Natal (KZN), had collapsed and after several failed management interventions during the 1980s, a moratorium was placed on the species in 1998 (Mann 2007).

Although large (up to 120 cm TL), the seventy-four is not the largest sea bream in S. Africa. However, it has one of the shortest and most predictable spawning seasons of the South African sea bream assemblage, appears to be the most threatened sea bream and its collapse is one of the best documented examples of severe overfishing in S. African waters (reviewed in Mann 2007). Its large spawning aggregations once lasted from July to November and were heavily fished leading to marked declines in catches and, ultimately, the need for management. However, the species showed little recovery despite a fishing moratorium. While there are positive indications of larger adults in KZN and increased abundance of juveniles in the Eastern Cape, poaching continues and the high price paid for this desirable, and now rare, fish means the greatest threat to its recovery is the lack of effective enforcement (Mann 2007). Another sea bream, the red steenbras (*Petrus rupestris*) has suffered a similar fate. Although its spawning aggregations are less well known; experienced fishers strongly indicate that this species aggregates during its spawning periods (August-November) when the largest catches are made (Bruce Mann personal communication 2009).

The croakers include many highly valued species aggregating to spawn, typically in coastal or estuarine areas and which are targeted at this time by commercial or recreational fishers (Sects. 8.2.2 and 8.2.3). Of 28 species reviewed, information on aggregation behaviour was available for 10, mainly the largest (>1 m TL), species that had the shortest reproductive seasons (Tuuli 2010). In the Colorado River Delta in the northern Gulf of California the totoaba and Gulf corvina (*Cynoscion othonopterus*) have undergone complete fishery collapses and were the only species known to form massive, dense, brief and highly localized aggregations at just a few sites (Cisneros-Mata et al. 1995; Roman-Rodriguez 2000). The totoaba was the first commercial marine food fish to be listed on Appendix I (1975) and is yet to recover. In Australia, aggregation-fishing appears to be the major reason for declines in the mulloway and black jewfish (see above), and in China it was very likely the principal factor leading to the threatened conservation status of the Chinese bahaba, and the large yellow croaker (Sadovy and Cheung 2003; Liu and Sadovy de Mitcheson 2008).

8.3.1.4 Approach Four – Spawning Aggregations Within a Species, Geographic Variation in Fishing Intensity and Stock Condition

Fishery status can be compared for a single species among places or populations where aggregations are subjected to different levels of fishing pressure. To do this we need (1) assessments of population status (either from fishery stock assessment or using some other indicator such as trends in body size or in CPUE) and (2) monthly landings data or information that distinguish catches between spawning and non-spawning seasons. Although more quantitative data are needed to identify the effects of fishing on aggregations versus impacts of fishing on the stock as a whole, available qualitative and quantitative information for the Nassau grouper strongly suggests declines in fish sizes and numbers associated specifically with aggregation-fishing. For example, where aggregations have been protected for a number of years and monitored, numbers are substantial or have stabilized (e.g. Cayman Islands; Philippe Bush 2009), whereas where there has been little effective protection aggregations are much reduced or no longer form (e.g. Belize, Cuba, Puerto Rico and parts of Mexico) (Sadovy 1993; Aguilar-Perera 1994, 2007; Sala et al. 2001; Heyman and Wade 2007; Claro et al. 2009).

Since it is unlikely that more detailed assessments are forthcoming in the near term, we propose that the indications from different Nassau grouper stocks, combined with the analyses in approaches 1–3 above, unequivocally call for a conservative approach to managing aggregation-fisheries.

8.3.2 Effects of Gear Types and New Technologies

Access to and exploitation of spawning aggregations has become easier due to the emergence of new technologies and more effective gear types. Devices such as detailed fishing charts, Geographic Information Systems (GIS), bathymetric maps, sonar, and Global Positioning Systems (GPS) make aggregations less difficult to find, characterize, exploit, relocate, and communicate to others (Sadovy and

Domeier 2005). Satellite imagery (e.g. Google Earth) provides a bird's eye view of fishing areas, increasing the likelihood of locating the spawning grounds of target species once the physical attributes of such sites are better understood. The live fish trade industry has used helicopters and planes to seek concentrations of fishing activity at aggregations (Leban Gisawa personal communication 2008, Bob Johannes personal communication 2000). Increased range and capacity of large fishing vessels, including those with live wells or viviers that can carry 15–20 mt, greatly increase interest in commercial aggregation fisheries (Johannes and Riepen 1995; Johannes 1997). Finally, the widespread introduction of ice plants in the Pacific to encourage and facilitate market linkages is a favoured development tool often tied to tuna licenses; iceplants greatly increase access to urban markets by remote fishing communities to markets by providing temporary storage of fish until cargo vessels can take them to market, thereby opening up remote aggregations to commercial exploitation (Being Yeeting personal communication 2009).

Certain gear types and fishing practices have negative impacts on aggregation sites and fishes. Gill nets or bottom trawls damage important habitat features of aggregation sites (Koslow et al. 1997; Hamilton et al. 2005). In the Gulf of Mexico, sites with high densities of *Oculina* coral hold high abundances of gag, *Mycteroperca microlepis*, and scamp, *Mycteroperca phenax*, groupers; commercial trawl fisheries damage these spawning habitats, thereby accelerating population declines (Koenig et al. 2000). Dynamite is regularly applied to take milkfish, *Chanos chanos*, in the Philippines (Table 8.1). Discards of sub-legal size fish may comprise a substantial proportion of the recreational or commercial catch at aggregation sites but are often associated with high post-release mortality due to barotrauma, gut-hooking, stress and fatigue from prolonged handling times, or predation following release (Burns et al. 2002; Rudershausen et al. 2007).

Expansion of the SCUBA diving tourist industry, especially the increase in availability of inexpensive equipment (tanks, fins, underwater lights, etc.) has greatly contributed to the rise in the number of commercial, recreational, and artisanal fishers and divers who utilize this method to harvest fishes from aggregations for sport or profit (e.g. Paz and Truly 2007). Night-time spearfishing, which involves compressed air supplied via SCUBA or hookah, allows divers to easily harvest large numbers of resting fishes at aggregation sites with minimal effort. This activity is widely illegal but its prohibition is rarely enforced, and it is considered to be the major cause of aggregation declines in the Gulf of California and throughout the Pacific islands (Gillett and Moy 2006, www.seawatch.org) (Fig. 8.9). Even the simple technology of a reliable d-cell battery torch (Toshiba and others), allowed night fishing while snorkelling in many areas of the Pacific (Pat Colin personal communication 2010).

8.4 Biological Effects of Fishing Spawning Aggregations

Animals congregate for numerous reasons. Conservation biologists and fishery managers, however, rarely concern themselves with the implications of grouping for conservation action (Reed and Dobson 1993). The one exception is in relation to the

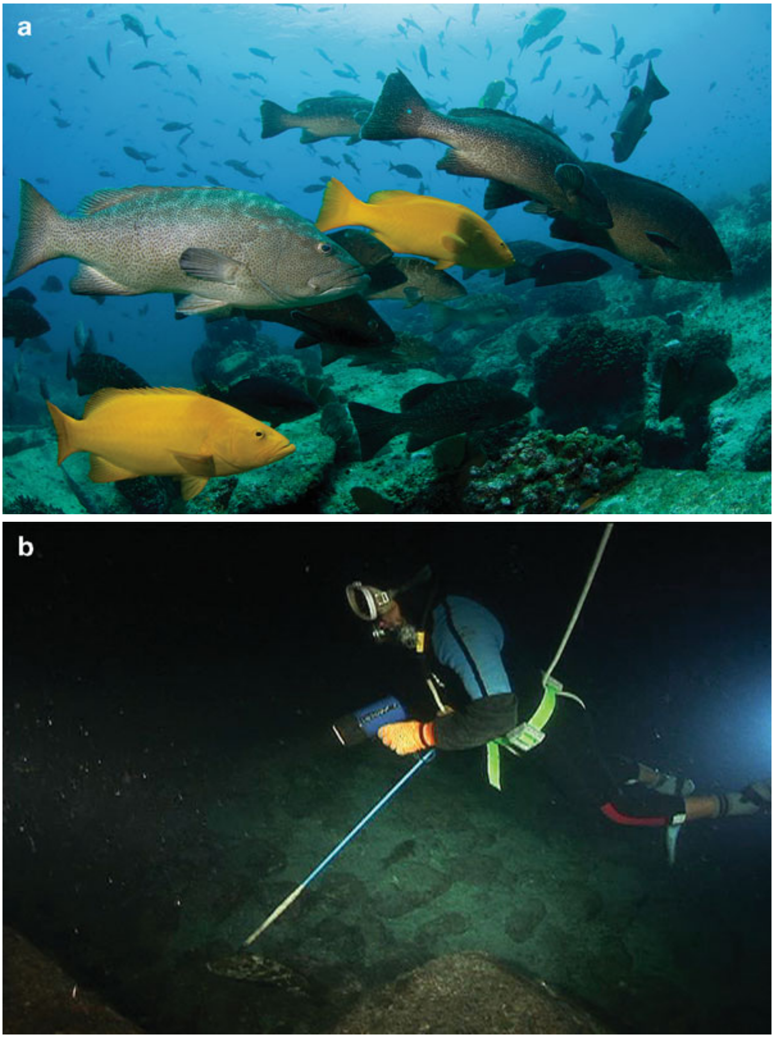

Fig. 8.9 (**a**, **b**) Illegal nighttime fishing for leopard grouper, *Mycteroperca rosacea* in the Gulf of California, Mexico (Photos: © Octavio Aburto/iLCP (fish) and © Seawatch.org (divers))

Allee Effect (Allee 1931) whereby reduced populations show unexpectedly low rates of recovery (see Sect. 8.4.2).

Spawning aggregations have evolved for reasons that have yet to be fully understood and that may well vary among species and lineages (Chaps. 2 and 4). Such reasons are important to consider, not just for academic interest but for understanding the impact of fishing. Possible adaptive advantages to spawning in large temporary groups include conditions important for fertilization, encountering mates and synchronizing spawning, sexual selection and related behaviours such as stimulation of spawning by conspecifics and anti-predator reasons. The specific times and locations where gatherings of ripe fish occur may provide selective benefits related to larval dispersal, conditions associated with egg/larval survival, or habitat factors such as appropriate substrate for nesting (e.g. in triggerfish, Chap. 12.23) or high substrate complexity where large numbers of adults can temporarily find shelter. However, the significance of mate choice or of specific habitats for reproducing in large groups has been little examined in fishes (Chap. 3). Therefore, we must keep in mind the various possible adaptive reasons for aggregation-formation when exploring the possible direct and indirect biological impact(s) of exploiting spawning aggregations.

When fisheries heavily target spawning aggregations, the most obvious sign of change to the fishery manager is likely to be declines in landings volumes or reduced numbers of fish at the aggregation site. Depending on the level of fishing effort, such declines may take a long time to become apparent because of *hyperstability* (Fig. 8.6, Chap. 11). Yet significant negative changes to the population may occur before landings decline. Many reef fishes have complex social and mating systems that may be disrupted by fishing activities. Fishing could directly alter population structure, via shifts in adult sex ratio or mean body size, in ways that affect reproduction. Indirectly, declines in fish numbers due to fishing could affect reproduction by impairment of visual, olfactory or auditory stimuli, social cue transmission or by influencing other interactions such as courtship or sexual selection that only occur during brief aggregation periods. For those species that live in deep-water or habitats or are normally solitary, the spawning aggregation may be the only time fish encounter conspecifics for mating, or are exposed to the population sex ratio or other aspect of the demographic profile (see Chap. 12.7).

The possible biological effects of fishing on aggregations will, therefore, depend on the way(s) in which fishing is conducted, the absolute and relative volumes of fish taken, the selectivity of fishing, differential movements of sexes in and out of aggregations and the adaptive significance for the species of the aggregating habit itself. The combination of direct and indirect effects of fishing could ultimately influence the reproductive output from aggregations with short and long-term implications for the fishery as well as for the targeted population. These issues are addressed below and considered in light of fishery management implications and future information needs.

8.4.1 Abundance, Sex Ratio, and Body Size

Unmanaged harvesting from fish spawning aggregations by commercial, recreational, or even artisanal fisheries is often associated with declines in aggregation size (number of fish) over time. This is not surprising, given that heavy fishing can remove large proportions of aggregations in just a few days (e.g. 10–20%, Nassau grouper, Sala et al. 2001; 20–30%, camouflage grouper, Rhodes and Sadovy 2002a, b), and that heavy exploitation of aggregations might reflect high fishing mortality in the fishery in general. In extreme cases, entire aggregations have been removed

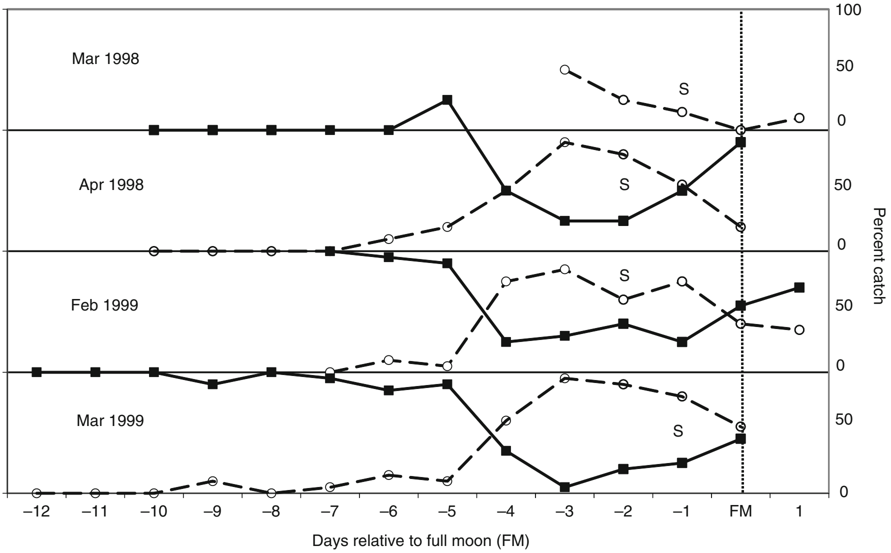

Fig. 8.10 Percent of males (*square and solid line*) and females (*circle and dotted line*) of camouflage grouper, *Epinephelus polyphekadion*, in aggregation catches in the 12 days leading up to full moon (*FM*) and 1 day after FM in Pohnpei during one of several annual spawning months from the Kehpara Island Marine Sanctuary (February 1998–March 1999). *Graph* shows arrival of males followed by females several days later and the resulting shift in adult sex ratio at the site (Spawning = *S*) (Rhodes and Sadovy 2002a, b)

within a single or a few spawning seasons (Johannes and Riepen 1995; Hamilton et al. 2005). Serial depletions from fishing are likely a major contributor to the complete disappearance of a target species from larger regions (seventy-four Chale-Matsau et al. 2001, orange roughy Clark 2001, large yellow croaker Liu and Sadovy de Mitcheson 2008, *Epinephelus quinquefasciatus = itajara,* Sala et al. 2004, Nassau grouper Sadovy and Eklund 1999; Sala et al. 2001; Aguilar-Perera 2007; Claro et al. 2009).

Sex-specific differences in the temporal movement patterns of fish into, out from, and around aggregation sites can interact with fishing in ways that can alter adult sex ratios. In red hind (*Epinephelus guttatus*), camouflage grouper and Atlantic cod males arrive earlier and remain longer at aggregation sites than females, presumably to establish and maintain mating territories (Nemeth et al. 2007, Rhodes and Sadovy 2002a, b; Robichaud and Rose 2003, Windle and Rose 2007, Rhodes and Tupper 2008) (Fig. 8.10). Conversely, females of these species may be more transient, moving onto spawning grounds to spawn and then leaving or migrating to nearby areas between mating periods to ripen new batches of eggs and/or to feed (Morgan and Trippel 1996; Nemeth et al. 2007, Chap. 2). In such cases, fishing only on the spawning grounds or only on adjacent areas can selectively remove one or the other sex, thereby altering reproductive sex ratios with potential to reduce reproductive output (Beets and Friedlander 1992; Shapiro et al. 1993; Rowe and Hutchings 2003). Selective fishing could have explained the highly male-skewed sex ratio of squaretail coarlgrouper at Ulong Channel, Palau (Johannes et al. 1999) (see below).

Sex ratio effects are also relevant to sex-changing species, which tend to have naturally male-biased (protandrous) or female-biased (protogynous) adult sex ratios. In certain protogynous groupers that form spawning aggregations (e.g. red hind, Shapiro et al. 1993, gag grouper Koenig et al. 1996), sex ratio assessment during aggregation periods may be an important cue for sex change, since this is the only time when adult males and females are known to come together in significant numbers; in all sex-changing species studied, the incidence and timing of sex change is mediated at the level of social groups in response to behavioural cues (Muñoz and Warner 2003; Munday et al. 2006). Particularities in fisher behaviour can also skew sex ratios. In an exploited aggregation of tiger grouper, *Mycteroperca tigris*, sex ratios in catches were skewed towards males because spearfishers actively selected males to "protect" females and the eggs they bear (Sadovy et al. 1994a, b; Matos-Caraballo et al. 2006). The selective male removals could potentially cause problems with mate choice, mate encounter rates, or other reproductive behaviours, depending on the mating system. In another example, a male-biased sex ratio in an aggregation of squaretail coralgrouper in Palau was associated with greater harassment (i.e. chasing) of the relatively smaller number of ripe females moving around the aggregation site in Palau compared to sites with less male bias (Johannes et al. 1999).

Heavy fishing pressure on spawning aggregations could be a major factor in reducing the average length and size range of fish, although this may be a general effect of fishing rather than one specifically related to aggregation fishing. In leopard coralgrouper in Australia (Adams et al. 2000), Nassau grouper in Belize and Mexico (Carter et al. 1994; Aguilar-Perera 2007), red hind in the United States Virgin Islands (USVI) (Beets and Friedlander 1999), and in leopard grouper, *M. rosacea* in the eastern Pacific (Sala et al. 2003) sizes of fish taken from aggregations have declined relative to past baselines (Figs. 8.11, 8.12). In a few species, such as Atlantic cod, stripey seaperch (*Lutjanus carponatus*), gag grouper and scamp, reduced body size is associated with reductions in ages of sexual maturity and in sex change, or in decreases in egg size, larval survivorship, and batch fecundity of females (Coleman et al. 1996; Olsen et al. 2004, 2005; Evans et al. 2008). This is a major concern for fisheries, given the relative reproductive value of large females due to the association of high fecundity with large size and, in some species, high egg and larval quality (Berkeley et al. 2004; Birkeland and Dayton 2005). While declines in body size have several possible causes, aggregation-fishing could be a major contributing factor if it is particularly intensive or size-selective. Conversely, reduction of fishing pressure can result in larger and more plentiful fish (Nemeth 2005).

8.4.2 Allee and Other Mating Behaviour Effects

Allee Effects, expressed by positive relationships between various fitness components (e.g. number of matings or eggs fertilized) and population densities, are related to mate-finding factors that can be influenced by fishing (Allee 1931; Stephens et al. 1999). In birds, the once abundant passenger pigeon, *Ectopistes migratorius,* became extinct, at least in part, because pairs no longer bred once colony sizes were reduced

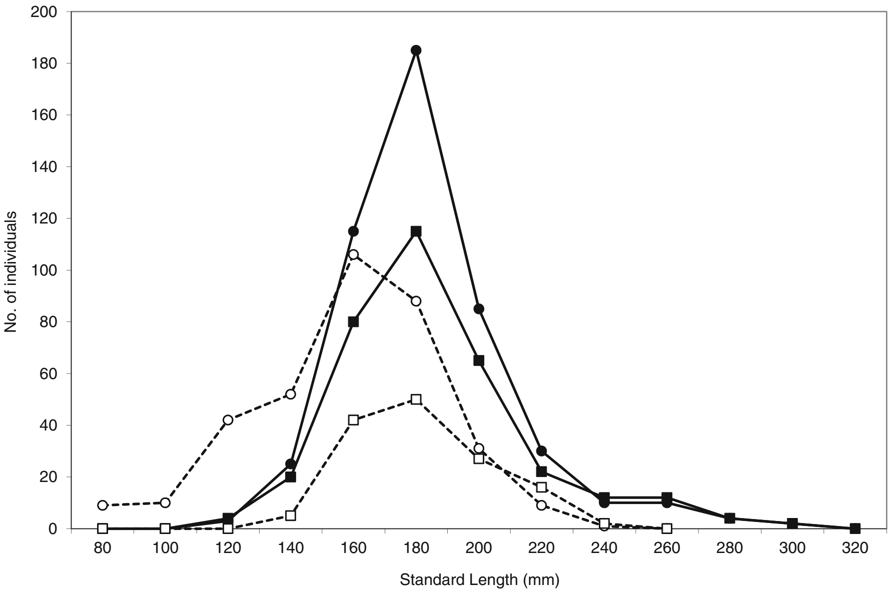

Fig. 8.11 Size frequency distribution by sex (female *circle*, male *square*) data for Nassau grouper, *Epinephelus striatus*, from catches taken at a (formerly) non-exploited aggregation site (Northern Two Caye, *solid symbols*) and an exploited aggregation site (Cay Glory, *open symbols*) in Belize. Data show that both sexes are smaller at the exploited site (Carter et al. 1994)

by hunting and habitat losses (Blockstein and Tordoff 1985). Allee Effects may be important if they constrain population growth and recovery in overfished fish species. Mate-finding Allee Effects may be important in aggregating species if the primary purpose of aggregation formation is to find mates and avoid the problem of low density (which may occur in large species that disperse widely during non-aggregation times), or if there is some positive reproductive effect of groups of animals coming together such as mate choice and fertilization rate (see Chap. 3). Important factors might involve mate encounter rates and mate attraction, gamete density and sperm limitation, physiological stimulation of courtship, female choice, sexual selection, and reproductive investment (Gascoigne et al. 2009). It is relevant to consider whether there is evidence that such factors might be associated with aggregation-spawning, or with different types of mating systems (i.e. transient versus resident aggregations, group- versus pair-spawning) within aggregations.

Species for which Allee Effects have been demonstrated or hypothesized range from Pacific sardine, Downs herring, scallops, abalone, sea urchins, and giant clams, to muskrats, flour beetles, sheep ticks, and passenger pigeons (Chap. 3, Frank and Brickman 2000). Examples of Allee Effects include difficulty in finding a mate, and a breakdown in social structure and migration patterns. Species that have characteristic social behaviour such as group-mating, group defense, and schooling may be at increased risk of extirpations under heavy exploitation due to Allee Effects (Frank and Brickman 2000). While there are few examples of clear Allee

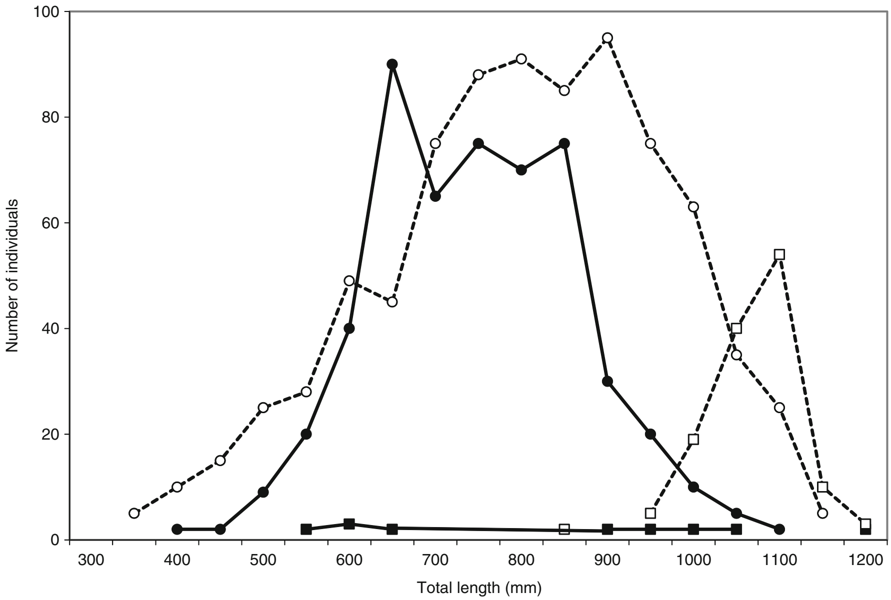

Fig. 8.12 Size frequency distribution of males (*squares*) and females (*circles*) gag grouper, *Mycteroperca microlepis*, from the Gulf of Mexico, USA. Historical data from 1977 to 1980 (*open symbols and dotted line*, Hood and Schlieder 1992), and from 1991 to 1992 (*closed symbols and solid line*, Koenig et al. 1996). Sex ratios of males to females dropped from 17% to 2%, and mean sizes of both sexes declined over the time period

Effects in commercial fishery species, data at small population sizes are few and the possibility cannot be ignored (Myers et al. 1995).

If one of the adaptive values of congregating to spawn is to bring together males and females within a complex mating system, or for mate selection, major deviations from the natural abundances, body sizes, or adult sex ratios within spawning aggregations may be important. Extensive disruption of mating behaviour due to fishing is also possible. Such changes could potentially result in significant declines in reproductive output that translate into disproportionately lowered population growth rates, i.e. an Allee Effect. For example, queen conch (*Strombus gigas*) normally aggregates to mate but spawning ceases below a threshold density of 48 individuals ha^{-1} (Stoner and Ray-Culp 2000). Densities are known to be important in determining the prevalence of group- versus pair-spawning in an area, for example in the bluehead wrasse (Chap. 12.14).

A decrease in the number of breeding males per female and reduction in sperm concentration could result in lowered numbers of fertilizations and a reduced population size. Sperm limitation may be a significant barrier to the recovery of overfished populations of gag grouper in Florida; in 1977–1982 males represented 17% of ripe fish at aggregation sites in the Atlantic and Gulf of Mexico, which declined to 1–3% by 1991–1994 when large numbers of gravid but 'unspawned' females were noted to be present at aggregations (Coleman et al. 1996) (Fig. 8.12). Model simulations designed to test the effect of fishing on reproductive activity of gag predicted that mean fertilization rate and the number of fertilized eggs per recruit are markedly lower in small mating groups (<50 individuals) than in larger aggregations (100–1,000 individuals, Alonzo and Mangel 2004). A study that examined the results of several independent captive-breeding studies in Atlantic cod found that fertilization rates declined and had higher variance as the number of males and breeding aggregation size decreased (Rowe et al. 2004). For both species, reductions in fertilization rates were attributed to sperm limitation associated with a low number of males and insufficient sperm to fertilize the eggs of all females during group-spawning events.

Mobile invertebrate examples show that high densities of eggs and sperm can be critical to fertilization success and presumably account for the clumping behaviour of adults for gamete release in some species. Sperm limitation can be severe unless numerous individuals spawn simultaneously (e.g. Levitan and Petersen 1995), although Yund (2000) suggests that sperm limitation may not be as severe as initially thought in marine free-spawners. Many commercially over-exploited non-sedentary invertebrate species are recruitment-limited or display density-dependent population dynamics and the effect of possible sperm limitation has sometimes been included in fishery models (Yund 2000). In the bluehead wrasse sperm numbers and fertilization rates are lower in single-male matings than during multiple-male matings (Shapiro et al. 1994; Marconato et al. 1997) (Chap. 3).

Fishing spawning aggregations could reduce reproductive output through effects on courtship and mate choice. Assortative mating, whereby individuals tend to mate with fish of similar size, is found in several aggregating species (bluehead wrasse Shapiro et al. 1994, bucktooth parrotfish *Sparisoma radians* Marconato and Shapiro 1996, Atlantic cod Rowe and Hutchings 2003, leopard grouper Erisman et al. 2007), while in others, females show preferences for larger males (e.g. Chap. 3 Rasotto et al. 2010). If preferred mate phenotypes are removed during or just prior to spawning periods by fishing, the choosier sex may respond by releasing fewer gametes or performing fewer spawning rushes, thereby reducing reproductive output (Shapiro et al. 1994, Marconato et al. 1997).

Fishing could potentially lower mating frequency or fertilization rates through disruption of courtship in other ways. For example, sound production plays an important role for attracting individuals at aggregation sites, in mate competition, during courtship, and for stimulating or synchronizing gamete release or maturation in several species of croakers (spotted weakfish *Cynoscion nebulosus* Gilmore 2003, white weakfish *Atractoscion nobilis* Aalbers and Drawbridge 2008, the goliath grouper Mann et al. 2008) and in the Atlantic cod (Rowe and Hutchings 2006). At reduced aggregation sizes, acoustic intensity may be insufficient to attract all individuals to spawning sites or may decrease fertilization rates due to reduced synchronization of gamete release (Rowe and Hutchings 2003).

Stress can affect reproduction in fishes although there is little evidence to suggest that this ultimately results in reduced annual reproductive output. In the common snook, *Centropomus undecimalis*, silver seabream and red gurnard, *Chelidonichthyes kumu*, stress in captivity can cause changes in hormone levels, fecundity, egg size and development, and egg survival (e.g. Morgan et al. 1999). However, the extent to which fishes may be stressed in exploited or disturbed spawning aggregations is not known.

Reductions in aggregation numbers could affect social cues that stimulate short or long-term changes in reproductive condition or are otherwise associated with mating. In many aggregating species, males show temporary courtship colour changes (Colin et al. 2003). In some groupers, courtship activity and colour pattern changes associated with spawning are less intense (qualitative observations include less activity by males in female pursuit and less frequent courtship) at sites with smaller, dispersed aggregations when compared to sites with large, dense aggregations (Nassau grouper Colin 1992, leopard grouper Erisman et al. 2007). Several groupers and the Atlantic cod form dominance hierarchies with male defence of breeding territories (e.g. scamp and gag grouper Gilmore and Jones 1992, tiger grouper Sadovy et al. 1994a, b, Atlantic cod Hutchings et al. 1999). Removal of fish during aggregation and breeding periods could affect these hierarchies, with unknown impacts on reproductive output. Since ovulation periods of aggregating species are often highly synchronized to coincide with short courtship and spawning periods, delayed or disrupted courtship could potentially cause eggs to over-ripen, thereby reducing egg viability or developmental success of eggs and larvae (Rowe and Hutchings 2003). The possible importance of aggregations for social cues in relation to sex change was addressed in Sect. 8.4.

One of the few specific examples of clear evidence that fishing on spawning aggregations can directly and negatively impact reproductive potential comes from the Atlantic cod (Rose et al. 2008). A spawning ground in Bar Haven, Placentia Bay, Newfoundland, was opened in 1997 and from 1998 to 2000 was heavily fished at spawning time. Between 33% and 40% of the total annual catch came from this area followed by a stock decline and less recovery in spawning biomass than predicted by fishery models. The data from the resulting model suggest not only that there was weak compensation in survival at low stock size, but that the mortality rate of the Bar Haven spawning fish was considerably higher than that in the general population, and that a decline in egg production and then recruitment were the results of aggregation-fishing.

Some aggregating species show high site fidelity, whereby fish return each year to spawn at the same sites; disruption of factors enabling such returns could potentially influence reproduction. Aggregations can persist at the same sites for many years, even decades, suggesting a degree of traditionality (Colin 1996; Domeier and Colin 1997). Examples of site fidelity across years exist for a range of species (*Epinephelus alexandrinus* = *Mycteroperca fusca* Waschkewitz and Wirtz 1990, groupers and wrasses Domeier and Colin 1997, Nassau grouper Starr et al. 2007, European plaice Hunter et al. 2003, camouflage grouper Rhodes and Tupper 2008). There is also good evidence in several species that social learning and tradition play a role in the repeated formation of aggregations at specific sites, and that younger fish learn to use and find sites from older, experienced fish (bluehead wrasse Warner 1988, 1990, Atlantic cod Rose 1993, European plaice Arnold and Metcalfe 1995, brown surgeonfish *Acanthurus nigrofuscus* Mazeroll and Montgomery 1998). Indeed, the learning component of fish migratory behaviour may be particularly important in those species comprised of multiple age groups, providing the opportunity for social transmission of migration routes (Dodson 1988). The removal of older, larger adults may therefore affect spawning and aggregation-formation indirectly through loss of knowledge of spawning site locations and migration routes and could seriously compromise recovery initiatives such as restocking using hatchery-produced fish in such species.

8.5 Socioeconomic Importance of Aggregation-Fishing and Aggregating Species

From a commercial perspective, aggregations represent excellent sources of large numbers of fish that can be taken quickly, predictably and efficiently, thereby saving both time and operation costs. These qualities, conversely, make them particularly challenging to manage. For valuable and high volume niche fisheries, such as those for live fish (e.g. groupers) and roe (e.g. mullet), and for species only accessible at aggregations, these are especially appealing, and, indeed, possibly the only (in the case of roe), time to quickly obtain high catches. Aggregations are also economically attractive for recreational fisheries, providing the opportunity for private-boat fishers to reach high catch limits in single trips, or, in the case of tourist fishers, allowing them to maximize the number of fish caught during daily fishing charters. They can also be very appealing to sports divers for viewing. We explore the socioeconomic implications of aggregation protection and exploitation.

8.5.1 Gluts, Prices, and Fisher Behaviour

The economics of having large gluts of fish filling local markets over a short spawning season and the potential for fish wastage have received little attention but likely offset some of the more obvious advantages associated with the commercial exploitation of aggregations. The flooding of a large number of fish into a limited market, i.e. where supply temporarily and massively exceeds demand, can result in the price per unit weight declining such that fishers get less cash per fish than at other times. In extreme cases, fish are wasted because there are too many for small local markets, or because they cannot be stored until market prices improve. During the peak fishing periods for Gulf corvina in the northern Gulf of California, Mexico, as much as 1,000 tonnes of fish may be caught and sold to local buyers over just 3–4 days. This flood of fish causes market prices to plummet, often over the course of hours. When the supply of fish exceeds the capacity of local processing and export plants, buyers close their markets completely, and several hundred tonnes of fish meat may be abandoned on the beach or thrown into the local dump by fishermen who can no longer sell their catch (Brad Erisman unpublished data) (Fig. 8.13).

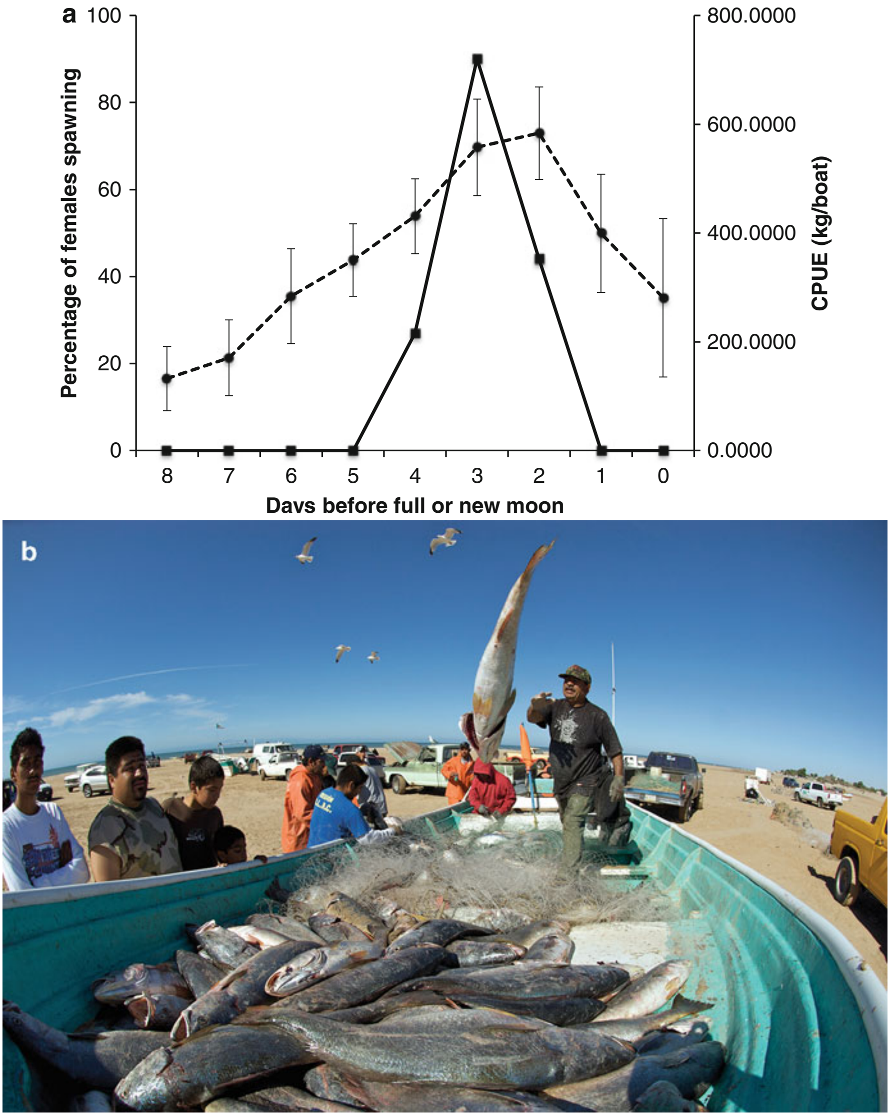

Fig. 8.13 (**a**, **b**) Gulf corvina, *Cynoscion othonopterus,* aggregations are fished with 12.5 cm mesh gillnets deployed from small boats that harvest up to 1 tonne of fish in a single net. Fisheries regulations allow only 1 net per boat. The commercial fishery only takes fish during the time periods when corvina migrate into the area to form aggregations and spawn in and near the estuaries during the week preceding the new and full moons from late February to early May each year (i.e. 4–5 times); spawning months have been combined for the graph. Each fishing period lasts 4–8 days, with the majority of landings occurring at the exact days of spawning when fish are inside the estuary. During these days, the landings and CPUE (*dotted line*) are highest; percent females spawning solid line (Photo: © Octavio Aburto/iLCP)

The problem of wastage may also be associated with the taking of ripe females. Aggregations are an obvious focus of interest for the LRFT because of the desire by fishers or traders to quickly accumulate large volumes ready for export in large carrier vessels (Sadovy et al. 2003). Females in many transient aggregations are found on or close to the spawning site for at least a few days until they spawn, after which they leave (Fig. 8.10). This means that most adult females taken at or around aggregation sites tend to be full of eggs. These gravid fish do not survive well after capture and high mortalities can occur during the holding phase that precedes export. Where there are no cost implications for traders (because mortality costs tend to be borne by the fishers) there is little incentive to cease fishing. While some traders prefer not to accept such fish from fishermen because of these high mortalities, others actively seek aggregations to fish and appear unconcerned about the waste.

Three examples illustrate the problem of gluts and suggest possible solutions. First, the silver seabream snapper fishery in Shark Bay, Western Australia, initially targeted only the spawning aggregations that formed from May to August. Commercial fishermen maximized catches during that period by using large fish traps (Chap. 12.12), which resulted in a glut of relatively low-priced landings during a short period flooding local markets. The fishery was placed under strict management in 1987 with entry limited to 51 tradable permits. In 2004 only 23 vessels were targeting snapper. Since 2001 these dedicated finfish boats were managed with an annual quota. These changes have caused fishers to think about ways of increasing the value of their individual catch, rather than ways of catching more fish. Nowadays the catch is landed throughout the year, avoiding the annual glut which occurred in the spawning season, and resulting in much better quality fish being taken to market (Gary Jackson personal communication 2010).

In the second and third examples, quite different, fisheries show possible responses to the problem of gluts. In Fiji several coastal species are fished heavily on aggregations. In some places, the price paid to the fisher, per fish or weight, at such times is lower (10–50%) for certain species when landings increase during aggregation time (Nanise Kuridrani Fiji Fisheries unpublished data). Concerns over the long-term implications of aggregation-fishing led the Fijian Fisheries Department to prohibit the capture of fish, destined for export, during the aggregation period. (Aisake Batibasaga Head of Fisheries Research Fiji Fisheries). In the third example, record low prices for the Atlantic wreckfish, *Polyprion americanus*, during spawning aggregations spurred the creation of an individual transferable quota (ITQ) system that resulted in catches being more evenly spread throughout the year (Gauvin et al. 1994).

While restrictions on sales or catches during the aggregation period may address problems associated with price declines due to gluts of target species, successful management will also depend heavily on both the responses of fishers to management and on market forces. For example, in the international LRFT, fish supply cannot fill demand and so all fish will get good prices even when seasonally plentiful. Moreover, as one supply area dries up, another will be opened such that the Hong Kong trade centre for the LRFT brings in fish from a wide range of, and ever changing, supply countries (Sadovy et al. 2003). In this case, and possibly for other international markets where demand is far higher than supply, local short-term gluts are unlikely to affect retail prices, although they can affect prices paid locally to fishers.

At the national level, examples of fisher responses to aggregation protection are instructive. In the Gulf of Mexico, USA, fishers for gag grouper, in response to protection from fishing during its peak aggregation month, changed their behaviour and intensified activity prior to and after protection; note that, initially, only one spawning month was protected with all spawning months protected subsequently. Economic analyses show that gag aggregation protection did not result in reduced fishing pressure on the target stock, or in increases in biomass, probably because of this behaviour (Smith et al. 2008). In other words, fisher response was so marked that it evidently offset the biological benefits from the temporary fishing restriction. The study indicates that seasonal restrictions cannot necessarily operate alone to reduce fishing pressure in an open-access fishery and highlights the importance of factoring in fisher behaviour and economics to biological models for management. In Pohnpei, during the closed season for grouper aggregations, the pressure on other reef fishes increased, in particular for parrotfishes (Scaridae), goatfishes and emperors, (Lethrinidae), to maintain overall sales (Rhodes and Tupper 2007; Rhodes et al. 2008). Loss of Nassau grouper stocks in the USVI and elsewhere due to lack of management and overfishing in the late 1970s led to fishers targeting smaller, less frequently marketed, groupers (e.g. Munro and Blok 2005; Karras and Agar 2009).

8.5.2 Costs and Benefits of Aggregation vs. Non-aggregation Fishing

Large and predictable fish gatherings are an obvious target for fishing, but long-term sustainability in the absence of sufficient controls may only apply for subsistence, or occasional cultural, uses. When commercial pressures come into play, without effective management (Sect. 8.5.1) this activity is considerably less appealing as a long-term good use of natural resources. A summary of the costs and benefits of aggregation exploitation versus total protection, highlights areas where further analyses are warranted to determine best overall and long-term monetary value from aggregating species (Table 8.2). The middle ground of managed aggregation fishing is also a possibility, with elements of both benefits and costs from the more extreme examples presented (see also Chap. 11).

While aggregation closures may greatly benefit stocks, associated costs and other implications can have serious detrimental effects on communities that may depend significantly on aggregations for their livelihood, and all possible management options should be considered. For example, the Colorado River Delta region located in the northernmost section of the Gulf of California is one of the most productive fishery regions in Mexico. A major source of this productivity is the seasonal occurrence of several commercially important fishes such as Gulf corvina, totoaba, Gulf croaker, *Micropogonias megalops*, sierra mackerel, *Scomberomorus sierra*, and several species of sharks and rays that migrate there to feed on sardines and shrimp and to spawn within massive aggregations (Cudney and Turk 1998; Rodriguez-Quiroz 2010). The local communities that surround the Delta rely on these seasonally plentiful resources as their main source of revenue, and the closure of their

Table 8.2 Economic and social benefits and costs of aggregation fishing versus total aggregation protection if aggregations supply a significant component of the annual catch of the target species population

Aggregation fishing permitted	Aggregation completely protected from fishing
Benefits	
– Reduced search time – Cost savings on fuel – Large, predictable catches can increase short-term profits – May temporarily reduce pressure on other reef resources – A ready periodic larder for social/cultural needs – Regular seasonal event for occasional community or customary activities	– Higher catch at non-aggregation times and over the long-term – Protection relatively easy to enforce as limited in time and space – Possible use for recreational diving benefits from aggregations – May produce more stable, higher market prices throughout the year by avoiding market gluts and ensuring larger fish populations, assuming that population is not overfished at non-aggregation times
Costs	
– Market gluts of fish that can lower price per fish and produce uneven supply of fish to market over the year – Taking risks in bad weather because competitors are fishing – Lack of consideration for making best long-term economic use of the fishery overall – Gluts can lead to wastage of unsold fish or those that cannot be stored for long time periods – Inequality of resource access, if some people can reach aggregation and some cannot – Possibility of overfishing resulting in long-term loss of resource for all and throughout year (Sect. 8.2)	– Loss of revenue to commercial/artisanal/recreational fisheries that have traditionally depended on fishing of aggregations – Possible increase in pressure on other reef resources temporarily – High incentive for poaching – Benefits of aggregation protection could be reduced if non-aggregation fishing intensifies and is unmanaged – Could be expensive to manage an aggregation and enforce protective regulation – Could lead to irregular/low supply of target species at certain times of the year – Could disrupt social or cultural activities

Note that the expense of monitoring is not included since this is necessary for both options

fisheries would likely result in the socioeconomic collapse of these areas. On the other hand, uncontrolled aggregation fishing could ultimately lead to loss of these valuable resources so careful management is clearly needed. Indeed, total protection of aggregations may, in the long term, enhance catches at non-reproductive times of the year and avoid waste of resources due to gluts with greater overall societal benefits. Economic analyses and fisher behaviour, therefore, in addition to biological considerations, are needed for understanding the effects of fishing on aggregating and non-aggregating animals and the implications of aggregation protection and to highlight the consequences of no protection. Such analyses might lead to solutions like ITQs or catch controls. For economic benefits, there is one further element that needs attention – the recreational value. This includes both recreational fisheries on aggregations and aggregation viewing by divers.

8.5.3 *Economic Benefits from Recreational Use of Spawning Aggregations*

In some places there may be considerable economic benefit in protecting aggregations entirely from commercial exploitation, substituting sport diving for extractive use, or introducing catch and release recreational fisheries. For example, the value of an aggregation of grouper in Belize was estimated at 20 times that of the extracted fish (per annum) if protected and used solely for diving tourism (Sala et al. 2001). This calculation focused only on the recreational diver benefit without factoring in the (additional) long-term benefit/value to the non-aggregation fishery of allowing fish to spawn. The extent to which displaced fishers might directly benefit in such cases is not clear, but work in Belize has successfully retrained displaced fishers as tour guides (Janet Gibson personal communication 2010). In Komodo National Park, Indonesia, the estimated value to the fishery of protecting aggregations within the park, allowing fish to fulfil their reproductive function and for their diving recreational value was significant (Ruitenbeek 2001). In the western Atlantic Turks and Caicos Islands, the Nassau grouper is a high-profile species in the dive tourism industry and divers are evidently willing to pay more for dive packages on which they observe more and/or larger fish (Rudd and Tupper 2002). Lack of effective management of such fisheries may thus impose significant economic externalities on the dive tourism industry (Rudd and Tupper 2002). Recreational fisheries on aggregations can be economically valuable and are covered in Sect. 8.2.2.

8.6 Perceptions and Education Needs

Despite a growing understanding of the aggregating habit in fishes, the food and commercial importance of aggregating species general, and recognition of the need for management, this is rarely a high fishery or conservation priority. Reasons for this include: (1) a lack of understanding, or even awareness of the presence of exploited aggregations in an area or that known aggregations may need management; (2) the presence of other management measures in the fishery which are assumed to provide sufficient protection in the absence of aggregation management; (3) the attractiveness of fishing seasonal high abundances and hence strong resistance to management; (4) the existence of roe fisheries that depend specifically on spawning fish; (5) the long-term traditional use of aggregations but lack of any previous experience of their vulnerability because, historically, levels of use were too low to be a problem or because of a shifted baseline with younger fishers unaware of changes; (6) a desire or need to maintain regular supplies of target fish to markets; (7) the need to increase fish landings to satisfy local or international markets (Sect. 8.1); (8) a lack of knowledge about the various possible direct and indirect effects of fishing on aggregations that are, as a consequence, not incorporated into fishery models (see research needs Sect. 8.7) and; (9) a lack of regular inclusion of targeted aggregation sites or of habitat often associated with aggregations (such as outer reef slope/shelf drop-off areas) into marine protected area planning (Sadovy de Mitcheson et al. 2008).

Challenges also persist in achieving effective aggregation management because of misperceptions or lack of understanding that make it difficult to gain public and political support. It is particularly in such areas that greater awareness and better understanding of these fisheries, and the economic and social implications of losing them, are needed. An obvious example is that the many fish taken over a short, often intense, period of time from aggregations give the illusion that there are plenty of fish, with no hint that a high proportion of a stock or population might be involved and hence that management might be advisable. As just one example, orange roughy in the 1980s seemed to be a boundless resource. "On one occasion 54 tonnes were caught in only 20 minutes' trawling – but this apparent abundance was an illusion, as the fish had been concentrated in spawning schools." http://www.teara.govt.nz/en/fishing-industry/5 (Robertson 1991). In managed fisheries, there may also be the belief that conventional management obviates the need for specific attention to be paid to aggregation management (e.g. leopard coralgrouper trout in Australia Chaps. 11, 12.9).

From a technical fishery monitoring perspective the seasonal change in behaviour of both fish and fishermen associated with aggregations make fish abundance difficult to estimate because catchability (i.e. the proportion of the total stock caught by one unit of fishing effort) changes over the year with the result that CPUE (widely used as an indicator of fish abundance) is not proportional to fish abundance. High catchability means that fish will continue to be caught in large numbers in aggregations even as the population as a whole declines, making aggregation CPUE a poor indicator of fishery status (Fig. 8.6, Chap. 11). For this reason, much care is needed if only fishery-dependent data are available to assess aggregation status, and every effort made to periodically monitor aggregations by fishery-independent means, ideally including visual assessment (e.g. Colin et al. 2003).

The value of protecting spawning adults to the fishery at non-aggregation times needs to be considered in fishery models to assist managers and political and community leaders in better appreciating the practical and economic implications of management, or lack thereof, in the long term. It is unlikely that dive tourism alone will bring higher economic benefits, especially if there is heavy social or economic pressure to fish in the region. The switch from viewing spawning aggregations as a target of fishing to a focus of protection will require a major shift in understanding and perspective that fishery analyses can provide. It is of value to note that many fishers intuitively understand the importance of allowing females full of eggs to spawn and can readily accept why aggregations might need to be managed (YSM and BE personal observation). Indeed, in some countries (e.g. New Zealand, Australia, USA, Bahamas) berried lobsters (females with external fertilized eggs) have variously been protected in fisheries for as much as 100 years; the same thinking has not yet been applied to female fish.

Finally, we recognize the problem of shifting baselines (Pauly 1995). Most exploited aggregations are not managed, may have already declined substantially or there is no community experience of reduced landings in aggregations when these are newly exploited. This means that much of the potential production from an aggregation may be lost before action is understood to be needed. Since even small numbers of fish concentrated briefly in one small area can appear remarkable, even scientific workers newly exposed to aggregations may have little idea about former abundances. As one specific example in reef fisheries, young researchers today in the Caribbean conducting UVC are often impressed to see a few hundred Nassau grouper gathered in one aggregation at sites that just three or four decades ago held tens of thousands of fish (YSM personal observation). Old film footage and verbal accounts of divers, biologists, or fishermen who have seen such spectacular biological events are particularly valuable for highlighting such changes.

8.7 Data Gaps

Based on the above review, we identify key data gaps which, if addressed, could substantially improve our ability to effectively monitor, manage and assess aggregations. Focusing on the gaps would help answer important questions such as how many fish can be removed safely from a fished aggregation, the economic value of management, whether full aggregation protection may result in a significant improvement of the associated, non-aggregation, fishery, and could explain why some, such as Atlantic cod, are not recovering as predicted by fisheries models (Hutchings and Reynolds 2004).

8.7.1 Empirical Data on Effects of Fishing on Reproductive Output and Fishery Modelling

Biological studies and theoretical considerations suggest that certain biological attributes of fishes could and sometimes do predispose some species to negative impacts on reproductive output brought about by aggregation-fishing or by related disturbances. What little evidence there is, however, while suggestive, is inconclusive and focused studies are needed to test hypotheses regarding possible impacts.

What is clear is that a precautionary approach is needed because so little is known about the subtleties of long-term effects of fishing on reproductive output and how such effect(s) might be mediated. We have only to consider the other animal taxa and a few of the examples presented in this section to acknowledge the possibilities. It is clearly a failing that fishery models and management thinking rarely take such actual and potential complexities of life history into account (Sadovy and Vincent 2002, Sect. 8.4). For example, direct, observational and experimental studies on the relationship between aggregation size, density, and reproductive activity would be particularly useful for determining whether minimum aggregation sizes are necessary to maintain viable populations. While reproduction may well continue even in much reduced populations, whether such could maintain a substantial fishery at historical levels seems unlikely based on what we currently know.

8.7.2 Fisheries Effects of Various Management Policies

It is important to document or model how various forms of management or protection of aggregations can generate increased revenue to fisheries in the long term, to track successes and failures following management, and to understand fisher responses following protection. Nemeth (2005) demonstrated that closure of spawning aggregations for red hind led to increased aggregation densities as well as increased the number and average length of red hind in adjacent fisheries. Likewise, the banning of commercial gillnets on the spawning grounds of white seabass is correlated with a recent increase in CPUE and catch of commercial fisheries in California (Allen et al. 2007).

Other possible management models could also be explored, such as pulse fishing or rotational closures (e.g. Graham 2001). However, while in principle complex management approaches might make sense on paper, the reality of management capacity usually precludes such approaches and calls for more conservative and simple measures.

8.7.3 Fisheries-Independent Surveys and Underwater Monitoring of Aggregations

Direct surveys of aggregation sites are necessary to validate the existence of spawning aggregations, estimate fish abundance and monitor the timing and duration of aggregations. The evaluation of these and other characteristics (e.g. catchment areas, larval connectivity) of aggregations is necessary because fisheries landings and CPUE data often do not accurately reflect the status of stocks for aggregating species due to the problem of hyperstability (Chap. 11, Sect. 8.3). Certain aggregation sites pose serious challenges for monitoring due to their remote locations, poor visibility for diving, strong currents, or other factors. Increased utilization of multibeam hydroacoustic surveys and other new technologies show considerable promise for surveying aggregation sites. However, hydroacoustic surveys are unreliable unless carefully ground-truthed (Chap. 9).

8.7.4 The Economics of Aggregation Fisheries

Economic assessments of aggregation fisheries and alternative uses of aggregations are important because economics drive natural resource use practices and policies, in which gains or losses in revenues rather than ecosystem health impart the greatest influence on decision-makers. Appreciation of the overall and long-term economic value of the fishery production supported specifically by aggregations, as well as economic implications of their losses, can come through fishery modelling combined with economic data and biological information. This requires data on the numbers, sizes and catchment areas of aggregating fish, market prices of fish, biological impacts of overexploitation of reproductive fish on the overall fishery, basic fishery parameters and percentage of annual catch from aggregations, fishing costs, profitability, general market conditions of supply and demand under different scenarios, and differences in catchability between spawning and non-spawning periods. The value and characteristics of the non-aggregation fishery component with or without aggregation management also need assessment.

8.7.5 Advantages of Fully Protected Aggregations and Implications

If certain aggregation sites are closed to fishing, other human use activities will usually need to be implemented to mitigate economic losses from fishing restrictions. These may include the introduction of diving charts to view aggregations or training for catch-and-release sportfishing of aggregations. Before such activities can be offered as alternative uses, however, it must be considered whether the alternatives could themselves potentially have negative impacts on reproductive activity requiring specific management steps. Therefore, studies which focus on understanding how the presence of divers, the use of various fishing gears, and catch-and-release fishing activities affect mating behaviour or survivorship are needed. While divers can evidently approach some species without apparent impact (as in the case of spawning cubera snapper in Belize), or species may be habituated to divers, little attention has been paid to this subject to date. In the case of the humphead wrasse (or Napoleon fish) *Cheilinus undulatus*, for example, the presence of divers interrupts courtship and spawning (Patrick Colin personal observation). Wider implications of protection also warrant examination, such as the impacts of shifting fishing effort from aggregations to other reef resources during periods of aggregation protection.

8.7.6 Information on Importance of Aggregations to Fisheries and Ecosystem Health

Due to widespread declines in harvested fish populations and the pervasive degradation of marine ecosystems worldwide over the past several decades, fisheries management is undergoing a theoretical and sometime actual shift away from single-species management and towards more ecosystem-based management approaches. To integrate spawning aggregations into this new management framework, their role(s) in ecosystem trophic and community structure, food web dynamics, and other ecosystem processes and parameters need to be appreciated (Chap. 2).

Unfortunately, research specifically aimed at understanding the effects of decreased aggregation sizes, or the extirpations of spawning aggregations, on the structures and processes of marine ecosystems, or on the target fisheries at non-aggregation times, is in its infancy (Chaps. 2 and 11). Certainly, there is anecdotal evidence that aggregations can attract large biomasses of megafauna and that some have long been in existence (Chap. 1).

8.7.7 Inclusion of Aggregation Sites as Key Biodiversity Areas or 'Indicators' of Reef Fishery Condition

While aggregations are not routinely incorporated into marine protected area design, their possible importance for 'congregatory' species that help to identify important areas for biodiversity, is being evaluated. For example, the selection of 'key biodiversity areas' as a conservation tool was initially applied to terrestrial species and the criteria used for evaluation address the vulnerability and irreplaceability of such sites (Eken et al. 2004). For congregatory species, sites that hold large proportions of the global population of a species on a regular basis and at specific times might be considered irreplaceable. This has already been applied in the case of birds for which the threshold is provisionally set at 1% of the global population of the species. Such a criterion could apply to fish species with relatively few transient aggregations. Considerably more information is needed to better understand the importance of individual aggregation sites for this criterion to be applied, however. The problem with site-only based protection of exploited species is that it does not, alone, address the problem of overexploitation so could only be one tool used in the case of most commercial fishes that are fished on their aggregations.

Aggregations have considerable potential to be used as markers of ecosystem, or as indicators of general fishery health (Chaps. 1 and 10), which would both highlight their importance and attract greater attention to them. While there are both advantages and disadvantages of using aggregations as indicators, on balance information to date suggests that they appear to be a good indication of the condition of related fisheries: where there is heavy overfishing, aggregations are small or non-existent, whereas in relatively unfished or managed areas, they persist (Sadovy de Mitcheson et al. 2008, SCRFA Newsletter No. 12, May 2009 www.SCRFA.org).

8.7.8 Perception and Education

Understanding fisher perceptions of the success, or otherwise, of protected sites and seasons is a crucial part of overall long-term acceptance and effectiveness of management measures. In one of the relatively few studies to directly address this, fishers from St. Croix, USVI, gave mixed responses as to whether they felt that a newly expanded area more effectively protected an aggregation site than existing area/season protection and gave them benefits. The general sense was that they did not fully understand the purpose of the additional protection and also felt that poaching was occurring because of insufficient enforcement and unclear boundaries to the protected area. There was also lack of clarity over perceived benefits of the seasonal closure, possibly due to slow recovery, and concern over economic hardship from the measures (Karras and Agar 2009). This study, and other experiences following management, demonstrates the importance of effective enforcement, communication with, and involvement of, fishers in planning, and monitoring of management outcomes. More studies on fisher perceptions are needed.

8.8 Concluding Comments

The habit of congregatory spawning is found in many species of fish from different ecosystems, in addition to coral reefs, and is common among commercial species. Indeed, it may be that the aggregating habit characterizes many exploited species expressly because it is a reproductive strategy associated with high productivity. If so, it is perhaps ironic that it is the aggregating habit that makes many such species particularly vulnerable to uncontrolled fishing.

Understanding the implications of overfishing or of eliminating aggregations is frustrated by insufficient information and by our lack of understanding regarding why aggregations have evolved. Empirical data from aggregations at different stages of exploitation and in relation to the populations they support are needed. From a biological perspective, there is much opportunity to incorporate elements of fish mating systems into fishery models to generate different scenarios against which to assess observations and make predictions or conduct comparative assessments. For example, if sperm competition is important for group-spawners and is negatively affected by declining fish numbers or sex-selective fishing, then one might predict that such species might show more marked declines than non group-spawning species. What are the effects of reduced aggregation sizes on reproductive activity and is there a minimum threshold size below which spawning ceases to occur? We might predict that transient aggregations are more vulnerable to targeted aggregation fishing than resident aggregators. From an economic perspective, are there more long-term benefits from fishing outside of aggregations and avoiding the possible waste and reduced prices associated with fishing gluts of spawning fish?

Turning to management, answers to the preceding questions should point the way to better determining the most effective and acceptable approach(es) to managing different types of aggregating species, and whether management of aggregations is necessary, in addition to management measures on target stocks (Chap. 11). Furthermore, valuable insights gained as we learn more of these species point to other important considerations. As just one example, it is clear that many transient spawning species aggregate at outer shelf edge areas, including drop-offs and reef passages. These are habitats that could be incorporated into marine protected areas since they currently receive little management or protection.

While in principle it should be possible to control fishing activity on aggregations to within sustainable levels, in practice this is unlikely to occur. Moreover, we still understand little of the implications of overfishing or of selective fishing on the long-term persistence of populations of aggregating species. And, even when management is in place, compliance is often low and enforcement typically falls short of being sufficient. For these reasons, it is clear that the most practical and precautionary approach is to avoid anything other than subsistence aggregation-fishing, at least in the case of transient aggregations, and to treat them as critical sources of fish that require protection for the benefit of the fishery. This situation calls for extreme caution in widely revealing the locations of little-known aggregations since it could easily expose them to greater fishing pressure. It also calls for consideration of the future of fisheries that depend exclusively on spawning fish, such as for roe or because the reproductive season is the only time that ripe fish can be caught.

More effort is needed to directly survey and monitor aggregations, since fishery-dependent data may not always reflect the status of aggregations (due to hyperstability), and to assess the economic value under scenarios ranging from unmanaged to fully protected aggregations. While new technologies may be applied or developed to survey aggregations at locations in which diver surveys are not possible, care is needed to assess their reliability, as in the case of hydroacoustic methods. Economic analyses are needed of aggregating fisheries, alternative use activities, and of assessments of the importance of aggregations to ecosystem structure and health. Finally, the benefits of managing and protecting aggregations need to be communicated to stakeholder groups, policy makers, and the general public so that consensus, support and compliance for policies are obtained.

Underpinning progress in management is a need for a shift in understanding about the importance of aggregations for both the fishery and the fish themselves. In particular, the 'illusion of plenty' that a healthy aggregation will inevitably produce represents a particular challenge for aggregation-fisheries. In many situations, it will be necessary to undergo a major paradigm shift, from seeing spawning aggregations as special opportunities for fishing to understanding them as particularly important times at which fish need to be protected, to ensure that they produce the next generation.

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