REPORT

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Are aggregation-fisheries sustainable? Reef fish fisheries as a case study

Abstract Reef fish spawning aggregations are attractive and often lucrative to fish but particularly vulnerable to fishing, with many cases of declines or extirpations. While awareness of the risks of aggregation exploitation has grown substantially in the tropical western Atlantic in the last decade, the phenomenon of aggregation-spawning is little known in the vast Indo-Pacific region where few aggregations are managed or monitored, and are rarely considered in marine-protected area designations. Even in the tropical western Atlantic and Caribbean, marine-protected area planning, until recently, did not typically consider spawning aggregations. Available data and analyses of aggregation-fisheries and aggregating species strongly suggest that: (1) the majority of known aggregations that are exploited are yielding declining landings; (2) aggregating species show greatest overall declines in local fisheries when their aggregations are also exploited; (3) from an economic perspective, aggregation fishing may yield lower prices for fish, or aggregations may be more valuable unexploited, as a source of fish for local fisheries or as tourist attractions; (4) hyperstability can mask declines in aggregation-fisheries, based on fishery-dependent data; (5) monitoring of aggregation catches by either fishery-dependent or fishery-independent means is deceptively challenging. There are also possible ecosystem-level consequences of reducing or eliminating spawning aggregations. We conclude that aggregation-fisheries are likely to be sustainable only for limited subsistence-level use, that the precautionary principle should be more widely applied in aggregation-fisheries and that, despite growing interest in aggregations over the last decade, few of the key biological questions necessary for effective management have been, or are being, addressed.

Keywords Vulnerable species · Management · Monitoring · Hyperstability · Transient spawning aggregations · Reef fisheries

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Introduction

Many reef fishes aggregate in large numbers to spawn at sites and times that are predictable, and hence susceptible to fishing. These aggregations are the only known reproductive opportunities for many species, yet many exploited aggregations are severely reduced, some have ceased to form, and few outside of the western Atlantic are monitored or regulated. The objectives of this study were to examine the viability of tropical aggregation-fisheries by a synthesis of the relevant literature, analysis of an aggregation-fishery in Cuba, and reference to data collected from fisher interviews in the western Pacific. We also examine fishery-dependent and fishery-independent approaches used to monitor the catches of aggregating species and identify key areas of research that need to be addressed for effective management. Where relevant, we refer to illustrative non-tropical examples of aggregation fishing.

For clarity and consistency, we follow Domeier and Colin (1997) who defined spawning aggregations in general terms and further distinguished different categories based upon the frequency of occurrence and length of time that individual fish remain at the aggregation site. In general, a spawning aggregation is a group of conspecific fish, gathered at a specific site and time, for the purpose of spawning, with fish densities, or

numbers, significantly higher than those found during the non-reproductive period. Aggregations consisting of fish that travel relatively long distances and persist at the aggregation sites for days to weeks are termed *transient spawning aggregations*, while those involving fish that travel short distances and persist for minutes to hours are termed *resident spawning aggregations* (Domeier and Colin 1997). Resident aggregations form at specific times of the day, often synchronized to a particular lunar phase, over a lengthy spawning season (sometimes year-round), while transient spawning aggregations are brief and form at specific times of the year, often during a specific lunar phase. Many commercially important reef fishes aggregate to spawn, and most of these form transient spawning aggregations (e.g. species of the families Serranidae, Lutjanidae, Lethrinidae, etc.; see Domeier and Colin 1997 for complete list). These are the major focus of this paper.

The problem: aggregations are a lucrative target

Aggregation fishing poses unique threats in that aggregations, once found, are particularly easy to relocate and heavy fishing can rapidly remove a significant proportion of assembled individuals with potentially serious implications for reproductive and economic outputs. A global database compiled by the Society for the Conservation of Reef Fish Aggregations (SCRFA) shows that within exploited aggregations of known history ($n = 140$) over 60% show evidence of declines, almost 20% may have ceased to form, while the remaining 20% show stability or, in a few cases, may increase (http://www.SCRFA. org). The increasing use of sonar, and Global Positioning System (GPS) technology has made spawning aggregation sites easier to find, relocate, or communicate to others. Aggregations are sometimes associated with distinctive physical features of reefs that are identifiable on good quality charts, photos, or by direct observation. In the case of the live reef food-fish trade (LRFFT), spotter planes are reportedly used to search for potential spawning aggregation sites from the air while large live fish transporter vessels (viviers) can reach remote and otherwise inaccessible locations (Johannes and Reipen 1995; Johannes 1997). The high price paid for live fishes by consumers (sometimes exceeding US $100 per kg) make such expensive practices economically viable (Sadovy et al. 2003). Fishing for the chilled fish market, using a range of fishing gears (e.g. longline, gill net, fish trap, hook and line and speargun) can also involve heavy pressure on aggregations. The aggregating behavior of certain spawning reef fish species, possibly their only reproductive opportunity, makes it possible for the fishery to remove a large proportion of an aggregation over just a few days (e.g.,10–20%, Sala et al. 2001; 20–30%, Rhodes and Sadovy 2002). The possible negative consequences resulting from aggregation-fishing call for analyses of both biological and economic outcomes from the practice.

Examples of aggregation fisheries

One of the best-documented examples of a major fishery targeting spawning aggregations is that of the orange roughy, *Hoplostethus atlanticus*, a long-lived deepwater species. Although not a coral reef fish, it serves as a useful example of the potential effects of aggregation fishing. Orange roughy have been the focus of intense aggregation fishing at the tops of seamounts off New Zealand, Australia, and Namibia. After the aggregating behavior was discovered in New Zealand, orange roughy catch from seamounts grew from about 30% of the annual catch in 1985 to 80% of the annual catch by 1995, subsequently stabilizing at 60–70% (Clark and O'Driscoll 2001). Reduced catches by the 1990s led to active searching for new seamount habitat, and by 2000 about 80% of known seamounts in the appropriate depth range had been fished (Clark and O'Driscoll 2001). Landings were sustained only through the discovery of these new aggregation sites (Clark 2001). Where trawl vessels once took great care to shave only the edges of the aggregation, for fear of overwhelming and losing their gear with an excessive catch, trawls dragged over the centre of historical catch areas now produce only discarded trash and carcasses from years gone by (J. Holdsworth, orange roughy fisherman, personal communication). In Namibia, quotas of orange roughy were reduced from 12,000 tons to 1,875 tons as the stock was fished to below 30% of virgin biomass in only 6 years (Branch 2001; Boyer et al. 2001). Similarly, large aggregations of orange roughy were first discovered off southeast Australia in 1989; catches peaked in 1990 at about 50,000 tons, and by 1996 were believed to be sustainable at a much-reduced 5,000 tons (Koslow et al. 1997). It is unclear whether the orange roughy fishery, practiced in this way, is sustainable in the long-term (Clark 2001).

The Nassau grouper is the best-documented example of the consequences of intensely exploiting transient spawning aggregations of a coral reef fish. This was once the most commonly landed species within the Caribbean and tropical western Atlantic but is now classified as endangered in the IUCN (World Conservation Union) Red list, and as threatened by the American Fisheries Society (Musick et al. 2000). How could such a change in status have come about? In many areas, the majority of annual landings (up to 90%) of Nassau grouper, are, or once were, taken from spawning aggregations (Sadovy and Eklund 1999). Fewer than 100 aggregations of this species are known, most of which occur (or occurred) in the Bahamas, Cuba, and Central America. Although documented in the 1800s (Vilaro Diaz 1884), it was only in the early 1970s that the first detailed report of a spawning aggregation was published; an estimated 30,000–100,000 fish were reported from a single Nassau grouper aggregation in the Bahamas, based on underwater observation (Smith 1972). However, of the six Bahamian sites surveyed in 2001, most had very few fish

and one site, which had hundreds of fish in the early 1990s, yielded just a few tens of fish in 2001 (Colin 1992; D. Eggleston, personal communication). In the Cayman Islands, several aggregations are considered to be economically extinct, while a recent survey in Belize determined that seven out of nine exploited spawning aggregations no longer form (Sala et al. 2001; Whaylen et al. 2004). In Cuba, few aggregations evidently persist in unspecified numbers, while annual landings have plummeted, more so than for any other finfish (Fig. 1). These patterns were repeated elsewhere in the Caribbean (Olsen and LaPlace 1979; Sadovy and Eklund 1999). Overall, an estimated one-third of all known spawning aggregations of this species have either disappeared or diminished to negligible numbers (Sadovy and Eklund 1999).

In the Indo-Pacific and Red Sea, aggregations are systematically and increasingly sought out and depleted. This trend is especially marked in Indonesia and some islands of the western Pacific in response to pressure from the Southeast Asian-based LRFFT. In the early 1980s, marked depletions of several grouper aggregations were noted in Palau within a couple of years following their exploitation for this trade, prompting Palau's withdrawal from exporting live fish shortly thereafter (Johannes and Reipen 1995). In Indonesia, grouper aggregation sites have also been heavily targeted. For example, in the Komodo National Park, while absence of baseline data precludes detailed evaluation of possible impacts, numbers of fish at aggregation sites of several species are considered to be uncharacteristically low (Pet and Muljadi 2001). Off Sinjai in southwestern Sulawesi, heavy fishing, including the targeting of aggregations, over the last decade for live fish has led to serial aggregation depletions (Sadovy and Liu 2004). In parts of Fiji, pressure from the local chilled fish markets has led to declines in aggregations and aggregating species (Sadovy 2004). Elsewhere in the Pacific, grouper spawning aggregations are declining or may have stopped forming, very probably due to overfishing (Johannes et al. 1999; Sala et al. 2003; http://www.SCRFA.org). The emperor, *Lethrinus nebulosus*, in

Egypt was heavily targeted at its aggregations for 8 years, with marked declines in catches and mean sizes noted (Salem 1999). The above examples call for a precautionary approach to aggregation exploitation, especially in the absence of evidence that aggregations recover once extirpated.

Key biological considerations

Spawning aggregations are an important life history phase for many reef fishes where much, or all, reproductive activity occurs. The most obvious direct effect of heavy aggregation exploitation is the rapid depletion of adults and the associated reduction in egg production. The long-term impacts of such a reduction will depend on several factors, the most important being recruitment. Given the longevity and late sexual maturation of many aggregating species, as well as sporadic recruitment known for some (e.g., coral trout, Russ et al. 1996), effects of heavy aggregation fishing may not be noted for many years, leading to greater risk of overexploitation through delayed management action. Moreover, given that the stock-recruitment relationships in reef fishes are largely unknown, the possibility of Allee effects being associated with severely reduced spawning biomass, in temporary reproductive concentrations, adds further uncertainty.

Theoretically, heavy fishing on a specific spawning aggregation could result in its permanent loss from a particular site, even after stock recovery. Individual aggregations of reef fishes can persist at precisely the same site for decades (Colin 1996; Warner 1988; Aguilar-Perera 1994), but the sequence of events that leads to the initial development of a spawning aggregation cannot be precisely determined because of the many generations it may take for this to occur. There is some evidence that social learning, or tradition, plays a key role in the development and repeated formation of an individual spawning aggregation, suggesting that new recruits may learn to use spawning sites from older and experienced individuals, thus passing the information

Fig. 1 Total annual landings of Nassau grouper (*Epinephelus striatus*) (*dashed line* left *y*-axis in mt) and of all finfish combined (*solid line* right *y*-axis in mt) between 1962 and 1998 in Cuba. Redrawn from Claro et al. (2001) and Claro and Lindeman (2003), with kind permission of the authors
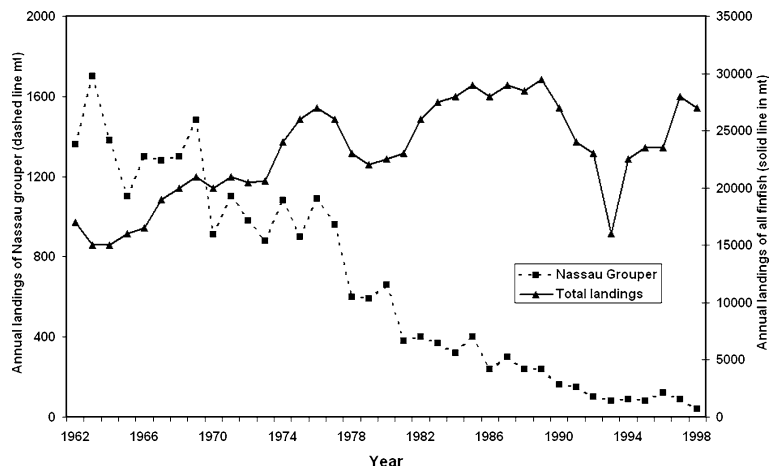
down from one generation to the next. This has been indicated for bluehead wrasse (*Thalassoma bifasciatum*) (Warner 1988, 1990), a coral reef fish, and cod (*Gadus morhua*) (e.g. Rose 1993; Arnold and Metcalfe 1995), a non-reef fish example; spawning site fidelity has also been reported in the North Sea Plaice (Hunter et al. 2003). Experimental extirpation of bluehead wrasse (*Thalassoma bifasciatum*) spawning aggregations, followed by the introduction of a new population of identical structure (number and sex ratio), revealed that previously used sites were no more likely to be chosen by the new population than were other identified potential sites (Warner 1988). If the bluehead wrasse pattern holds true for more commercially valuable species, it would indicate that a spawning aggregation fished to extirpation may not necessarily reform at the same site. Understanding the biology and evolution of aggregation spawning, then, will assist in management decisions. Ensuring protection of existing aggregations may be important to ensure that valuable (traditional) information is not lost from the fish population.

The very presence of a spawning aggregation at a particular site may itself be an indication of long-term ecological stability. One sign of such stability is the development of a novel and short-lived trophic tier consisting of megafauna that aggregate over the spawning aggregation to feed on the large volume of eggs released by spawning fish; examples include the gathering of whale sharks over spawning lutjanids in Belize (Heyman et al. 2001), and manta rays feeding on the spawn of acanthurids in the Cook Islands (L. Mildbrand, personal communication). Drastic reduction or extirpation of spawning aggregations will certainly affect the behavior, if not health, of these megafauna, but even broader ecological impacts can be expected. Since many commercially valuable reef fishes that aggregate to spawn occupy high trophic levels, overfishing of these aggregations could ultimately have ecosystem level effects by causing shifts in fish community structure. This effect, termed "fishing down marine food webs" (Pauly et al. 1998; Myers and Worm 2003) has been demonstrated in some regions of the Gulf of California where spawning aggregations have disappeared (Sala et al. 2004).

Less obvious impacts from aggregation-fishing should also be considered. For example, destructive fishing practices could destroy reef cover that would normally provide shelter from predators for aggregated individuals where habitat type or density may be an important characteristic of the spawning site (e.g. Sadovy et al. 1994; Koenig et al. 2000). The existence of sites where many species spawn, i.e., multi-species aggregations, may mean that the site-selection process is similar over a broad phylogenetic range, or indicate that particular locations are somehow uniquely desirable to many different species; multi-species spawning sites have been reported in both the tropical western Atlantic and Indo-Pacific (http://www.SCRFA.org; Coleman et al. 2004). As a non-fish example, a specific type of critical

habitat was identified for brooding aggregations of the Dungeness crab, *Cancer magister* (Scheding et al. 1999).

Whatever the reason for movement to certain sites may be, severe damage to aggregation habitats could compromise spawning aggregation formation, and hence the viability of associated fish populations; much depends on the reasons for and consequences of aggregation formation. If hermaphroditic species use spawning aggregations to gather cues related to sex change, then sex-selective removals may disrupt important social cues (Shapiro et al. 1994; Koenig et al. 1996). If aggregations are timed to take advantage of particular oceanographic regimes of benefit to the egg or larval phase, then their disruption may significantly influence subsequent recruitment success; in one example, a preliminary study that examined the seasonal current patterns over a Florida spawning aggregation site found favourable conditions for recruitment to occur only near the time the aggregation forms (Domeier 2004). Inevitably speculative, these examples nonetheless underscore the importance of better understanding why and how aggregations form and also when and where they do, such that the impacts of aggregation disturbance and declines can be determined and mitigated.

Other important unanswered biological questions relevant to the effective management and conservation of spawning aggregations fall into two categories. Important among these are: (1) where do the adults come from (i.e. 'catchment area'), and (2) where do the resulting larvae settle? Knowledge of the geographic extent from which a particular aggregation site draws individuals, and to which it supplies recruits would allow for best management of the associated population and optimal placement of protected areas. Self-recruitment is the simplest scenario for effective aggregation management. However, if an aggregation depends on recruits from another source (e.g. another aggregation), this could be within the jurisdiction of a second independent political body, forcing the need for cooperation and standardization of management. Studies must ultimately determine the connectivity of spawning aggregations to surrounding regions, as well as the relative importance of aggregation versus non-aggregation exploitation of the target stock. The few studies of potential larval dispersal from spawning aggregation sites suggest that aggregations may be supplying recruits to a very large area (Domeier 2004), or locally (Colin 1992). Certainly the scale of recruitment will vary from site to site and seasonally. We also need, therefore, to better understand the extent to which specific aggregations may differ in their timing and location to ensure that such variability is factored into seasonal and/or spatial management measures.

Economic considerations

Although the short-term economic benefit of fishing a spawning aggregation may be obvious, both short-term and long-term negative economic impacts can result

from overfishing. In the short term, heavy landings from aggregations may flood the market causing declines in the value of the unit catch during the aggregation period; fishers may receive only a fraction of the price/kg they would earn for their chilled fish during the non-aggregation period. In the Atlantic, examples of this exist for a tropical species of snapper, *Lutjanus analis* (P. Gladding, commercial fisher, personal communication), as well as for a grouper-like temperate aggregating species, *Polyprion americanus* (Iudicello et al. 1999). Examples also exist from the Indo-Pacific, where some Fijian fishers receive between 10% and 50%less for fish taken during aggregations than at other times of the year (Sadovy 2004).

Over the long term, depletion of the stock by aggregation-fishing makes it more difficult to catch the species during the rest of the year. In Fiji, aggregating groupers, rabbitfishes, and a species of sweetlips (Haemulidae) were identified by fishers as species that had also decreased more than other (non-aggregating) species in the fishery (Sadovy 2004). In Cuba, mullets (in the 1990s) and lane snapper, *Lutjanus synagris*, (in the 1970s) landings likewise showed declines, disproportionately severe relative to most other reef fishes over the same period, most probably the result of indiscriminate use of set nets on spawning migration routes (Claro et al. 2001). In some cases these concerns have resulted in management changes; the record low prices for *P. americanus* spurred the creation of an individual transferable quota (ITQ) system that resulted in catches being more evenly spread throughout the year, while concerns over the long-term implications of aggregation fishing led the Fijian fisheries department to prohibit the supply of live fish for export from aggregations (A. Batibasaga, Head of Fisheries Research, Fiji Fisheries). The great majority of known spawning aggregations, however, are not managed at all.

Economic analyses have shown that there can be considerable value in protecting aggregations and substituting ecotourism-related activities for fisheries. One aggregation in Belize was estimated at twenty times the value of the extracted fish (per annum) if protected and used for diving tourism (Sala et al. 2001). Moreover, this calculation did not consider the long-term benefit/value to the non-aggregation fishery of the species. In Komodo National Park, Indonesia, the estimated value to the fishery of protecting aggregations within the marine component of the park, thereby allowing them to fulfil their reproductive function and replenish the fishery, was similar to the total recreational value associated with the famous terrestrial component of the park itself (Ruitenbeek 2001). Economic analyses are valuable for understanding and illustrating the fishery and non-fishery values of maintaining viable spawning aggregations.

Monitoring and management

Given the many problems associated with aggregation-based fishing, and the implications this has for the overall condition of the fishery, we advocate that, ideally, spawning aggregations should not be exploited. While we also recognize that there will continue to be circumstances when some level of managed subsistence or recreational fishing on aggregations might be necessary, or even desirable, we stress that even subsistence or artisanal level fishing pressure can quickly deplete aggregations (e.g. Olsen and LaPlace 1979; Sadovy and Eklund 1999; Whaylen et al. 2004).

Unfortunately, there is no 'one size fits all' for managing commercially exploited, aggregating reef fishes. Some species are more vulnerable than others and may well need management, not only during aggregation but also in non-aggregation periods (e.g., the Nassau grouper, which forms relatively few large aggregations and is also otherwise particularly susceptible to overfishing because of its biology). Others might not be so severely affected by the loss of a few small aggregations (e.g., coral trout, *Plectropomus leopardus*, which forms many, relatively small, aggregations). Some species may be better, or more practically, protected by seasonal measures, others by spatial management or gear controls. Currently, the most commonly applied management measures for fisheries on species that aggregate to spawn are seasonal bans during the reproductive period when the species cannot be fished or traded, and with occasional exceptions for subsistence use (Domeier et al. 2002; http://www.SCRFA.org). This is often the most practical approach when enforcement of individual sites is not possible, many sites are not yet known (indeed, in many areas the best protection that aggregation sites may have is to remain unknown), and/or landings are concentrated in a few public markets. Another approach involves the protection of spawning aggregation sites during the spawning season, or their incorporation into Marine Protected Areas (MPAs—defined here as permanent no-take areas) (e.g. Johannes 1998; Coleman et al. 1999, 2004; Eklund et al. 2000; Domeier 2004). Protecting only the site, however, would not protect species vulnerable while migrating en route to aggregations. Nor is it effective at sites that are heavily fished at other times, where protection does not encompass all aggregation months or when effort consequently increases outside of the aggregation period (e.g. Johannes et al. 1999; Domeier et al. 2002; Claro and Lindeman 2003; Coleman et al. 2004). There are some examples of restricting fishing effort over spawning aggregations by limiting the number of fishers or only permitting certain gear types (e.g. Cayman Islands, Mexico, USA), but these restrictions are so new that it is impossible to determine whether they will result in a sustainable fishery.

An essential component of successful management is long-term monitoring, a deceptively difficult challenge for aggregation spawners whether by fishery-dependent or fishery-independent means. Monitoring requires assessment of abundance over time. In fisheries, abundance is usually determined by a proxy like catch per unit of effort (CPUE) that is typically assumed to be
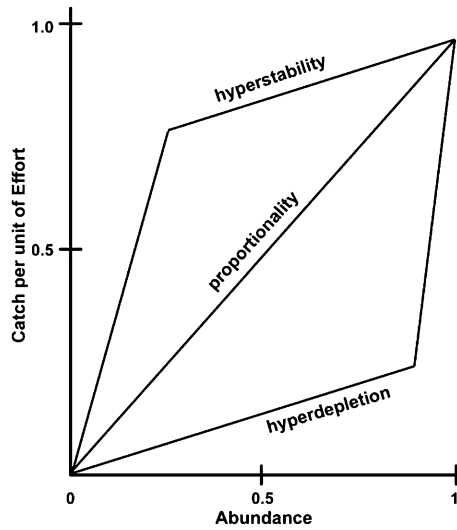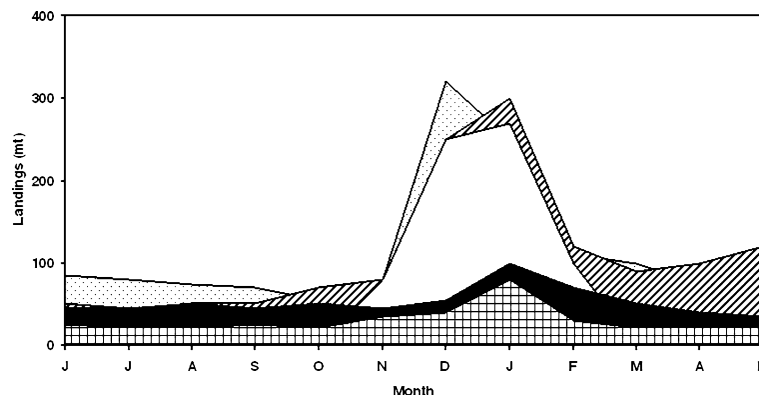
Fig. 2 Relationships between catch per unit of effort (CPUE) and abundance under hyperstability when fish or fisher behavior results in elevated CPUE even as fish abundance declines until the stock starts to collapse, and hyperdepletion when catches fall disproportionately with effort. Based on Hilborn and Walters (1992)

known as 'hyperstability' and is a major problem for both monitoring and management (Hilborn and Walters 1992). When hyperstability occurs, fishers may resist management in the absence of evidence of dwindling catches; while for managers it poses the problem that a monitored stock can decline without any change in aggregation CPUE to indicate problems until very late (Fig. 2).

Several major fishery collapses globally are attributed to hyperstability, in particular clupeoid collapses, although the 'aggregations' in these cases relate to changes in schooling behavior as well as reproductive aggregative behavior (e.g. Hilborn and Walters 1992; Pitcher 1995). Examples from demersal fisheries are far fewer but recent work examines the problem of non-proportionality of abundance and CPUE in such species in more detail and further examples are coming to light. One attempt examined fisheries for which both CPUE and fishery-independent (survey) data were available, and found considerable evidence for hyperstability in several species (Harley et al. 2001). A classic example of this problem is encountered in the Atlantic cod, which exhibits increased shoaling behavior as population numbers decline. Despite declining numbers, high CPUE was maintained by fishers who knew where to find remaining shoals, even as the stock plummeted, until numbers were so low that a moratorium was implemented in the early 1990s (Hutchings 1996). Likewise, fisheries for aggregating prawns show strong stock declines or fishery collapses, indicating that aggregating penaeids are particularly prone to overfishing (Die and Ellis 1999).

Demonstrating hyperstability associated with the fishing of reef fish spawning aggregations is difficult because both CPUE and fishery-independent data for the same aggregation fishery are rarely available. One possible example is the Nassau grouper fishery in Cuba where, historically, over 90% of the landings were taken from spawning aggregations and where both total annual catches, as well as those taken only during the spawning season, are available at the national level for a long time series. Monthly landings data are available from 1962 to 1985 and can be compared between spawning (December and January) and non-spawning periods each year over this period (Fig. 3). Assuming that the landings data are comparable month for month across years (i.e. December

directly proportional to abundance. However, the ways in which fish and fishers are distributed in space and time can have considerable impacts on both catches and the relationship between CPUE and abundance. This is particularly important when the behavior of fish changes in a predictable way, such as in the case of temporary aggregating behavior. When large numbers of fish periodically concentrate predictably, the relationship between CPUE and abundance is no longer directly proportional. If an aggregation-based fishery is not over-saturated and fishers are taking as much as they can, CPUE is likely to remain stable even as the actual number of aggregated fish declines. This is a condition

Fig. 3 Monthly landings of Nassau grouper, *Epinephelus striatus*, between 1963 and 1985 from Cuba (from highest to lowest December and January landings: *light stipple* 1963–1965, *diagonal* 1966–1970, *white* 1971–1975, *black* 1976–1980, *squared* 1981–1985). The reproductive season is December and January and most annual landings are taken from spawning aggregations. Redrawn from Claro and Lindeman (2003), with kind permission of the authors

with December, etc.) aggregation catches remained high and apparently stable between 1962 and 1975 (Fig. 3), despite a drop in annual landings of almost 50% during the same period (Fig. 1). Then around the mid 1970s there was a collapse in aggregation catches: imminent aggregation collapse was not detectable from trends in aggregation landings prior to collapse despite declines in the overall fishery evident from total annual landings. Particularly for spawning aggregations, therefore, monitoring cannot rely solely on fishery-dependent data taken solely from aggregations.

Monitoring of aggregation-fisheries requires data collection year-round. Fishery-dependent monitoring has the potential problem of hyperstability. On the other hand, fishery-independent monitoring, for example by underwater visual census (UVC) on aggregations, is fraught with difficulties. Problems include high variability in fish numbers over the course of a brief aggregation period, even during the course of a single diel cycle, the considerable demands of developing and sustaining a meaningful UVC protocol, and challenging underwater working conditions (Samoilys 1997; Colin et al. 2003). Moreover, UVC-based surveys can be expensive, even to the extent of costing more than the landed value of the fish (Johannes et al. 1999). Given such problems, more acute in areas for which there is little funding for fishery monitoring, UVC methodology is best developed on a site-by-site, species-by-species, basis. This again points to the need for regular non-aggregation monitoring of target species, given that these typically exhibit other life history characteristics, such as long life and late sexual maturation, making them inherently vulnerable to anything other than low levels of fishing pressure (Jennings et al. 1999).

Does protecting aggregations work, and is it worth the cost and effort of management and monitoring? There is evidence that protection does work and, conversely and importantly, many indications that declines and even extirpations occur in the absence of protection. A spawning aggregation of the red hind, *Epinephelus guttatus*, in St. Thomas State waters, United States Virgin Islands, was closed seasonally in 1990 and subsequently incorporated into a Marine Conservation District for year-round closure. Following protection, the number of red hind aggregating to spawn, assessed by UVC, increased by over 400% over 4 years. By 1997, mean individual fish length had increased by 100 mm, biomass and density increased, and the sex ratio had recovered from a heavy female bias to four females to one male (Beets and Friedlander 1998; Nemeth 2005). Protective measures in Palau may have shielded aggregations from growing fishing pressure (Johannes et al. 1999).

Conclusion

Through the presentation of biological, historical, and economic examples, using fishery-dependent and fishery-independent data, we have demonstrated the pressing need to study, protect, monitor, and manage known exploited reef fish spawning aggregations, aggregating species, and possibly, aggregation site habitat. Although many other workers have identified the need for such work, there are few comprehensive fishery or biological studies that address many of the core questions about aggregations that are key to their effective protection. While biological information is still needed to determine the finer points of conservation and management, we know that exploited and unprotected aggregations can and do become rapidly and seriously depleted, putting aggregation-based fisheries at risk of sudden collapse because of hyperstability. While the need for aggregation protection is now obvious to most biologists, and, ironically, often to fishers themselves, the vulnerability of spawning sites, aggregations and aggregating fish species is still not yet widely recognised by managers, particularly in the Indo-Pacific, but this is also the case in the Caribbean: a recent review of marine reserves showed that only four out of 55 no-take reserves had considered spawning aggregations in their design (Appeldoorn and Lindeman 2003). Few aggregations globally are currently managed or specifically incorporated into MPAs, and other means of protection, such as seasonal closures or effort limitation, should be more often considered. Very few exploited aggregating species are regularly monitored. There is a need for greater awareness among managers, fishery biologists and the general public that spawning aggregations are vulnerable and spectacular biological phenomena that must be placed higher on conservation, research and management agendas. The recently adopted IUCN recommendation (November 2004) to better protect reef fish spawning aggregations is a move in the right direction.

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