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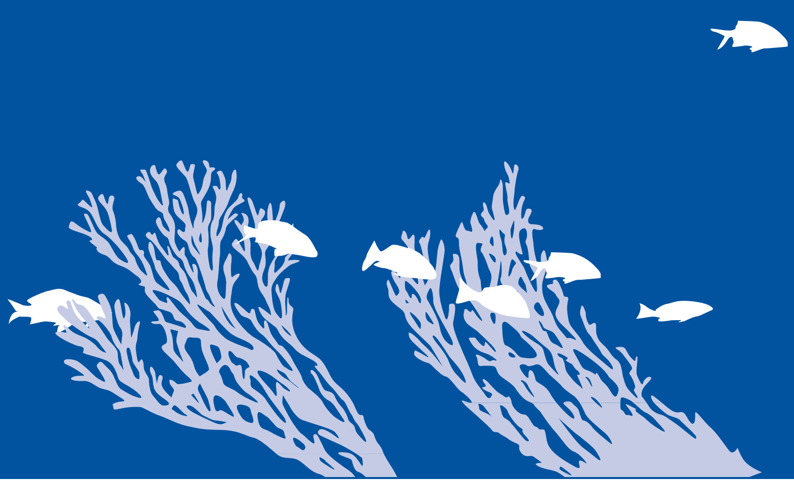
Spawning Aggregations of Reef Fishes on the Great Barrier Reef: Implications for Management

Martin Russell

Fisheries Issues Group



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Contents

ABSTRACT

Many species of tropical fish associated with coral reefs aggregate at specific times and locations to spawn. Spawning aggregations of fishes are influenced by season, lunar phase and temperature and commonly form at traditional spawning sites. These traditional spawning sites, known as fish spawning aggregation sites (FSAS), typically occur at locations with several key characteristics, including water movements that transport eggs and larvae offshore or into the water column to facilitate the open-water phase of development.

In recent years spawning aggregations of 49 species of fish have been reported in the Great Barrier Reef Marine Park. An additional 84 species of fish that occur on the Great Barrier Reef have been reported to aggregate to spawn elsewhere within their geographical range.

The increased abundance of fish in localised areas at predictable times makes spawning aggregations particularly vulnerable to overexploitation. The Great Barrier Reef Marine Park Authority is concerned that fishing, tourism and, to a lesser extent, research activities are impacting on FSAS and the fishes when they aggregate to spawn at these sites. There is concern that fishers are targeting spawning aggregations of coral trout, *Plectropomus spp*. and other predatory fishes on the Great Barrier Reef; that tourism facilities and activities occur at or near FSAS; and that some research activities directly impact spawning fishes.

The importance of developing policy and management strategies to protect fish spawning aggregations in the Great Barrier Reef Marine Park has been recognised. This report provides an overview of the status and vulnerability of spawning aggregations of reef fishes in a global context. It uses this background as a basis for developing management strategies to protect aggregating fishes from anthropogenic impacts in the Great Barrier Reef Marine Park.

INTRODUCTION

For some time the Great Barrier Reef Marine Park Authority (GBRMPA) has been aware of the need to protect spawning aggregations of fishes in the Great Barrier Reef Marine Park (GBRMP) from impacts of human activities, particularly fishing, tourism and, to a lesser extent, research.

Submissions to the recent draft Cairns Area Plan of Management (GBRMPA 1999) recommended that greater consideration be given by GBRMPA to the management of spawning aggregation sites of reef fishes. Two major areas of concern were identified. Firstly, there was concern that reef fish stocks were being overfished, partly as a result of targeted fishing on spawning aggregations throughout the GBRMP. Secondly, there was concern that existing and proposed structures such as pontoons, anchorage areas and moorings were in or close to fish spawning aggregation sites (FSAS) and that tourism activity at these sites disrupted the normal spawning behaviour of aggregating fishes.

While potential tourism impacts on spawning aggregations will be localised, particularly in the Cairns and Whitsundays regions, fishing impacts could affect aggregations throughout the GBRMP. Research activities also can have similar impacts as fishing and tourism.

A GBRMPA Interim Policy for fish spawning aggregation sites and tourism activity management (December 1997) aims to protect, to some degree, fish spawning aggregations from the impacts of tourism. Further to this Interim Policy, in this report consideration is given to management options to protect spawning aggregations of fishes from the impacts of fishing, tourism and research. These management arrangements would complement management arrangements proposed by other agencies, such as the Queensland Fisheries Service (QFS).

This report draws on two main sources of information, viz. a review of the available literature (published and unpublished) on spawning aggregations of reef fishes relevant to the Great Barrier Reef (GBR), and findings of a workshop in 1998 with Queensland fisheries managers and researchers to address issues relating to spawning aggregations and associated management issues. The information in this report is by no means exhaustive and merely provides a basis for further discussion and protective strategy development for spawning fishes in the GBRMP.

1. SPAWNING AGGREGATIONS OF TROPICAL REEF FISHES

1.1 What are Fish Spawning Aggregations/Aggregation Sites?

Many species of tropical fish associated with coral reefs aggregate at specific times and locations to spawn. Spawning aggregations of fishes are influenced by season, lunar phase and temperature and commonly form at traditional spawning sites. The types of fishes that aggregate to spawn range from predatory serranids (Smith 1972; Samoilys & Squire 1994), trevallies (Thresher 1984; Johannes 1981) and snappers (Carter & Perrine 1994) to herbivorous parrotfishes and surgeonfishes (Colin & Clavijo 1988; Myrberg et al. 1988). Spawning aggregations occur in at least 21 families of tropical reef fish world-wide (reviewed by Domeier & Colin 1997; Squire & Samoilys (unpub.)), with all species producing pelagic eggs.

There are many possible reasons why fishes aggregate to spawn at specific locations. Spawning aggregations typically form at sites with several key characteristics. It has been suggested that water movements that transport pelagic eggs and larvae into the water column or offshore (Thresher 1984) facilitate the pelagic phase of development. The geomorphology offers a platform or 'arena' for spawning events, and topography facilitates males setting up territories and offers refuge for females to hydrate eggs and rest from the attention of males (Squire, L. 2000, pers. comm.). Large numbers of pelagic eggs released simultaneously might swamp the ability of egg predators to feed (Johannes 1978). Also, aggregations might facilitate the ability of individuals to find mates and to synchronize physiological readiness to spawn (Colin & Clavijo 1988).

Spawning aggregations of fishes can vary considerably both within and between fish species. Spawning aggregations can form on a daily basis with associated movements over short distances (Colin and Clavijo 1988; Myrberg et al. 1988), or on a seasonal basis as a result of large-scale migrations (Colin 1992; Shapiro et al. 1993). In general terms, a spawning aggregation is defined as 'a group of conspecific fish gathered for the purpose of spawning with fish densities or numbers significantly higher (≥ 3 fold increase) than those found in the area of aggregation during the non-reproductive periods' (Domeier & Colin 1997). A FSAS is defined as a reef area traditionally used by one or more species of fish to aggregate for spawning purposes.

When investigating the spawning patterns of the common coral trout *Plectropomus leopardus* on the GBR, two different types of aggregation sites - primary and secondary - have been observed by Samoilys (1997). During the spawning season most fish aggregate at one primary site on a reef; however, some fish visit other secondary sites where smaller groups are spawning. Formations of spawning aggregations at primary sites are highly predictable from year to year, whereas formations of aggregations at secondary sites are not (Samoilys 1997; Zeller 1997).

1.2 The Need for Protection of Fish Spawning Aggregations

There are many species of fish on the GBR that aggregate to spawn (section 1.3). Aggregating fishes need protection because they are under threat, mainly from three human activities: fishing, tourism and, to a lesser extent, research. Targeted fishing of spawning aggregations, particularly of coral trout *Plectropomus spp.*, has been reported to occur at several aggregation sites on the GBR (QFMA 1996).

Sadovy (1996) emphasises that, from a fishery perspective, there is an urgent need to better estimate and maintain reproductive output in exploited populations. Fishers may target spawning aggregations, because they are often consistent in time and space. Targeting of spawning aggregations has been a common fishing practice

around the world and has resulted in the collapse of several commercially important fish stocks (Sadovy 1990; Sadovy 1992; Domeier & Colin 1997). Sadovy and Giacomello (2000) suggest that spawning fishes need protection because egg production is greatly diminished by significantly reduced aggregation numbers, as well as by reductions in mean female size and extreme skews in sex ratios. Davies (2000) suggests that an increase in catchability of common coral trout on mid-shelf reefs in the Cairns Section of the GBRMP during September is attributable to fish aggregating to spawn. Catchability of common coral trout is likely to increase as a result of the aggregated distribution of fish in locations which can be efficiently exploited by fishers and the heightened feeding activity of the fish associated with spawning (Johannes & Squire 1998; Samoilys & Squire 1994; Davies 2000).

Tourism activities pose an additional threat, in varying degrees, to spawning aggregations on the GBR. At present many tourism activities occur in areas where several fish species are known to form spawning aggregations. It is possible that activities such as concentrated boating and large numbers of snorkellers and divers could inhibit the formation of spawning aggregations or disturb normal spawning behaviour. If spawning activities are reduced, fish stocks may not be replenished and may diminish over time.

Extractive and non-extractive scientific research activities on the GBR may have an impact on some spawning aggregations, depending on timing, location and the type of activity. It is likely that extractive research during and around fish spawning seasons will have similar impacts as fishing and tourism, but are likely to have a less dramatic effect unless the research specifically targets spawning fishes.

Although only reported within the past 10 years, spawning aggregations of common coral trout (Samoilys, M. 1999, pers. comm.), blue-spot trout, *Plectropomus laevis*, and humphead maori wrasse *Cheilinus undulatus* (Squire, L. 1999, pers. comm.), have already diminished in size and number at various locations in the northern GBR. Recently, management strategies have been implemented in other countries, such as Palau and the USA, in an attempt to protect spawning aggregations from further exploitation. From the examples of over-exploitation overseas and the concerns raised of the threats to the GBR, it is quite obvious that protection of spawning aggregations is necessary to ensure the future replenishment and sustainability of fish stocks on the GBR.

1.3 Fish Species that Aggregate to Spawn on the Great Barrier Reef

Presently, 133 species of fish in 21 families have been reported to form spawning aggregations, either on the GBR itself or elsewhere in their geographical range (Appendix 1). Forty-nine species from 12 families have been observed to form spawning aggregations on the GBR, and 84 other species that also inhabit the GBR have been reported to form spawning aggregations in other locations. These spawning aggregations have been observed in Palau, Indonesia, Philippines, other island countries of the Pacific, Japan, and in the Red Sea (Appendix 2), (Squire & Samoilys, unpub.; Squire, L., 2000 pers. comm.).

Many species that aggregate to spawn are important species in the reef fish fishery on the GBR and are targeted by commercial and recreational fishers. These include fish in the families Serranidae (common coral trout and blue-spot trout); Lethrinidae (red-throat emperor, *Lethrinus miniatus*) and Lutjanidae (large-mouth nannygai, *Lutjanus malabaricus*). Other aggregating fish include fusiliers (Caesionidae), wrasse (Labridae), surgeonfish (Acanthuridae), parrotfish (Scaridae) and rabbitfish (Siganidae).

Several families of pelagic fish also form spawning aggregations at specific sites near coral reefs, including barracuda (Sphyraenidae), trevally (Carangidae) and mackerel (Scombridae) (Johannes 1980; Thresher 1984; Squire & Samoilys, unpub.). The importance of spawning aggregation sites to these fishes is not known.

There is little or no information on the life histories or spawning patterns of many reef fish species (Thresher 1984; Domeier & Colin 1997). It is likely that many of these species also aggregate to spawn and that as field investigations continue many more reef fish species will be identified as forming spawning aggregations (Johannes 1980; Domeier & Colin 1997; Squire & Samoilys, unpub.).

1.4 Reproductive Characteristics of Fishes that Aggregate to Spawn on the Great Barrier Reef

Only in recent years have detailed studies been conducted to identify the timing and location of spawning aggregations of reef fishes on the GBR. Most studies have focused on the reproductive patterns of common coral trout, because this is the most important fish in the GBR reef fish fishery. The reproductive characteristics of only a few families are known in any detail. Squire and Samoilys (unpub.) currently are compiling information on the characteristics of fish spawning aggregations of GBR fishes and other Indo-Pacific fishes. Details of spawning seasons and locations of aggregating fish species that have not been investigated specifically on the GBR but inhabit the GBR region are summarised in Appendix 2.

Eight species of surgeonfish (Acanthuridae) have been reported to spawn on the GBR (Robertson 1983; Squire & Samoilys, unpub.). Robertson (1983) observed spawning aggregations of brown surgeonfish *Acanthurus nigrofuscus*, striped surgeonfish *A. lineatus*, lined bristletooth *Ctenochaetus striatus* and brushtail tang *Zebrasoma scopas* at Lizard Island during December and January. These species commonly moved from intertidal and shallow sub-tidal areas to the base of the reef slope at the lower limit of coral growth. Spawning occurred in late afternoon during both flood and ebb tides. The blue tang *Paracanthus hepatus* has been observed to aggregate to spawn in January, February and March at Escape Reef, northern GBR, spawning in the late afternoons (Robertson 1983).

Serranids generally are protogynous hermaphrodites. Individuals change from female to male as they mature, and sexual changeover is most likely triggered by social behaviour (Goeden 1978). Coral trout such as common coral trout and blue-spot trout typically spawn throughout spring and summer on the GBR (Goeden 1978; Ferreira 1993, 1995; Johannes & Squire 1988; Samoilys & Squire 1994; Samoilys 1997). The bar-cheeked trout *Plectropomus maculatus* is a 'multiple spawner' (individuals spawning several times during the spawning season) reproductively active between September and November on the central region of the GBR (Ferreira 1993).

Common coral trout form spawning aggregations in both the northern and central regions of the GBR (Samoilys & Squire 1994; Samoilys 1997; Zeller 1997). Currently, no information is available that common coral trout aggregate to spawn in the southern region of the GBR. However, this does not necessarily indicate that spawning aggregations do not occur (Brown et al. 1994). Although previous studies in the southern GBR hypothesised that the spawning season starts one month later (November) compared with the northern GBR (Goeden 1978; Brown et al. 1994; Johannes & Squire 1988), current information suggests that the common coral trout spawning season starts in September or October throughout the entire GBR and continues through to December or January (Squire, L. 2000, pers. comm.).

Aggregations of common coral trout comprising some 130 individuals have been reported on the GBR (Samoilys & Squire 1994). Individual fish were found to travel 0.2–5.2 km from their established home ranges to reach specific aggregation sites (Zeller 1997). Movement studies of common coral trout in the GBRMP suggest that once juveniles have recruited to a reef, they do not move between reefs. However, common coral trout move considerable distances within reefs to spawning aggregation sites (Davies 2000). Not all mature individuals migrate to spawn and many adults remain in their usual home range throughout recognised spawning seasons (Zeller 1997). Work on the GBR by Samoilys (1997) has shown that common coral trout begin aggregating at specific sites on the full moon, with spawning generally occurring around the new moon at dusk on flood tides. There is evidence that the timing of spawning for several serranids, including common coral trout, is also correlated with temperature (Samoilys 1997).

Many spawning aggregations of blue-spot trout have been observed to form on the outer reefs of the Cairns and Far Northern Sections of the GBR between September and January (Johannes & Squire 1988; Carlos & Samoilys 1993). At any given location the timing of the formation of spawning aggregations of blue-spot trout can vary by about a month from year to year (Johannes & Squire 1988). Johannes and Squire (1988) reported up to 60 adult fish in a spawning aggregation. Such aggregations occurred at specific locations on reefs. Carlos and Samoilys (1993) observed three separate aggregations of 20–30 adult fish. One of these aggregations occurred around the new moon, whereas the other two aggregations occurred on either the half or full moon.

The emperors (Lethrinidae) are most likely protogynous hermaphrodites (Young & Martin 1982; Brown et al. 1994). A spawning aggregation of only one emperor species, yellow-tailed emperor, *Lethrinus atkinsoni*, has been observed on the GBR (Squire & Samoilys, unpub.). Spawning seasons of the commercially-important red-throat emperor range from July to August in the northern GBR and from September to November in the southern GBR (Brown et al., 1994). Little published information is available on whether lethrinids are serial or annual spawners. Ebisawa (1990) determined that the spangled emperor *Lethrinus nebulosis* in Okinawa is a serial spawner.

Unlike the serranids and the lethrinids, the snappers (Lutjanidae) appear to be gonochoristic, i.e. males and females are separate, and do not change sex (Grimes 1987). Spawning seasons of the red emperor *Lutjanus sebae*, large-mouth nannygai, and small-mouth nannygai *Lutjanus erythropterus* occur during spring and summer (September to February) on the GBR (McPherson 1989; McPherson et al. 1992). Spawning peaks for both red emperor and large-mouth nannygai occur between November and January, while spawning of small-mouth nannygai peaks during October and November (McPherson et al. 1992). Spawning aggregations of these fishes have been reported in Palau, with spawning occurring around the full moon (Johannes 1981).

In general, wrasse (labridae) are protogynous hermaphrodites (Thresher 1984). Spawning aggregations of 200–300 humphead maori wrasse have been observed along reef walls of outer reefs in the northern GBR (Johannes & Squire 1988), although spawning of these fish has not been observed on the GBR. These aggregations occur from November to February at specific locations on reefs.

1.5 Physical Features of Spawning Aggregation Sites

Many specific FSAS on reefs are shared by several different fish species (Squire, L. 2000, pers. comm.). For instance, 24 fish species from four families were observed spawning in a reef channel at Shiraho Reef in Japan over an 11-day observation period (Moyer 1989). It is likely that fishes select specific physical features for their aggregation sites (Johannes 1981; Colin & Bell 1991).

The type of reef area used by spawning aggregations of GBR fishes varies considerably. Brief author descriptions of the reef types are presented in Appendix 2. Spawning aggregations may form in reef channels, on reef promontories or reef flats, around coral bommies or along reef walls. In many cases these sites are located on the outer edges of reefs (Appendix 2). However, Samoilys (1997) suggests that common coral trout aggregate in more protected areas.

A common feature of many FSAS is that sites seem to be well flushed, with moderate to strong tidal currents at certain times of the year (Appendix 2). The exact location of a FSAS can change slightly, depending on the nature of the current. For instance, in Palau, aggregations of flowery cod *Epinephelus fuscoguttatus* and camouflage rockcod *Epinephelus polyphekadion* move about 100 m along a reef edge depending on the nature of the current (Johannes et al. 1999). Similarly, common coral trout aggregations are known to occur at different places around coral bommies, depending on current changes (Samoilys 1997).

The importance of the coral substrate at FSAS has been documented recently. At least for serranids, coral is used extensively by aggregating females to seek refuge and protection at FSAS (Johannes et al. 1999; Squire, L. 2000, pers. comm.). Males rely less on the coral substrate because they establish territories when aggregating and remain very active (Johannes et al. 1999). Aguilar-Perera (1996) found that the substrate choice by the Nassau grouper *Epinephelus striatus* aggregating off the south coast of Quintana Roo, Mexico, consisted of low-relief, patchy, hard corals interspersed with plexaurids and gorgonians, indicating water flow.

Successful dispersal of pelagic eggs or survival of larvae might require the release of eggs at locations swept by specific current regimes (Doherty et al. 1994). However, work in the Caribbean by Hensley et al. (1994) and Appeldoorn et al. (1994) has shown that water movements offshore may not be as relevant as hypothesised for the Bluehead wrasse. The selection of spawning sites may be a complex process, with compromises between proximate factors (e.g. water flow at the site or ability to migrate) and ultimate factors (e.g. fate of eggs). Aguilar-Perera (1996) noted that currents were slow during observations of Nassau grouper spawning off the south coast of Quintana Roo, Mexico. Hensley et al. (1994) concluded that advantages of water flow appeared to be most strongly manifested during the short time after spawning.

Spawning of many tropical fish species outside the GBR has been reported to occur throughout the year (Appendix 2). Many serranids in the western tropical Atlantic are winter spawners, for instance the Nassau grouper (Sadovy, Y. 2000, pers. comm.). Some species, such as the bluespine unicornfish *Naso unicornis*, exhibit year-round spawning in Palau (Johannes 1981). Most spawning aggregations on the GBR have been reported to occur in spring and summer. Investigations on the GBR have occurred mainly in spring and summer, so that information on winter and/or year-round spawning is limited. Therefore, it is likely that further investigations into the spawning and aggregating patterns of other species will reveal spawning outside spring and summer on the GBR.

Many spawning activities of reef fishes, particularly of serranids, lutjanids and lethrinids, are correlated to lunar phase (Johannes 1981; review by Robertson 1991; Samoilys 1997). These lunar phases can be associated with larger tides than occur during other lunar phases and possibly assist with the flushing of larvae into open water at these times.

The lunar phase at which a fish species spawns can vary depending on the species and, even within a species, can vary depending on location (Appendix 2).

The timing of spawning varies among different species of fish that aggregate. For the smaller species, such as surgeonfish and rabbitfish, spawning may occur in the mornings, throughout the day, or in the afternoon, depending on tidal phase (Myrberg et al. 1988; Robertson 1983; Thresher 1984). However, larger species, such as *Plectropomus spp*. and *Epinephelus spp*., have been observed to spawn at and/or after dusk (Johannes 1981; Samoilys & Squire 1994; Samoilys 1997; Rhodes 2000). The only observed spawning of maori wrasse was at midday in Palau, and several observations have been made of maori wrasse displaying pre-spawning behaviour during the day in Palau, French Polynesia and Northern Mariana Islands (Sadovy, et al., in prep). However, it is thought that on the GBR maori wrasse may spawn after dusk (Squire, L. 2000, pers. comm.).

Domeier (2000) suggested that topographical and hydrodynamic characteristics play a significant role in spawning site choice. Studies of a reef promontory on the Belize Barrier Reef have shown that up to 21 species of reef fish use this area for spawning. The fertilised eggs rise to the surface and are transported offshore and away from the reef (Heyman et al. 2000). However, Shapiro et al. (1993) commented that a Nassau grouper aggregation in Mahahual, Mexican Caribbean, allowed males and females to find mates. Aggregation sites represent convenient gathering spots but do not necessarily comprise unusual physical characteristics.

Information held by the GBRMPA on the locations of FSAS in the GBRMP suggests that two different types of FSAS are used by fish species such as common coral trout. These are given the term primary FSAS and secondary FSAS. Common coral trout aggregate at both primary and secondary aggregation sites on the GBR (Samoilys 1997; Zeller 1997). Primary FSAS are, as the name suggests, the main preferred sites visited each year, and may be characterised by geomorphological and topographical features that facilitate territory establishment, and tidal currents that consistently transport eggs and larvae into open water. Secondary FSAS may have similar characteristics to primary FSAS, but are less favourable and possibly more variable. Consequently, these secondary sites seem to be larger in area. The aggregations of fishes at secondary sites are less predictable and more widely dispersed than at primary sites (Squire, L. 2000, pers. comm.).

2. IMPACTS ON FISH SPAWNING AGGREGATIONS

2.1 Impacts of Fishing

The increased abundance of reef fishes in a localised area at predictable times makes spawning aggregations vulnerable to overexploitation by fishing. Spawning aggregations often are targeted by fishers because large numbers of fish are concentrated at a single location and large catches can be made relatively easily at these sites (Johannes & Squire 1988; Sadovy et al. 1994; Domeier & Colin 1997). The most common fishing technique used on reef fish spawning aggregations is hook and line fishing, although spearfishing, traps and mesh netting are also used in some locations (e.g. Gladstone 1996; Aguilar-Perera 1994).

The vulnerability of aggregating fishes depends on the biology of the species, the intensity and selectivity of fishing and the responses of aggregating individuals to selective removals.

Some of the large grouper species throughout the world form large spawning aggregations during their spawning seasons, while some of the smaller grouper species form aggregations of varying sizes (Squire, L. 2000, pers. comm.).

The impacts of targeted fishing on spawning aggregations of tropical fishes in the Caribbean Sea and Gulf of Mexico have been well documented. Fishing in these areas has had a major and often detrimental impact on spawning aggregations of commercially important groupers such as the jewfish *Epinephelus itajara*, Nassau grouper, tiger grouper *Mycteroperca tigris*, scamp *Mycteroperca phenax* and gag *Mycteroperca microlepis*, as well as other species (Sadovy 1990).

It is common practice for fishers to begin harvesting while fish are moving to or as soon as fish arrive at a FSAS, before the fish have had a chance to spawn (Johannes & Squire 1988; Fine 1992; Gladstone 1996; Coleman et al. 1996; Koenig et al. 1996). Some species such as squaretail trout *Plectropomus areolatus* and Nassau grouper travel to spawning sites in a group and consequently are extremely vulnerable to capture at this stage (Sadovy, Y. 2000, pers. comm.). Fishing prior to or during the spawning period can cause major long-term impacts on the fish stock because the number of fish taking part in reproduction is greatly reduced (Carter et al. 1994). Fishing usually continues until the spawning period is over and the fish have either been harvested or have dispersed (Gladstone 1996; Koenig et al. 1996). In Puerto Rico, Nassau grouper was a common and very important food fish, but the fishery has now collapsed (Bohnsack 1989). The Nassau grouper spawning aggregations in the Caribbean have been heavily fished since the 1920s, and two out of the six known aggregations in Belize have been fished out (Sala et al. 2000).

Recent surveys in the Bahamas show that Nassau grouper, which travel up to 110 km to a FSAS at High Cay, have been heavily exploited by fishing; aggregations no longer occur, except for a few fish scattered in shallow water (Carleton et al. 2000; Bolden 2000). Jewfish aggregate to spawn on isolated wrecks in the Gulf of Mexico in July-September. Prior to exploitation, 40–100 adult jewfish formed these aggregations and now, after a few years of exploitation, only up to five individuals aggregate (Eklund et al. 2000).

Berkeley (2000) suggested that protracted spawning over a broad period of time during a spawning season represents a bet-hedging strategy to increase the probability that some larvae in that year will encounter favourable environmental conditions. It is suggested that because older fish of many species spawn at different times than younger fish, even moderate fishing can reduce the number of age classes in the population, which effectively could shorten the spawning season and reduce

the likelihood of larval survival. Generally, traditional fisheries management restricting effort and catch allows fishing of these important older fish. Also, Sadovy and Giacomello (2000) suggest that egg production is greatly diminished by reductions in mean female size. Chapman et al. (2000) suggests that the removal of the larger, more aggressive males from FSAS will cause a change in sex ratios, and the change in sex ratios could lead to reductions in effective population sizes and loss of genetic variation.

Intense fishing of spawning aggregations does not always select for males. Removing significant numbers of individuals of either sex can be disruptive, particularly when members of the group depend on each other for spawning cues. Individual fish of several species of grouper have been observed to visit the same FSAS in consecutive years (Gilmore & Jones 1992). Therefore, FSAS could be traditional and a spawning aggregation at a given site could consist of a distinct social group. Bolden (2000) found that many species of fish are entrained to particular FSAS in the Bahamas and may learn migratory routes from older fish and are capable of precise return migration. Newly recruited, inexperienced fish learn the location of a particular FSAS by migrating with experienced fish. Fishing a FSAS until no individuals are left results in no experienced fish to entrain recruits into a social group (Coleman et al. 1996). This process is believed to have caused the collapse of Nassau grouper fisheries throughout the Caribbean and western Atlantic (Olsen & La Place 1978; Bannerot et al. 1987).

Fishery simulation models have revealed that hermaphroditic fishes are more susceptible to over-fishing than gonochoristic fishes if fishing pressure reduces the normal proportion of males in the population (Bannerot et al. 1987; Huntsman & Schaaf 1994). Typically, in protogynous hermaphrodites, such as the serranids (*Plectropomus spp*. and *Epinephelus spp*.), males are differentially removed or selectively harvested on the basis of size because they are generally larger than females (Gilmore & Jones 1992; Koenig et al. 1996) and fishing tends to select for larger fish. Koenig (1996) suggests that fishing on aggregations can take some populations to a point where the populations are sperm limited. For example, comparison of sex ratios in populations of gag and scamp between present and historical populations in the Caribbean have revealed that the proportion of males has decreased over the past 20 years, from 17% to less than 3% and from 36% to 18% respectively (Coleman et al. 1996). As a result, reproductive capacity has been restricted and these populations have suffered severe declines (Beets & Friedlander 1992; Carter et al. 1994; Koenig et al. 1996; Coleman et al. 1996).

The changeover of hermaphroditic fishes from female to male is believed to relate to size and/or social behaviour, for example bar-cheeked trout (Ferreira 1993). Data from Coleman et al. (1996) have revealed a decrease in size at transition in over-exploited populations of gag and scamp which supports social rather than size-mediated change. There is concern that the changeover of females to males occurs at a smaller size than normal when large fish that are predominantly male have been taken from the aggregation. Small females are less fecund than large females, so a reduction in the overall reproductive outputs of the population is likely (Goeden 1977; Shapiro et al. 1993).

On the GBR the tropical coral reef fish fishery is made up of commercial and recreational fishers, including fishing tours (charter) using hook and line to target demersal reef fishes. There are some 240 principal licensed operators in the commercial reef line fishery, and a further 1400 commercial fishers with more limited licensing arrangements to take reef fishes. These fishers take up to 3500 tonnes of reef fishes annually. About 120 fishing charter vessels take about 265 tonnes, and about 800 000 recreational fishers in the GBRMP. The major fishes targeted include species in the families Lethrinidae, Lutjanidae and Serranidae (Brown et al. 1994; QFMA 1996).

In recent years, commercial and recreational fishers have expressed concern over the targeting of spawning aggregations and overexploitation of demersal fishes in the Cairns and northern regions of the GBR (Johannes & Squire 1988; QFMA 1996; Turnbull & Samoilys 1997). However, lack of data on spawning seasons and aggregations of fishes on the GBR makes it difficult to detect changes in abundance and occurrence. Recently, it has been verified that one of two main spawning aggregations of common coral trout on reefs near Cairns has diminished over the past two years, most likely due to overfishing (Samoilys, M. 1999, pers. comm.). Similarly, spawning aggregations of humphead maori wrasse and blue-spot trout documented by Johannes and Squire (1988) have also been depleted at some sites in the Cairns Section over the past 10 years, with aggregations no longer being formed at Ribbon and Jewell Reefs (Squire, L. 2000, pers. comm.).

There is concern about the sustainability of fishing *Plectropomus spp*. spawning sites on the GBR. Reports of people targeting spawning aggregations of these species have been made to both the QFS (QFMA 1996) and the GBRMPA. Turnbull and Samoilys (1997) examined commercial logbook catch data for common coral trout on the GBR but could not detect targeted fishing trends at times when the fish were most likely aggregating to spawn. However, increased fishing pressure was reported from September to November (Mapstone et al. 1996 as cited by Turnbull & Samoilys 1997), which corresponds with the spawning season for common coral trout as well as other important fishery species. Using computer modelling, Fulton (1996) investigated the vulnerability of spawning aggregations of common coral trout if targeted by fishers; he found that aggregating fish were more vulnerable to fishing at this time because of their increased activity in moving to and from the FSAS.

Spawning aggregations formed by Caribbean species, such as *Epinephelus spp*., seem to be different from those of serranids and other species on the GBR. Some Caribbean species migrate long distances to particular FSAS. For example, Nassau grouper travel up to 150 km (Carter et al. 1994), with as many as 100,000 individuals occurring at a FSAS (Smith 1972). GBR fishes such as the common coral trout and blue-spot trout seem to aggregate at one or two locations per reef. Davies (2000) concluded from a tagging study that movement of common coral trout between reefs in the mid-shelf reefs in the Cairns Section is negligible. However, there was a significant level of movement of common coral trout within reefs, which may represent movement to FSAS. Fishing a FSAS comprising fish aggregating from a large area and number of reefs may have a large impact on the spawning success of that species. However, fishing a FSAS comprising fish aggregating from within one reef may impact self-recruitment of that reef, but may have lesser impact if surrounding reefs have protected FSAS.

Another direct impact of fishing on spawning aggregations is damage caused by boat anchoring. Most recreational and commercial fishing vessels use a 'reef pick' to anchor on a reef in the GBR. When using the momentum of a vessel to dislodge an anchor from coral substrate there is a high risk of dislodging coral, such as large tabular forms, causing considerable damage and modifying the topographical characteristics of a FSAS.

2.2 Impacts of Tourism

Commercial tourism is a major industry on the GBR and on other coral reefs worldwide. Tourists visited the GBRMP for a total of some 1.3 million visitor days in 1998–99 (GBRMPA Environmental Management Charge Data). More than 90% of these tourists visited the Cairns-Port Douglas and Whitsunday regions, which cover 4% of the GBRMP. About 500,000 tourists dive or snorkel in the Cairns-Port Douglas area each year (Aiello 1996).

Tourism activities may impact fish spawning aggregations if they occur at or close to FSAS. The presence of tourist vessels, in-water tourist activity, fish feeding and physical damage to coral at FSAS may inhibit the formation of aggregations and spawning behaviour of aggregating fishes.

Recent mapping by the GBRMPA of the locations of mooring sites and FSAS in the Cairns-Port Douglas region has revealed that many mooring sites are positioned in or close to known primary and some secondary FSAS for major commercial fish species.

In the GBRMPA Cairns Area Plan of Management (GBRMPA 1999), which regulates tourism use in the Cairns Section, 270 private mooring sites and an additional seven reefs where no limit on mooring numbers is specified have been included within the planning area. Within this area there are 10 reefs where known FSAS exist and where additional moorings have been identified, but are yet to be installed.

From the information available on the effects of individual research divers (section 2.3), it is likely that large numbers of tourists diving and snorkelling at FSAS will disturb the spawning behaviour and subsequently affect the spawning success of aggregating fishes (Sadovy, Y. 2000, pers. comm.). It is likely that the presence of divers and snorkellers in the water will invoke a predator evasion response from fishes in the area. However, the potential impact of tourists diving and snorkelling at spawning aggregations is limited mainly to daylight hours and the significance of the impact will depend on the spawning behaviour of the fish species using the area.

Daily feeding of fishes is a popular activity at tourist sites, particularly adjacent to tourist pontoons (Sweatman 1996). Fish feeding can attract groups of predatory fishes such as spangled emperor, red bass *Lutjanus bohar* and potato cod *Epinephelus tukula*, as well as pelagic species, such as the trevallies and schooling barracuda, which may normally feed at other locations (Sweatman 1996; Squire, L. 2000, pers. comm.). It is of concern that the presence of these predators is likely to prevent the formation of spawning aggregations of smaller fishes at these sites. For example, it has been suggested that regular feeding of potato cod and red bass at the Cod Hole, northern GBR, has resulted in the cessation of large spawning aggregations of surgeonfish (*Acanthurus spp*.) and other fishes from frequenting the site because of the presence of predators (Squire, L. 2000, pers. comm.).

Information on the importance of coral reef structure to fishes at a FSAS has not been well documented, but recent research in Palau has revealed its importance for several serranids (Johannes et al. 1999). Females use the corals for shelter and protection, i.e. as refuge, at FSAS, spending a considerable amount of time amongst the coral. Vessel anchoring can cause substantial damage to coral reefs (Aiello 1996; Tourism Review Steering Committee 1997). High levels of coral damage from anchoring have been reported by tourists, tourist operators and Marine Park officers in both the Cairns and Whitsundays regions of the GBR (Tourism Review Steering Committee 1997). The installation of moorings and pontoons on reefs has reduced physical damage, primarily anchor damage, to coral reefs in the GBR, but has localised the effects of tourist activities in certain areas (Aiello 1996; Tourism Review Steering Committee 1997).

Divers and snorkellers can cause physical damage to corals, which may alter the structure of a coral community over the long term (Hawkins & Roberts 1992; Rouphael & Inglis 1995). Reef sites that are used heavily by divers have significantly more damaged coral colonies, loose fragments of live coral, fragments of coral reattached to the substratum and partially dead and abraded corals, than reefs with low diver activity (Hawkins & Roberts 1993). Damage to coral by SCUBA divers and snorkellers has also been reported in the Cairns-Port Douglas and Whitsunday regions of the GBR (Tourism Review Steering Committee 1997). Combined effects of vessel, mooring, anchor and diver damage have the potential to alter the coral structure and affect the aggregation of fishes at FSAS frequented by tourists.

2.3 Impacts of Research

Scientific research activities in the GBRMP are subject to permission by GBRMPA. Many research activities on the reef are extractive and may have an impact on fish spawning aggregations, depending on the timing and location of the research activity. Extractive and non-extractive research during and around fish spawning seasons may cause similar impacts on FSAS, and the fishes when they aggregate to spawn at these sites, as do fishing and tourism, but generally may not be as dramatic. However, if a study involves targeting spawning aggregations of fish, the reproductive capacity of the targeted fish would be reduced. Similarly, if a FSAS is used for non-extractive research purposes, such as transect surveys during a spawning event, the spawning success of aggregating species may be reduced. The presence of individual research divers at FSAS has been reported to disrupt the spawning behaviour of several fish species, including *Acanthurus spp*. (Randall 1961a, b), red hind *Ephinephelus guttatus* (Shapiro et al. 1993), common coral trout (Samoilys, M. 1999, pers. comm.), blue-spot trout (Carlos & Samoilys 1993) and various parrotfish (Randall & Randall 1963). Aggregating fish that are courting or are about to spawn commonly seek shelter if they are approached or disturbed by a diver. Additionally, the colour patterns exhibited by courting males of blue-spot trout (Carlos & Samoilys 1993) and *Acanthurus spp*. (Randall 1961, b) have been observed to change back to normal (non-reproductive colour) when disturbed by a diver.

3. MANAGING THE IMPACTS ON FISH SPAWNING AGGREGATIONS

3.1 What is Currently Being Done Outside Australia?

The detrimental effects of fishing on spawning aggregations of fishes are recognised globally. Recently, management strategies have been implemented in Belize, the Caribbean, Indonesia, Mexico, Micronesia, Palau and the United States of America, in an effort to protect existing populations of aggregating fishes from further overfishing.

Over a seven-day period in 1999 local fishing on grouper spawning aggregations in Pohnpei, Micronesia, removed about 30% of the aggregation. Subsequently, regulations were introduced to expand the Kehpara Marine Sanctuary to include all grouper spawning aggregations, to ban fishing and sales of grouper during March and April, and to enhance monitoring and enforcement at the Sanctuary (Rhodes 2000).

In the Komodo Islands it has been found that spawning aggregations of groupers occur from September to February over the new moon phase, and many other reef fishes use the same FSAS at other lunar phases. These FSAS have been heavily fished, and recently a zoning system similar to the GBRMP zoning to protect these sites as a source of recruits for surrounding fishing grounds has been introduced (Pet & Squire 2000; Squire, L. 2000, pers. comm.).

Seasonal area closures to protect fish spawning aggregations have been in place in the Caribbean since 1990. Currently, local governments of Puerto Rico and the US Virgin Islands, and the US Federal Government jointly manage four red hind protection sites, one mutton snapper protection site and one no-take marine conservation zone for the protection of corals and a spawning aggregation of red hind. These management arrangements were made using limited, but the best available, data at the time. Following establishment of the reserve, the average total length of red hind and mutton snapper in the Hind Bank Marine Protected Area is increasing (Garcia Moliner 2000).

The Belize Government established a marine reserve in May 2000 at a promontory on the Belize Barrier Reef to protect up to 21 species of fish that use the area for spawning (Heyman et al. 2000).

Off the coast of South Carolina, USA, studies of snowy grouper on rocky reef habitats on the continental slope (175–300 m) show evidence of overfishing. Because of the depth inhabited by these fish, size limits will be ineffective due to fish experiencing fatal anatomical trauma during retrieval. Marine reserves are being considered as the preferred approach to rebuilding the population (Wyanski et al. 2000).

The Nassau grouper is known to travel up to 110 km to a FSAS in the Bahamas (Bolden 2000) and is at risk of local extirpation and economic extinction. Recently, a number of closures for Nassau grouper have been introduced in the Bahamas and Caribbean (Sadovy & Eklund 1999; Carleton et al. 2000). The Nassau grouper and jewfish have now been protected in all waters of the USA and Bermuda. Once common commercial fishes, both species presently are on the US endangered species list (Sadovy & Eklund 1999). Total harvest bans have also been proposed for several other serranids that are believed to have been overfished in the USA, including the speckled hind *Epinephelus drummondhayi*, warsaw grouper *Epinephelus nigritus*, snowy grouper *Epinephelus niveatus*, misty grouper *Epinephelus mystacinus* and yellowedge grouper *Epinephelus flavolimbatus* (Sadovy 1990).

A common management strategy implemented in the USA has been to prohibit fishing at recognised FSAS throughout the fishes' spawning periods. The rationale for regulating FSAS rather than spawning seasons is that in some circumstances an area might be easily patrolled during the fishes' short spawning period each month. In addition, protection of an area does not put undue hardship on fishers who are harvesting from other areas and are not targeting spawning aggregations (Beets & Friedlander 1992). Spawning aggregations of red hind in Bermuda are protected from fishing activity throughout their spawning season. In 1990, fishing on spawning aggregations of Nassau grouper was prohibited in the Dominican Republic before a total prohibition on the taking of this species was introduced. In the Cayman Islands, aggregation fishing of Nassau grouper is restricted to local residents using hook and line only. At St. Thomas, U.S. Virgin Islands, fishing is prohibited over the three-month period identified as the red hind spawning season at a location in Federal waters south of the island. In addition, the immediate closure of either FSAS or seasons was recommended recently in order to protect populations of gag from fishing in the eastern Gulf of Mexico (Koenig et al. 1996).

Prohibition of fishing at specific locations can be effective if a species has only a few spawning sites in a region. However, this may be impractical where spawning aggregations are numerous and widespread. In such circumstances, seasonal closures are more appropriate. In Palau, for instance, the sale, purchase, or capture for commercial purposes of five species of grouper are illegal throughout the fishes' four-month spawning period (Johannes et al. 1994).

The single strategy of prohibiting fishing of spawning aggregations has been recognised as only a partial solution to the problem of overfishing (Sadovy 1990; Sadovy 1992; Beets & Friedlander 1992; Johannes et al. 1996). Sadovy (1990 & 1992) warns that protection of spawning aggregations without any other type of protective management, including gear restrictions, harvest limits and minimum size of capture at other times of the year, will not ensure sustainability of fish populations. One example which illustrates this point is the protection of a spawning aggregation of squaretail coral trout at Ngerumekaol, Palau. This FSAS has been protected from fishing for over 20 years, but despite such protection and site monitoring the population size is still very small, with dangerously low numbers of females. Overfishing of females inhabiting the shallow reef waters occurs during their non-reproductive periods, and the reproductive capacity of the population has diminished as a consequence (Johannes et al. 1994; Graham, T. 1998, pers. comm.).

At present, the only known management strategy that protects spawning aggregations from disturbance by tourism activities occurs in Palau. In 1995, the local government of Koror requested that dive operators comply with a voluntary four-month prohibition each year to access a FSAS at Ngerumekaol, an important spawning site for depleted populations of squaretail coral trout, flowery cod and camouflage rockcod *Epinephelus polyphekadion*. There was concern by the government that the 20-30 divers visiting this site each day could disturb or prevent spawning of the aggregating fishes. Generally, this voluntary prohibition works well and is accepted by the small number of dive operators working at the site (Graham, T. 1998, pers. comm.).

3.2 What is Currently Being Done or Proposed on the Great Barrier Reef?

3.2.1 Fishing

Currently, the GBRMPA zoning plans indirectly provide for protection of some FSAS from fishing, through the protective zoning of reefs throughout the GBRMP, although protection of FSAS was not part of the original intent of the zoning plans. In the near future, the GBRMP will be undergoing a rezoning as part of the GBRMPA Representative Areas Program; the locations of FSAS will be considered in the identification of areas in need of protection.

The GBRMPA and the Queensland Fisheries Service (QFS) are considering strategies that protect spawning aggregations of fishes from overexploitation on the GBR. The vulnerability of stocks of commercially important aggregating fish species throughout their spawning periods is understood.

In July 1999, the QFMA released a draft Management Plan for Queensland Tropical Coral Reef Fish Species (QFMA 1999). The draft plan included provisions for the protection of spawning aggregations by banning all reef fish fishing for nine-day periods in October and November in the northern regions of the GBR north of Cape Bowling Green, and November and December in the southern regions of the GBR south of Cape Bowling Green. The proposed nine-day closure to reef fish fishing in each month would commence four days before the new moon. Although the proposed ban is based on the spawning patterns of the common coral trout (which spawns on the new moon), it is anticipated that aggregations of other fishes will also benefit from the closures.

3.2.2 Tourism

The GBRMPA implemented an Interim Policy for Fish Spawning Aggregation Site and Tourism Activity Management Measures in December 1997 (GBRMPA 1997). The interim policy states that moorings are to be installed at least 100m away from a FSAS. Any public anchoring reserve identified within a plan of management should not contain any part of a fish spawning aggregation site. Where moorings occur in the vicinity of FSAS, permit holders should be encouraged to adopt an appropriate voluntary code of conduct for operations to minimise disturbance to the fish spawning aggregations.

The Cairns Area Plan of Management (GBRMPA 1999) recognises the importance of FSAS and the management of impacts. The plan states that FSAS are essential for the reproductive cycles of many reef fishes, that many species of coral reef fish aggregate to spawn at sites with specific attributes and that use may damage FSAS and disturb normal spawning behaviour. The Authority will continue to consider the location of known FSAS when locating moorings, pontoons and reef anchorages, and will continue to monitor and develop measures for FSAS protection in planning areas as part of Marine Park-wide strategies.

3.2.3 Research

Two forms of research are considered here: research that impacts FSAS and the aggregating fishes; and research necessary for specifically identifying and reducing the impacts on FSAS.

Currently, research permits granted by the GBRMPA are assessed on ethical grounds and appropriateness in a particular GBRMP zone or reef. The Fisheries Issues Group (FIG) provides comment and recommendations on these applications, and the impacts on FSAS and aggregating fishes are included.

Currently, information on the identification of FSAS, the characteristics of the sites and the fishes that aggregate on the GBR is being collated by the FIG, GBRMPA.

3.3 What Could be Done on the Great Barrier Reef?

A workshop was co-ordinated by the GBRMPA Effects of Fishing Program in 1998 to discuss options for management strategies, under the *Great Barrier Reef Marine Park Act 1975* and the *Queensland Fisheries Act 1994*, to protect fish spawning aggregations from fishing and tourism activities. Outcomes from the workshop have been included in this discussion.

3.3.1 Fishing

Seasonal fishing closures to protect spawning aggregations of blue-spot trout and maori wrasse were first recommended to GBRMPA for the Cairns and northern areas of the GBR in 1988 (Johannes & Squire 1988). Since then, several researchers and management agencies have discussed the importance of controlling or prohibiting fishing activity on spawning aggregations by seasonal or site closures during the spawning periods (e.g. Brown et al. 1994; QFMA 1996; Turnbull & Samoilys 1997).

Seasonal closures were considered by the GBRMPA workshop participants as the most appropriate way of ensuring aggregating fishes were protected from fishing during the main spawning season. It was considered that this would be best achieved through the Queensland fisheries management planning process. The proposed new-moon closures during the months October–December would be beneficial to other species besides common coral trout. However, there was concern that this period might not be long enough to allow many species, including common coral trout, to aggregate, spawn and disperse from their spawning aggregation sites. The period of increased activity when common coral trout move to and from spawning aggregation sites is when this species is most at risk from fishing activity (Fulton 1996). A longer period of closure, preferably over the entire three to four-month spawning period, was considered to be a more favourable option. A longer period to allow protection shortly prior to and shortly following the main aggregation periods would be appropriate to allow fish to reach and disperse effectively from aggregation sites (Sadovy, Y. 2000, pers. comm.). Such a closure would also provide protection for fishes that spawn at lunar periods other than around the new moon. However, a closure of several months is likely to have a significant economic impact on all fishing sectors, particularly the commercial and charter sectors. One solution to this may be the introduction of closed seasons in respect of commercially important or vulnerable species, as is done in Palau, USA, Bermuda, Cayman Islands and the Virgin Islands, allowing fishing to continue for other species. An alternative would be to increase the nine-day closures to at least 15 days to allow fishes such as common coral trout a greater window of opportunity to aggregate and spawn before and on the new moon.

The establishment of permanent reserves has been recommended as an appropriate long-term management strategy to protect fish spawning aggregations (Bell 1980; Johannes & Squire 1988; Sadovy & Figuerola 1992; Beets & Friedlander 1992; Sadovy 1990; Sadovy 1992). Marine reserves protect community structure, population age structure and genetic diversity of aggregating fishes (Sadovy & Figuerola 1992). Site-specific spawning closures to exclude fishers from known FSAS were considered by the GBRMPA workshop participants as an excellent strategy, but it was thought that such closures would be ineffective in practice. There was consensus that small site closures on the GBR would be extremely difficult to enforce without some form of satellite tracking device on all fishing vessels, and/or a labour intensive enforcement program. Until such satellite tracking technology is available for reef-line fishing vessels, small spatial closures are likely to be ineffective. Further, the size and shape of site closures would have to account for annual variations in the location of spawning sites. Closures may also displace fishing effort to adjacent reefs. The designation of site closures could highlight the location of spawning aggregation sites and increase the risk of targeted poaching. These issues highlight the urgent need for a vessel monitoring system (VMS) to be introduced into the Queensland reef-line fishery.

Area/seasonal spawning closures would involve the temporary closure of specific reefs during the main part of the spawning season, e.g. September to December for common coral trout. While this strategy would reduce the economic impact on the fishing industry, fishing effort throughout this time is likely to be displaced. Additionally, without VMS, enforcing closures for short periods would be difficult.

Although protection of common coral trout was considered to be important, it was suggested by workshop participants that other species are more vulnerable to fishing pressure because of their low natural abundance, reproductive biology, or particular spawning site requirements, and so limited take of other vulnerable fish species has been suggested. At the GBRMPA workshop maori wrasse, blue-spot trout, barramundi cod, flowery cod, camouflage cod and red-throat emperor were considered to be the most important species requiring additional protection from fishing. Information suggests that high-value commercial species such as maori wrasse have very specific spawning site locations and utilise fewer spawning aggregation sites than common coral trout. Consequently, their populations would be affected to a greater degree if fishers targeted their FSAS. Considering the iconic value of species such as maori wrasse, such species should be afforded protection with a no-take policy. Catch limits of one fish per boat for maori wrasse and barramundi cod as proposed by the QFS would, if policed, prevent these fish being taken in large numbers from FSAS. However, if these species are to be protected, a more enforceable approach to their conservation would be to prohibit the take.

Some of the GBRMPA workshop participants suggested that fishing gear restrictions, such as a maximum breaking strain on fishing lines, would prevent the capture of large spawning individuals. This measure is recognised as difficult to enforce.

There was consensus at the GBRMPA workshop that more information was required on what characterises a FSAS for a particular species and whether such sites were used by one or more species. Information is required on the spatial and temporal use of sites by both fishery targeted and non-targeted species.

The current level of concern, both overseas and within Australia, that many reef fishes are vulnerable to spawning-site overfishing, emphasises the need for a responsible and precautionary management approach. The long-term cost to all stakeholders is clear if fish stocks are overfished because of targeted fishing of spawning aggregations. There was consensus at the GBRMPA workshop that reef closures, combined with seasonal closures and limited or no-take of certain species, are the most favourable protective options and these should be pursued.

3.3.2 Tourism

The GBRMPA Interim Policy for Fish Spawning Aggregation Site and Tourism Activity Management Measures (GBRMPA 1997) forms the basis for a long-term strategy to ensure tourism activity in the GBRMP has minimal impact on spawning fishes. The interim policy highlights the need for a reef-wide protection policy and the need for more information on the location of FSAS and the timing of the spawning seasons for reef fishes throughout the GBRMP. A new reef-wide policy needs to be developed to minimise or negate impacts by tourism, fishing and research activities on fish spawning aggregations. The policy should include provisions that all site planning or assessment for structures in the GBRMP should be assessed for potential impacts on fish spawning aggregations, with all new structures to be installed at a specified minimum distance from a primary FSAS. This distance should take into consideration that FSAS may vary in size from year to year.

Rouphael & Inglis (1995) suggested that the impacts attributed to divers can be minimised by managing diver behaviour and by managing impacts through dive site selection. GBRMPA planning and management should utilise FSAS information as it becomes available, and ensure that no site planning or assessment for structures (e.g. pontoons, moorings and anchorage areas or reserves) is conducted in the GBRMP without an assessment by persons trained in FSAS identification. GBRMPA and Marine Parks site assessment officers need to be trained in identifying FSAS before conducting site assessments.

Fish feeding can attract groups of predatory fishes and cause fishes to adopt a new feeding behaviour different from their normal behaviour. These changes can affect the formation of spawning aggregations. There are two options to reduce this impact: prohibit fish feeding throughout the GBRMP, or prohibit fish feeding in Marine National Park B (green) zones. Prohibiting fish feeding in the GBRMP is feasible if fish feeding is deemed an inappropriate activity in the World Heritage Area. Prohibiting fish feeding in green zones will ensure the high protection status of green zones is maintained, allowing relatively undisturbed normal spawning behaviour of reef fishes, while permitting fish feeding to continue on reefs with less protection. Both options would discourage unnaturally high numbers of predatory fishes from frequenting these areas and improve conditions for smaller fishes to form spawning aggregations at these sites. Given that fishing is allowed in zones of less protection status than green zones, the latter option is the preferred one.

3.3.3 Research

The GBRMPA Environmental Research Ethics Advisory Committee (EREAC) was established by GBRMPA to consider ethical issues associated with research proposed in the GBRMP. To control the amount and type of research that may impact on FSAS and the aggregating fishes, the GBRMPA EREAC needs to understand the ethical implications of allowing research on FSAS and the aggregating fishes, and recommend changes to research design to reduce these impacts. The impact of research needs to be considered in the context of how it will affect the World Heritage and nature conservation values of the GBRMP. If there is a viable alternative to the location, species and number of specimens to be taken, this should be explored. Research permit applications are also referred to the FIG for comment. The FIG, in its role of co-ordinating the Authority's response to fisheries issues affecting the GBRMP, assesses these permit applications for potential impact on FSAS and the fishes when they aggregate to spawn at these sites. The FIG should make recommendations to the delegate on whether or not a permit should be granted, and/or changes to research methodology to prevent impacts on FSAS and the fishes when they aggregate to spawn at these sites.

With respect to research that is necessary to assist in identifying and reducing the impacts on FSAS, Johannes et al. (2000) suggested that it is not possible to protect every FSAS, but it is possible to protect the important ones. The characteristics of primary FSAS for commercially exploited fish species on the GBR should be identified. Identifying important spawning aggregation sites should be a routine part of habitat surveys made in connection with the siting of marine protected areas. The impact of fishing on hermaphroditic species such as *Plectropomus spp*. is not understood and, as Sadovy (1996) discussed, will be difficult to assess until we understand the factors that induce sexual changeover.

To develop the best possible management strategies to protect spawning aggregations of fishes on the GBR, information required on fish spawning aggregations includes:

- information on the geomorphology, topography and hydrodynamic features that are characteristic of known FSAS on the GBR (determination of such features could provide important clues in identifying other FSAS);
- information on the locations and timing of FSAS on the GBR. (Most studies on spawning aggregations have been undertaken in spring and summer. It is possible that many fishes spawn at other times of the year);
- historical data on fish stocks, fish sizes, the numbers of fish that aggregate at FSAS and occurrence of spawning aggregations to assess whether fish stocks and the occurrence of spawning aggregations have changed over time;
- information on the spawning behaviour and activity of fishes at known FSAS; and
- information on the impacts of reef use, particularly fishing and tourism activities, including fish feeding, on FSAS.

CONCLUSIONS

Fishing, tourism and, to a lesser extent, research on FSAS are likely to have negative impacts on fish stocks on the GBR because of the relatively short widow of opportunity for spawning and the strong preference for specific spawning locations by tropical coral reef fishes. The importance of FSAS to the ecological sustainability of fish species that aggregate to spawn on the GBR is beginning to be understood. It is timely and of the utmost importance that management strategies to reduce anthropogenic impacts on spawning aggregations are implemented to ensure protection of FSAS and the fishes when they aggregate to spawn at these sites on the GBR. Immediate management initiatives are necessary to mitigate the occurrence of fishers targeting fish spawning aggregations on the GBR, tourism activities occurring on FSAS, and research activities unnecessarily disturbing the spawning behaviour of reef fishes. Of particular concern is the increasing evidence that spawning aggregations of reef fish can be, and are being, impacted by heavy fishing. On the GBR, the effects of intense fishing of FSAS, in both the short and long term, are unknown, but may seriously compromise the reproductive success of targeted species and the ecological sustainability of the Queensland reef fish fishery. This highlights the need for focussed research and management of FSAS in the GBR.

GBRMPA policy should be developed to ensure protection of FSAS and aggregating fishes in the GBRMP. The policy should ensure GBRMPA pursues and advocates fisheries management mechanisms, including spatial and temporal closures to fishing, that ensure protection of all FSAS and the fishes when they aggregate to spawn at these sites in the GBRMP. The temporal closures proposed by the QFS for the tropical coral reef fish fishery are an important step towards protecting fish while spawning. However, this management measure will not ensure adequate protection of many target species because of timing variations among fish species and the relatively short proposed closure periods. It is recommended that a combination of total protection of some FSAS in the GBRMP and temporal protection of FSAS through seasonal closures would be appropriate. The closures would protect not only aggregating fishes but also the physical habitat and juvenile nursery areas. Spatial protection of FSAS needs to be considered in the GBRMP re-zoning exercise, under the Representative Areas Program. Any spatial or temporal closures must be demonstrably enforceable. Small site closures would be extremely difficult to enforce and unrealistic, considering the potential numbers of FSAS on the GBR, although vessel monitoring systems on fishing vessels would assist enforcement.

The proposed closures to reef fish fishing on the GBR during three nine-day periods during the months October-December may provide some protection to fishes that aggregate to spawn during this time. For this particular management strategy to be effective for species such as coral trout, the closure period should start well before the new moon and finish one or two days after, to protect these fish while moving to a FSAS and during spawning. These closures should be long enough to allow species such as coral trout to aggregate, spawn and disperse from a FSAS, and may be more effective if extended to two weeks before the new moon and a few days after. However, it is recommended that the most effective seasonal fishing closure to protect aggregating fishes would extend over the peak spawning months. An annual temporal spawning closure, to protect all reef fish species, should extend over three months, from October to December. This will protect targeted species such as common coral trout and other species that aggregate to spawn during this time. However, it is recognised that this strategy will have significant impacts on the fishing industry and market supply. There is a trade-off between a long-term ecologically sustainable fishery and short-term economic gain. An alternative to this would be to introduce closures for particular species. However, this may not reduce the disturbance of spawning fish if the protected species is caught and returned to the water. This strategy also has inherent enforcement difficulties. Temporal closures

under the *Great Barrier Reef Marine Park Act 1975* could be implemented if the Queensland fisheries management planning process for coral reef fishes is delayed or management proposals are not adequate.

High-value or potentially threatened species such as maori wrasse, barramundi cod, Queensland grouper and potato cod should be afforded protection by prohibiting the take. For species such as maori wrasse, additional management other than FSAS protection is likely to be essential for their conservation. Other cod species such as flowery cod and camouflage cod should be afforded protection by means of size limits and reduced bag limits.

The GBRMPA Policy should ensure tourism impacts on FSAS are minimised. The assessment of proposed placement of moorings, pontoons and anchoring sites should have regard to FSAS and be positioned at least 200 metres away from a primary FSAS. A prohibition on fish feeding in 'green' zones is recommended to prevent unnaturally high numbers of predatory fishes from frequenting tourist areas in highly protected reefs.

With respect to knowledge gaps, more information is required on locations and timing of FSAS for both fishery-targeted and non-targeted species and what characterises a FSAS for a particular species. Historical and baseline data on fish stocks, fish sizes, the numbers of fish that aggregate at FSAS and occurrence of spawning aggregations need to be obtained and the impacts of fishing and tourism activities need to be assessed. The GBRMPA should utilise this information when recommending fisheries management strategies and when undertaking site planning and assessments for structures in the GBRMP. Also, this information should be used in considering research permit applications and, where necessary, ensure changes are made to research design to reduce the impact on fish spawning aggregations.

REFERENCES

Aiello, R. 1996, Successes and failures of global reef management, Reef Tourism 2005, Cairns, 167 pp.

Aguilar-Perera, A. 1994, 'Preliminary observations of the spawning aggregation of Nassau grouper, *Epinephelus striatus*, at Mahahual, Quintana Roo, Mexico', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 43: 112–122.

Aguilar-Perera, A. & Aguilar-Davila, W. 1996, 'A spawning aggregation of Nassau grouper *Epinephelus striatus* (Pisces; Serranidae) in the Mexican Caribbean', *Environmental Biology of Fishes,* 45(4): 351–361.

Appeldoorn, R.S., Hensley, D.A., Shapiro, D.Y., Kioroglou, S. & Sanderson, B.G. 1994, 'Egg dispersal in a Caribbean coral reef fish, *Thalassoma bifasciatum*. II. Dispersal off the reef platform', *Bulletin of Marine Science*, 54(1): 271–280.

Bannerot, S,. Fox, W.W. & Powers, J.E. 1987, 'Reproductive strategies and the management of snappers and groupers in the Gulf of Mexico and the Caribbean', pp. 561–603 in *Tropical Snappers and Groupers*. *Biology and Fisheries Management*, eds J.J. Polovina & S. Ralston, Westview Press, Boulder, Colorado, USA.

Beets, J. & Friedlander, A. 1992, 'Stock analysis and management strategies for red hind, *Epinephelus guttatus*, in the U.S. Virgin Islands', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 42: 66–79.

Berkeley, S.A. 2000, 'Age-related temporal patterns in spawning: a reproductive bet hedging strategy?' *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Bell, J.D. 1980, Coral trout populations assessment in habitats in fished and unfished areas, 1979–80 Augmentative grant report to the Great Barrier Reef Marine Park Authority.

Bell, L.J. & Colin, P.L. 1986, 'Mass spawning of *Caesio teres* (Pisces: Caesionidae) at Enewetak Atoll, Marshall Islands', *Environmental Biology of Fishes,* 15: 69–74.

Bohnsack, J.A. 1989, 'The impact of overfishing on tropical fisheries', in *Proceedings of the Conference on Fisheries in Crisis,* September 1987, St Thomas.

Bolden, S.K. 2000, 'Long-distance movement of a Nassau Grouper (*Epinephelus striatus*) to a spawning aggregation in the central Bahamas', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Brown, I.W., Doherty, P.J., Ferreira, B., Keenan, K.C., McPherson, G., Russ, G., Samoilys, M. & Sumpton, W. 1994, Growth, reproduction and recruitment of Great Barrier Reef food fish stocks, Queensland Department of Primary Industries, Southern Fisheries Centre, FRDC Project 90/18.

Carlos, G.S. & Samoilys, M.A. 1993, An investigation of the occurrence of spawning aggregations of blue-spot coral trout (*Plectropomus laevis*) on the northern Great Barrier Reef, Report for Northern Fisheries Centre, Queensland Department of Primary Industries.

Carleton, R.G., McCormick Ray, M.G. Layman, C.A. & Silliman, B.R. 2000, 'Nassau grouper breeding aggregation at High Cay, Andros, Bahamas: implications for conservation', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Carter, J., Marrow, G.J. & Pryor, V. 1994, 'Aspects of the ecology and reproduction of Nassau grouper, *Epinephelus striatus*, off the coast of Belize', *Proceedings of the Gulf and Caribbean Institute*, 43: 65–111.

Carter, J., & Perrine, D. 1994, 'A spawning aggregation of dog snapper, *Lutjanus jocu* (Pisces: Lutjanidae) in Belize, Central America', *Bulletin of Marine Science,* 55(1): 228–34.

Chapman, R.W., Zatcoff, M., Sedberry, G.R. & Duane, S. 2000, 'Genetic variation in aggregating and non-aggregating groupers, Evidence of sex-ratio effects?' *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Choat, J.H. & Randall, J.E. 1986, 'A review of the parrotfishes (Family Scaridae) of the Great Barrier Reef of Australia with description of a new species', *Records of the Australian Museum,* 38: 175–228.

Coleman, F.C., Koenig, C.C. & Collins, L.A. 1996, 'Reproductive styles of shallow-water groupers (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fishing spawning aggregations', *Environmental Biology of Fishes,* 47: 129–141.

Colin, P.L. 1992, 'Reproduction of the Nassau grouper, *Epinephelus striatus* (Pisces: Serranidae) and its relationship to environmental conditions', *Environmental Biology of Fishes,* 4: 357–377.

Colin, P.L. & Bell, L.J. 1991, 'Aspects of the spawning of labrid and scarid fishes (Pisces: Labroidei) at Enewetak Atoll, Marshall Islands with notes on other families', *Environmental Biology of Fishes,* 31: 229–260.

Colin, P.L. & Clavijo, I.E. 1988, 'Spawning activity of fishes producing pelagic eggs on a shelf edge coral reef', *Bulletin of Marine Science,* 43: 249–279.

Davies, C.R. 2000, *Inter-reef Movement of the Common Coral Trout, Plectropomus leopardus*, Research Publication No. 61, Great Barrier Reef Marine Park Authority, Townsville.

Davis, T.L.O. & West, G.J. 1993, ‘Maturation, seasonality, fecundity, and spawning frequency in *Lutjanus vittus* (Quoy and Gaimard) from the North West Shelf of Australia’, *Fisheries Bulletin,* 91: 224–236.

Doherty, P, Fowler, A.J., Samoilys, M.A. & Harris, D.A. 1994, ‘Monitoring the replenishment of coral trout (Pisces: Serranidae) populations’, *Bulletin of Marine Science,* 54(1): 343–355.

Domeier, M.L. 2000, ‘Documentation of a recruitment pathway originating at a mutton snapper spawning aggregation’, *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Domeier, M.L. & Colin, P.L. 1997, ‘Tropical reef fish spawning aggregations: defined and reviewed’, *Bulletin of Marine Science,* 60(3): 698–726.

Ebisawa, A. 1990, ‘Reproductive biology of *Lethrinus nebulosus* (Pisces: Lethrinidae) around the Okinawa waters’, *Nippon Suisan Gakkai,* 56: 1941–1954.

Eklund, A.M., Douglas, E.H., Coleman, F.C. & Koenig, C.C. 2000, ‘Grouper aggregations in southern Florida, USA: the problems and successes of collecting data on small aggregations’, *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14-20, 2000.*

Ferreira, B.P. 1993, ‘Reproduction of the inshore coral trout *Plectropomus maculatus* (Perciformes: Serranidae) from the Central Great Barrier Reef, Australia’, *Journal of Fish Biology,* 42: 831–844.

Fine, J.C. 1992, ‘Greedy for groupers’, *Wildlife Conservation,* 95(6): 68–71.

Fulton, E.A.S. 1996, An investigation of the determinants of the commercial catch rate of *Plectropomus leopardus* (Serranidae), with regard to the targeting of spawning aggregations, using computer simulation, James Cook University, Australia.

GBRMPA 1999, *Cairns Area Plan of Management*, Great Barrier Reef Marine Park Authority, Townsville, Australia.

GBRMPA 1997, Interim policy for fish spawning aggregation site and tourism activity management measures, Great Barrier Reef Marine Park Authority, Australia.

Garcia Moliner, G. 2000, ‘Seasonal area closures for groupers and snappers in the U.S. Caribbean’, *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Gilmore, R.G. & Jones, R.S. 1992 ‘Color variation and associated behavior in the epinepheline groupers, *Mycteroperca microlepis* (Goode and Bean) and *M. phenax* Jordan and Swain’, *Bulletin of Marine Science,* 51(1): 83–103.

Gladstone, W. 1996, Unique annual aggregation of longnose parrotfish (*Hipposcarus harid*) at Farasan Island (Saudi Arabia, Red Sea), *Copeia,* 2: 483–5.

Goeden, G.B. 1977, 'The life and loves of the coral trout', *Australian Fisheries,* 36(8): 16–8.

Goeden, G.B. 1978, 'A monograph of coral trout', *Queensland Fisheries Research Bulletin,* 1: 1–42.

Grimes, C.B. 1987, 'Reproductive biology of the Lutjanidae', pp. 239–294 in *Tropical Snappers and Groupers. Biology and Fisheries Management*, eds J.J. Polovina & S Ralston, Westview Press, Colorado, USA.

Hasse, J.J., Madraisau, B.B. & McVey, J.P. 1977, 'Some aspects of the life history *of Siganus canaliculatus* (Park) (Pisces: Siganidae) in Palau', *Micronesica,* 13: 297–312.

Hawkins, J.P. & Roberts, C.M. 1992, 'Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs', *Biological Conservation,* 62: 171–178;.

Hawkins, J.P. & Roberts, C.M. 1993, 'Effects of recreational SCUBA diving on fore-reef slopes communities of coral reefs', *Journal of Applied Ecology,* 30: 25–30.

Helfrich, P. & Allen, P.M. 1975, 'Observations on the spawning of mullet, *Crenimugil crenilabis* (Forskal), at Enewetak, Marshall Islands', *Micronesica,* 11: 219–225.

Hensley, D.A., Appeldoorn, R.S., Shapiro, D.Y., Ray, M. & Turingan, R.G. 1994, 'Egg dispersal in a Caribbean coral reef fish, *Thalassoma bifasciatum*. I. Dispersal over the reef platform', *Bulletin of Marine Science*, 54(1): 256–270.

Heyman, W.D., Graham, R.T. & Kjerfve, B. 2000, 'Get to the point: conservation of reef promontories and associated spawning aggregations based on a test of the "offshore transport hypothesis", *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Huntsman, G.R. & Schaaf, W.E. 1994, 'Simulation of the impact of fishing on reproduction of a protogynous grouper, the graysby', *North American Journal of Fisheries Management,* 14: 41–52.

Johannes, R.E. 1980, 'Using knowledge of the reproductive behaviour of reef and lagoon fishes to improve fishing yields', in *Fish Behaviour and its Use in the Capture and Culture of Fishes, ICLARM Conference Proceedings, 5th edition, Manila*, eds J.E. Bardach, J.J. Magnuson & R.C. May.

Johannes, R.E., Squire, L., Graham, T., Sadovy, Y. & Renguul, H. 1999, 'Spawning aggregations of groupers (Serranidae) in Palau', *Marine Conservation Research Series,* 1.

Johannes, R.E. 1981, *Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia*, Berkeley: University of California Press.

Johannes, R.E. & Squire, L. 1988, Spawning aggregations of coral trout and maori wrasse on the Great Barrier Reef Marine Park, Unpublished report, CSIRO Hobart, QDPI Cairns*,* 13 p.

Johannes, R.E. 1978, 'Reproductive strategies of coastal marine fishes in the tropics', *Environmental Biology of Fishes*, 3: 65–84.

Johannes, R.E., Squire, L.C. & Graham, T. 1994, Developing a protocol for monitoring spawning aggregations of Palauan serranids to facilitate the formulation and evaluation of strategies for their management, First progress report, August 1994, FFA Report #94/28, South Pacific Forum Fisheries Agency, Honiara.

Johannes, R.E., Squire, L.C., Graham, T., Renguul, H. & Bukurrou, A. 1996, Palau grouper spawning aggregation research project 1995 progress report, South Pacific Forum Fisheries Agency, Honiara.

Johannes, R., Squire, L., Graham, T. & Sadovy, Y. 2000, 'Monitoring and managing reef fish spawning aggregations', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Koenig, C.C., Coleman, F.C., Collins, L.A, Sadovy, Y. & Colin, P. 1996, 'Reproduction in gag, *Mycteroperca microlepis* (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fish spawning aggregations', pp. 307–323 in ICLARM Conference Proceedings; no. 48.

Mapstone, B.D., McKinlay, J.P. & Davies, C.R. 1996, A description of the commercial reef line fishery logbook data held by the Queensland Fisheries Management Authority, Report to the QFMA from the CRC Reef Research Centre and the Department of Tropical Environment Studies and Geography, James Cook University, Townsville, Australia.

McPherson, G.R. 1989, 'North-eastern Australian demersal fishery', pp. 335–340 in *Proceedings of a Workshop Australia-Mexico on Marine Sciences, Mexico.*

McPherson, G.R., Squire, L.C.& O'Brien, J. 1992, 'Reproduction of three dominant *Lutjanus* species of the Great Barrier Reef', *Asian Fisheries Science,* 5: 15–24.

Moyer, J.T. 1989, 'Reef channels as spawning sites for fishes on the Shiraho coral reef, Ishigaki Island, Japan', *Japanese Journal of Ichthyology,* 36(3): 371–375.

Myrberg, A.A., Montgomery, W.L. & Fishelson, L. 1988, 'The reproductive behaviour of *Acanthurus nigrofuscus* (Forskal) and other surgeonfishes (Fam. Acanthuridae) off Eilat, Israel (Gulf of Aqaba, Red Sea)', *Ethology,* 79: 31–61.

Olsen, D.A. & LaPlace, J.A. 1978, 'A study of a Virgin Islands grouper fishery based on a breeding aggregation', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 32: 130–144.

Pet, J. & Squire, L. 2000, 'Grouper spawning aggregations in Komodo National Park', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Queensland Fisheries Management Authority (QFMA) 1996, Queensland tropical coral reef fish species, Discussion paper 2, 68p.

Queensland Fisheries Management Authority (QFMA) 1999, Draft recommended management arrangements to form a fishery management plan for tropical coral reef fish in Queensland, 41p.

Randall, J.E. 1961, 'A contribution to the biology of the convict surgeonfish of the Hawaiian Islands, *Acanthurus triostegus sandvicensis*', *Pacific Science,* 15: 215–72.

Randall, J.E. 1961b, 'Observations on the spawning of surgeonfishes (Acanthuridae) in the Society Islands', *Copeia,* :237–8.

Randall, J.E. & Randall, H.A. 1963, 'The spawning and early development of the Atlantic parrotfish, *Sparisoma rubripinne*, with notes on other scarid and labrid families', *Zoologica,* 48: 49–60.

Rhodes, K. 2000, 'Spawning aggregations of *Epinephelus polyphekadion* in Pohnpei, Micronesia and their management', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14-20, 2000.*

Robertson, D.R. 1991, 'The role of adult biology in the timing of spawning of tropical reef fishes', pp. 356-386 in *The Ecology of Fishes on Coral Reefs,* ed. P.F. Sale, Academic Press Inc.

Robertson, D.R. 1983, 'On the spawning behaviour and spawning cycles of eight surgeonfishes (Acanthuridae) from the Indo-Pacific', *Environmental Biology of Fishes,* 9: 193–223.

Rouphael, T. & Inglis, G. 1995, *The Effects of Qualified Recreational SCUBA Divers on Coral Reefs*, CRC Reef Research Centre Technical Report No. 4, Townsville, 39p.

Sadovy, Y.J. 1992, 'The case of the disappearing grouper: *Epinephilus striatus,* the Nassau grouper, in the Caribbean and western Atlantic', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 45: 5-22.

Sadovy, Y.J. 1990, 'Grouper stocks of the western central Atlantic: the need for management and management needs', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 43: 43–64.

Sadovy, Y.J. 1996, Reproduction of reef fishery species, pp. 15–59 in *Reef Fisheries*, eds N.V.C. Polunin & C.M. Roberts, Chapman & Hall Fish and Fisheries Series 20, London.

Sadovy, Y.J. & Eklund, A. 1999, Synopsis of biological data on the Nassau grouper, *Epinephelus striatus* (Bloch, 1792), and the jewfish, *E. itajara* (Lichtenstein, 18220, U.S. Dep. Commer., NOAA tech. Rep. NMFS 146, and FAO Fisheries Synopsis 157, 65p.

Sadovy, Y.J. & Figuerola, M. 1992, 'The status of the red hind fishery in Puerto Rico and St. Thomas, as determined by yield-per-recruit analysis', *Proceedings of the Gulf and Caribbean Fisheries Institute,* 42: 23–38.

Sadovy, Y.J., Colin, P.L. & Domeier, M.L. 1994, 'Aggregation and spawning of the tiger grouper, *Mycteroperca tigris* (Pisces: Serranidae)', *Copeia,* 2: 511–516.

Sadovy, Y.J., Rosario, A. & Roman, A. 1994, 'Reproduction in an aggregating grouper, the red hind, *Epinephelus guttatus'*, *Environmental Biology of Fishes,* 41: 269–286.

Sadovy, Y.J. & Giacomello, E. 2000, 'The effects of fishing spawning aggregations', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Sadovy, Y.J., Kulbicki, M., Labrosse, P., Letourneur, Y., Lokani, P. & Donaldson, T. (In prep), The humphead wrasse (*Cheilinus undulatus*): synopsis on an endangered and poorly known species.

Sala, E., Aburto Oropeza, O., Paredes Rios, G. & Ballesteros, E. 2000, 'The long-time exploitation vs the little known: grouper spawning aggregations in Belize and the Gulf of California', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Samoilys, M.A. 1997, 'Periodicity of spawning aggregations of coral trout, *Plectropomus leopardus* (Pisces: Serranidae) on the northern Great Barrier Reef', *Marine Ecology Progress Series,* 160: 149–59.

Samoilys, M.A. & Squire, L.C. 1994, 'Preliminary observations on the spawning behaviour of coral trout, *Plectropomus leopardus* (Pisces: Serranidae), on the Great Barrier Reef', *Bulletin of Marine Science,* 54(1): 332–342.

Shapiro, D.Y., Sadovy, Y. & McGhee, M.A. 1993, 'Periodicity of sex change and reproduction in the red hind, *Epinephelus guttatus*, a protogynous grouper', *Bulletin of Marine Science,* 53(3): 1151–1162.

Shapiro, D.Y., Sadovy, Y. & McGhee, M.A. 1993, 'Size, composition, and spatial structure of the annual spawning aggregation of the red hind *Epinephelus guttatus* (Pisces: Serranidae)', *Copeia,* 2: 399–406.

Smith, C.L. 1972, 'A spawning aggregation of Nassau grouper, *Ephinephelus striatus', Transactions of the American Fisheries Society,* 101: 257–261.

Squire, L.S. & Samoilys,M.A. (Unpub.) Report on observations of fish spawning aggregations on the Great Barrier Reef.

Sweatman, H. 1996, *Impact of Tourist Pontoons on Fish Assemblages on the Great Barrier Reef*, Technical Report No. 5, CRC Reef Research Centre, Townsville.

Thresher, R.E. 1984, *Reproduction in Reef Fishes*, Neptune City, New Jersey*:* TFH Publications Inc., 399p.

Tourism Review Steering Committee 1997, Review of the Marine Tourism Industry of the Great Barrier Reef World Heritage Area, Parts 1 & 2, June 1997.

Turnbull, C.T. & Samoilys, M. 1997, Effectiveness of spawning closures in managing the line fishery on the Great Barrier Reef, Report to ReefMac of QFMA, 28p.

Wyanski, D.M., White, D.B. & Barans, C.A. 2000, 'Temporal trends in population age structure and aspects of the reproductive biology of snowy group, *Epinephelus niveatus*, off the Carolinas, U.S.A.', *80th Meeting of the American Society of Ichthyologists and Herpetologists Program Book and Abstracts, Mexico June 14–20, 2000.*

Young, P.C. & Martin, R.B. 1982, 'Evidence for protogynous hermaphroditism in some lethrinid fishes', *Journal of Fish Biology,* 21: 475–484.

Zeller, D.C. 1997, 'Spawning aggregations: patterns of movement of the coral trout *Plectropomus leopardus* (Serranidae) as determined by ultrasonic telemetry*', Marine Ecology Progress Series,* 162: 253–263.

APPENDIX 1. List of fish species inhabiting the Great Barrier Reef that are known to form spawning aggregations

SPECIES	COMMON NAME	LOC.	AUTHOR
ACANTHURIDAE	**SURGEONFISHES**		
Acanthurus lineatus	striped surgeonfish	OS	Johannes 1981; Robertson 1983
Acanthurus mata	elongated surgeonfish	OS	Johannes 1981;
		OS	Squire & Samoilys, unpub.
Acanthurus nigricauda	blackstreak surgeonfish	GBR/OS	Squire & Samoilys, unpub.
Acanthurus nigrofuscus	brown surgeonfish	GBR	Robertson 1983; Squire & Samoilys, unpub.
		OS	Robertson 1983; Myrberg et al. 1988;
		OS	Squire & Samoilys, unpub.
Acanthurus olivaceus	orangeband surgeonfish	GBR	Squire & Samoilys, unpub.
Acanthurus triostegus	convict surgeonfish	OS	Randall 1961a, b; Johannes 1981; Robertson 1983
Acanthurus xanthopterus	yellowfin surgeonfish	OS	Johannes 1981; Squire & Samoilys, unpub.
Ctenochaetus striatus	lined bristletooth	OS	Randall 1961b; Robertson 1983;
		OS	Squire & Samoilys, unpub.
Naso brevirostris	spotted unicornfish	OS	Johannes 1981; Squire & Samoilys, unpub.
Naso hexacanthus	sleek unicornfish	OS	Johannes 1981
Naso lituratus	orangespine unicornfish	GBR/OS	Squire & Samoilys, unpub.
Naso unicornis	bluespine unicornfish	OS	Johannes 1981; Squire & Samoilys, unpub.
Naso vlamingii	Vlaming's unicornfish	OS	Squire & Samoilys, unpub.
Paracanthurus hepatus	blue tang	GBR	Robertson 1983
		OS	Squire & Samoilys, unpub.
Zebrasoma scopas	brushtail tang	GBR	Squire & Samoilys, unpub.
		OS	Randall 1961; Squire & Samoilys, in prep 1998
Zebrasoma veliferum	sailfin tang	GBR/OS	Squire & Samoilys, unpub.
CAESIONIDAE	**FUSILIERS**		
Caesio teres	blue and gold fusilier	OS	Bell & Colin 1986
Pterocaesio digramma	two-stripe fusilier	GBR	Thresher 1984
CARANGIDAE	**TREVALLIES**		
Caranx ignobilis	giant trevally	OS	Johannes 1981
Caranx melampygus	bluefin trevally	OS	Johannes 1981
Elagatus bipinnulata	rainbow runner	OS	Johannes 1981
Gnathanodon speciosus	golden trevally	OS	Johannes 1981
Megalaspis cordyla	finny scad	OS	Squire & Samoilys, unpub.
Selar boops	oxeye scad	OS	Johannes 1981
CHAETODONTIDAE	**BUTTERFLYFISHES**		
Chaetodon auriga	threadfin butterflyfish	OS	Squire & Samoilys, unpub.
Chaetodon ephippium	saddled butterflyfish	OS	Squire & Samoilys, unpub.
Chaetodon kleinii	Klein's butterflyfish	GBR/OS	Squire & Samoilys, unpub.
Chaetodon lineolatus	lined butterflyfish	GBR/OS	Squire & Samoilys, unpub.
Chaetodon melannotus	black back butterflyfish	OS	Squire & Samoilys, unpub.
Chaetodon rafflesi	latticed butterflyfish	OS	Squire & Samoilys, unpub.
Chaetodon semeion	dotted butterflyfish	OS	Squire & Samoilys, unpub.
Chaetodon trifasciatus	chevroned butterflyfish	GBR	Squire & Samoilys, unpub.
Chaetodon unimaculatus	teardrop butterflyfish	GBR	Squire & Samoilys, unpub.
Chaetodon vagabundus	vagabond butterflyfish	GBR	Squire & Samoilys, unpub.
Heniochus chrysostomus	pennant bannerfish	OS	Squire & Samoilys, unpub.
Heniochus singularis	singular bannerfish	OS	Squire & Samoilys, unpub.
Heniochus varius	humphead bannerfish	GBR/OS	Squire & Samoilys, unpub.

Note: GBR=Great Barrier Reef; OS=Outside the Great Barrier Reef Marine Park.

Not all the species listed in this table have been observed spawning. This table has been compiled using references that include observations of or anecdotal evidence of fishes aggregating to spawn.

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SPECIES	COMMON NAME	LOC.	AUTHOR
CHANIDAE	**MILKFISHES**		
Chanos chanos	milkfish	OS	Johannes 1981
EPHIPPIDAE	**BATFISHES**		
Platax orbicularis	orbicular batfish	OS	Squire & Samoilys, unpub.
HAEMULIDAE	**SWEETLIPS**		
Diagramma pictum	painted sweetlip	GBR	Squire & Samoilys, unpub.
Plectorhinchus chaetodontoides	many-spotted sweetlip	GBR	Debelius 1993; Squire & Samoilys, unpub.
Plectorhinchus chrysotaenia	gold-striped sweetlip	OS	Squire & Samoilys, unpub.
Plectorhinchus flavomaculatus	netted sweetlip	GBR	Squire & Samoilys, unpub.
Plectorhinchus gibbosus	brown sweetlip	GBR	Squire & Samoilys, unpub.
Plectorhinchus lineatus	diagonal-banded sweetlip	GBR/OS	Squire & Samoilys, unpub.
LABRIDAE	**WRASSES**		
Bodianus loxozonus	blackfin hogfish	GBR	Squire & Samoilys, unpub.
Cheilinus chlorourus	floral maori wrasse	GBR/OS	Squire & Samoilys, unpub.
Cheilinus fasciatus	redbreasted maori wrasse	GBR	Squire & Samoilys, unpub.
Cheilinus trilobatus	tripletail maori wrasse	GBR	Squire & Samoilys, unpub.
Cheilinus undulatus	humphead maori wrasse	GBR	Johannes & Squire, 1988
		OS	Squire & Samoilys, unpub.
Choerodon anchorago	anchor tuskfish	OS	Johannes 1981
Cirrhilabrus punctatus	dotted wrasse	OS	Squire & Samoilys, unpub.
Coris aygula	clown coris	OS	Squire & Samoilys, unpub.
Epibulus insidiator	slingjaw wrasse	GBR/OS	Squire & Samoilys, unpub.
Halichoeres hortulanus	checkerboard wrasse	GBR/OS	Squire & Samoilys, unpub.
Halichoeres prosopeion	twotone wrasse	OS	Squire & Samoilys, unpub.
Hemigymnus melapterus	blackeye thicklip wrasse	GBR/OS	Squire & Samoilys, unpub.
Macropharyngodon ornatus	ornate wrasse	GBR	Squire & Samoilys, unpub.
Pseudocoris yamashiroi	redspot wrasse	OS	Colin & Bell 1991
Stethojulis interrupta	cutribbon wrasse		Squire & Samoilys, unpub.
Thalassoma amblycephalum	bluntheaded wrasse	OS	Colin & Bell 1991
Thalassoma hardwicke	sixbar wrasse	OS	Squire & Samoilys, unpub.
Thalassoma lunare	moon wrasse	OS	Squire & Samoilys, unpub.
Thalassoma lutescens	sunset wrasse	OS	Colin & Bell 1991
Thalassoma purpureum	surge wrasse	OS	Squire & Samoilys, unpub.
Thalassoma quinquevitattum	fivestripe wrasse	OS	Colin & Bell 1991; Squire & Samoilys, unpub.
LETHRINIDAE	**EMPERORS**		
Lethrinus atkinsoni	yellow-tailed emperor	GBR	Squire & Samoilys, unpub.
Lethrinus harak	thumbprint emperor	OS	Johannes 1981
Lethrinus lentjan	pink-eared emperor	OS	Johannes 1981
Lethrinus miniatus	red-throat emperor	OS	Johannes 1981
Lethrinus nebulosis	spangled emperor	OS	Ekinawa 1990
Monotaxis grandoculis	big-eye bream	OS	Johannes 1981
LUTJANIDAE	**SNAPPERS**		
Aprion virescens	green jobfish	OS	Johannes 1981
Lutjanus argentimaculatus	mangrove jack	OS	Johannes 1981
Lutjanus bohar	red snapper	OS	Johannes 1981; Squire & Samoilys, unpub.
Lutjanus carponotatus	spanish flag or stripey	GBR	Squire & Samoilys, unpub.
Lutjanus gibbus	paddletail	OS	Johannes 1981
Lutjanus kasmira	bluestripe seaperch	OS	Squire & Samoilys, unpub.
Lutjanus malabaricus	large-mouth nannygai	OS	Johannes 1981
Lutjanus sebae	red emperor	OS	Johannes 1981
Symphoricthys spilurus	sailfin snapper	OS	Johannes 1981
Symphorus nematophorus	chinamanfish	OS	Johannes 1981

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SPECIES	COMMON NAME	LOC.	AUTHOR
MONACANTHIDAE	**LEATHERJACKETS**		
Amanses scopas	brush-sided leatherjacket	GBR	Squire & Samoilys, unpub.
Oxymonacanthus longirostris	beaked leatherjacket	OS	Squire & Samoilys, unpub.
MUGILIDAE	**MULLETS**		
Crenimugil crenilabis	fringelip mullet	OS	Hellfrich & Allen 1975; Johannes et al. 1981
Ellochelon vaigiensis	diamond-scale mullet	OS	Johannes 1981
MULLIDAE	**GOATFISHES**		
Mulloidichthys vanicolensis	yellowfin goatfish	OS	Squire & Samoilys, unpub.
MURAENIDAE	**MORAY EELS**		
species names not given		OS	Debelius 1993
POMACENTRIDAE	**DAMSELFISHES**		
Chromis cinerascens	green chromis	GBR	Squire & Samoilys, unpub.
POMACANTHIDAE	**ANGELFISHES**		
Centropyge bicolor	bicolour angelfish	GBR	Squire & Samoilys, unpub.
Pygoplites diacanthus	regal angelfish	GBR/OS	Squire & Samoilys, unpub.
Pomacanthus imperator	emperor angelfish	OS	Squire & Samoilys, unpub.
Pomacanthus sexstriatus	six-banded angelfish	GBR/OS	Squire & Samoilys, unpub.
PRIACANTHIDAE	**BIGEYES**		
Priacanthus hamrur	crescent-tail bigeye	OS	Squire & Samoilys, unpub.
SCARIDAE	**PARROTFISHES**		
Bolbometopon muricatum	bumphead parrotfish	OS	Johannes 1981; Squire & Samoilys, unpub.
Cetoscarus bicolor	bicolor parrotfish	GBR/OS	Squire & Samoilys, unpub.
Chlorurus sordidus	bullethead parrotfish	GBR/OS	Squire & Samoilys, unpub.
Hipposcarus longiceps	Pacific longnose parrotfish	OS	Squire & Samoilys, unpub.
Scarus altipinnis	minifin parrotfish	GBR	Squire & Samoilys, unpub.
Chlorurus bleekeri	Bleeker's parrotfish	OS	Squire & Samoilys, unpub.
Scarus chameleon	chameleon parrotfish	OS	Squire & Samoilys, unpub.
Scarus dimidiatus	yellowbarred parrotfish	OS	Squire & Samoilys, unpub.
Scarus forsteni	whitespot parrotfish	GBR	Squire & Samoilys, unpub.
Scarus frenatus	bridled parrotfish	OS	Squire & Samoilys, unpub.
Scarus ghobban	bluebarred parrotfish	GBR/OS	Squire & Samoilys, unpub.
Scarus globiceps	globehead parrotfish	GBR	Squire & Samoilys, unpub.
Scarus microrhinos	steephead parrrotfish	GBR/OS	Squire & Samoilys, unpub.
Scarus niger	swarthy parrotfish	GBR/OS	Squire & Samoilys, unpub.
Scarus oviceps	egghead parrotfish	OS	Squire & Samoilys, unpub.
Scarus rubroviolaceus	ember parrotfish	GBR/OS	Squire & Samoilys, unpub.
Scarus schlegeli	Schlegel's parrotfish	OS	Squire & Samoilys, unpub.
SCOMBRIDAE	**MACKERELS / TUNAS**		
Acanthocybium solandri	wahoo	OS	Johannes 1981
Grammatorcynus bicarinatus	shark mackerel	OS	Johannes 1981
Scomberomorus commersoni	spanish mackerel	OS	Johannes 1981
SERRANIDAE	**ROCKCODS/GROUPER**		
Anyperodon leucogrammicus	white-lined rockcod	GBR/OS	Squire & Samoilys, unpub.
Epinephelus fasciatus	black-tipped rockcod	OS	Debelius 1993
Epinephelus fuscoguttatus	flowery cod	OS	Johannes 1981; Johannes et al. 1994
Epinephelus malabaricus	malabar grouper	OS	Squire & Samoilys, unpub.
Epinephelus merra	dwarf spotted rockcod	OS	Randall & Brock 1960; Johannes 1981
Epinephelus polyphekadion	camouflage rockcod	OS	Johannes et al. 1994
Gracila albomarginata	thinspine rock cod	OS	Squire & Samoilys, unpub.
Plectropomus areolatus	squaretail coral trout	OS	Johannes,1981; Johannes 1988; Johannes et al. 1994

continued over. . . .

SPECIES	COMMON NAME	LOC.	AUTHOR
Plectropomus laevis	blue-spot coral trout	GBR	Johannes & Squire 1988; Carlos & Samoilys 1993
Plectropomus leopardus	common coral trout	GBR	Goeden 1978; Brown et al. 1994; Samoilys & Squire 1994;
		GBR	Samoilys 1997; Zeller 1997; Squire & Samoilys, unpub.
		OS	Johannes 1981
Pseudanthias pleurotaenia	squarespot anthias	OS	Squire & Samoilys, unpub.
Pseudanthius tuka	purple anthias	OS	Squire & Samoilys, unpub.
SIGANIDAE	**RABBITFISHES**		
Siganus argenteus	forktail rabbitfish	OS	Johannes 1981; Squire & Samoilys, unpub.
Siganus canaliculatus	white-spotted rabbitfish	OS	Hasse et al. 1977; Johannes 1981
Siganus lineatus	goldlined rabbitfish	GBR	Squire & Samoilys, unpub.
		OS	Johannes 1981
Siganus punctatus	goldspotted rabbitfish	OS	Johannes 1981
Siganus spinus	spiny rabbitfish	OS	Johannes 1981
SPHYRAENIDAE	**BARRACUDAS**		
Sphyraena barracuda	great barracuda	OS	Johannes 1981
Sphyraena genie	chevron barracuda	OS	Johannes 1981

APPENDIX 2. Reported spawning aggregations of fish species that occur on the Great Barrier Reef

*Note: Seasons differ according to location in Southern or Northern Hemispheres.

Species	Location	Aggregation site	Month*	Lunar phase	Tide	Author
ACANTHURIDAE						
Acanthurus lineatus	Palau	outer reef edge	Feb-Apr	prior to full	ebb	Robertson 1983
	GBR	seaward edge of outer Escape Reef	Dec		ebb	Robertson 1983
	Palau	southern tip of Peleliu Is; outer reef flat or above edge of outer reef drop-off	Apr	new		Johannes 1981
Acanthurus mata	Palau	reef flat	May, other	new/full		Johannes 1981
Acanthurus nigrofuscus	Red Sea	around coral knoll on most seaward edge in front of reef with deep water	Jun-Sep	all (daily)		Myrberg et al. 1988
	Aldabra	channel that drains Aldabra Lagoon	Nov-Dec	before new/full	ebb	Robertson 1983
	GBR	outer edge of fringing reef	Feb-Apr		ebb	Robertson 1983
	Palau	outer reef edge	Jan-Apr	5-7 d before new/ full	ebb	Robertson 1983
Acanthurus triostegus	Palau		May-Aug, other	after new		Randall 1961a
	Hawaii		Dec-Jul	12-2 d before full		Randall 1961b
	Aldabra Atoll		Nov-Dec		ebb	Robertson 1983
Acanthurus xanthopterus	Palau		Jan-May	new and full		Johannes 1981
Ctenochaetus striatus	Red Sea	around coral knoll on most seaward edge in front of reef with deep water	Jun-Sep			Myrberg et al. 1988
	Aldabra Atoll	outer reef edge of channel that drains Aldabra Lagoon	Aug-Dec	4-7d before full/ new	ebb	Robertson 1983
	Palau	outer reef edge	Jan-Apr	4-7d before full/ new	ebb	Robertson 1983
	Society Is.	Ava Iti Pass: 50 ft deep passage with strong current set to open sea. reef edge 8–25 feet deep.	Feb	not after new/full		Randall 1961b
Naso unicornis	Palau	outer reef slope	all year?	new/full		Johannes, 1981
Paracanthurus hepatus	GBR	outer barrier reef on seaward side	Dec		ebb	Robertson 1983
Zebrasoma scopas	Society Is.	10–20 ft over coral heads at edge of lagoon next to barrier reef. Strong current to open sea	May	not after new/full		Randall 1961
CAESIONIDAE						
Caesio teres	Marshall Is.	reef emerging from deep water with strong currents inside channel, Enewetak Lagoon	Mar-Aug	full	ebb	Bell & Colin 1986
Pterocaesio diagramma	GBR	windward side of reef, 18 m deep	early summer		before full	Thresher 1984

continued over. . . .

Species	Location	Aggregation site	Month*	Lunar phase	Tide	Author
LABRIDAE						
Cheilinus undulatus	GBR	southern end of reefs making up the outer barrier reef, located along walls in 2–40 m depth.	Oct-Jan			Johannes & Squire 1988
Choerodon anchorago	Palau	outer edge of fringing reefs	Jan-Mar	new/full		Johannes 1981
Pseudocoris yamashiroi	Marshall Is.	clear water reef bisecting main ocean-lagoon passage, strong tidal currents	Mar-May	throughout	ebb	Colin & Bell 1991
Thalassoma amblycephalum	Marshall Is.	clear water reef bisecting main ocean-lagoon passage, strong tidal currents	Mar-May, Sep, Nov		full	Colin & Bell 1991
Thalassoma lutescens	Marshall Is.	clear water reef bisecting main ocean-lagoon passage, strong tidal currents	Mar-May, Oct, Nov	full	ebb	Colin & Bell 1991
Thalassoma quinquenitattum	Marshall Is.	clear water reef bisecting main ocean-lagoon passage, strong tidal currents	Mar-May, Jul	full		Colin & Bell 1991
LETHRINIDAE						
Lethrinus harak	Palau	outer lagoon of fringing reef	most or all months	new, first 5 days		Johannes 1981
Lethrinus lentjan	Palau			new-full		Johannes 1981
Lethrinus miniatus	Palau	along outer and inner edges of barrier reef	most months	new, first 5 days		Johannes 1981
Lethrinus nebulosis	Japan		Mar-Jun	throughout		Ekinawa 1990
Monotaxis grandoculis	Palau	bottom of reef slopes	most months	new, first 4 days		Johannes 1981
LUTJANIDAE						
Lutjanus argentimaculatus	Palau	deep water in lagoon or over outer reef slope	Oct-Dec	Full moon		Johannes 1981
Lutjanus gibbus	Palau	deep water close to outer reef edge	Apr-May;	Full moon all		Johannes 1981
Lutjanus bohar	Palau	outer reef slope	Apr-Jul, all	Full moon		Johannes 1981
Lutjanus vitta	NW Shelf, Aus.		Sep-Apr	after full/new	high/ ebb	Davis & West 1993
Symphoricthys spilurus	Palau	edge of reef drop-off, off eastern shore of Peleliu	Mar-Jul	new/full moon		Johannes 1981
Symphorus nematophorus	Palau	edge of reef drop-off, off eastern shore of Peleliu				Johannes 1981
MUGILIDAE						
Crenimugil crenilabis	Marshall Is.	Japtan Islet, Enewetak Lagoon in very clear water with sandy bottom	June	1st quarter		Helfrich & Allen 1975
SCARIDAE						
Scarus schlegeli	GBR					Choat & Randall 1986

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Species	Location	Aggregation site	Month*	Lunar phase	Tide	Author
SERRANIDAE						
Epinephelus fuscoguttatus	Palau		May, Jun	new-full		Johannes 1981
	Palau	outer edge of a seaward channel				Johannes et al. 1994
	Marshall Is.		Nov, Dec			Johannes 1981
Epinephelus merra	Palau			full moon		Johannes 1981
Epinephelus polyphekadion	Palau	outer edge of a channel				Johannes et al. 1994
Plectropomus areolatus	Solomon Is.	deep passages from Marovo Lagoon through barrier reef to open ocean	Mar-May	7-d before new		Johannes 1988
						Johannes 1994
	Palau		May-Jun	full-new		Johannes 1981
Plectropomus laevis	northern GBR	Outer edge of bommies / promontories on outer reef corners, strong currents	Sep-Jan			Johannes & Squire 1988
	northern GBR	edges and extremities on northern edges of Ribbon reefs	Nov-Dec			Carlos & Samoilys 1993
Plectropomus leopardus	southern GBR		Nov-Jan			Brown et al. 1994
	northern GBR	10 m wide channel which cut through main reef and opened into lagoon to north. Mod-strong current				Samoilys 1997
	northern GBR		Oct, Nov	full-new	ebb	Samoilys & Squire 1994
						Goeden 1978
	northern GBR		Nov-Dec			Johannes & Squire 1988
	Lizard Is, GBR	down-current position of local reef structures, med-strong currents running off/parallel reef edge.		new moon		Zeller 1997
SIGANIDAE						
Siganus argentus	Palau		Mar-May	new/full		Johannes 1981
Siganus canaliculatus	Caroline Is.	channels with access to open ocean	Mar-May	4-5 d after full		Hasse et al. 1977
	Palau	outer reef slope in the channel mouth in 70 ft deep water	Feb-Jun, other	3-5 d after new	low/ slack	Johannes, 1981
Siganus lineatus	Palau	outer edge of fringing and barrier reefs	Mar-Jun, other	1st quarter		Johannes 1981

Appendix 3. Additional references for further reading

Bardach, J.E. 1958, 'On the movements of certain Bermuda reef fishes', *Ecology,* 39: 139–146.

Blamey, R.K. & Hundloe, T.J. 1991, Characteristics of recreational boat fishing in the Great Barrier Reef region, Unpublished report to the Great Barrier Reef Marine Park Authority.

Bohnsack, J.A. (Plan Development team) 1990, 'The potential of marine fishery reserves for reef fish management in the US Southern Atlantic', NOAA technical Memorandum NMFS-SEFC-261, 1–40.

Colin, P.L. 1982, Aspects of the spawning of western Atlantic reef fishes, The biological bases for reef fishery management. Oct 7-Oct 10, 1980; St. Thomas, US Virgin Islands.

Colin, P.L. 1996, 'Longevity of some coral reef fish spawning aggregations', *Copeia,* 1: 189–192.

Colin, P.L. & Clavijo, I.E. 1978, 'Mass spawning by the spotted goatfish, *Pseudopeneus maculatus* (Bloch) (Pisces: Mullidae)', *Bulletin of Marine Science,* 28(4): 780–782.

Colin, P.L, Shapiro, D.Y. & Weiler, D. 1987, 'Aspects of the reproduction of two groupers, *Epinephelus guttatus* and *E. striatus* in the West Indies', *Bulletin of Marine Science,* 40: 220–230.

Ferreira, B.P. 1995, 'Reproduction of the common coral trout *Plectropomus leopardus* (Serranidae: Epinephelinae) from the Central and Northern Great Barrier Reef', *Bulletin of Marine Science,* 56(2): 653–669.

McPherson, G.R., Squire, L.C. & O'Brien, J. 1988, Demersal reef fish project 1984-85: Age and growth of four important reef fish species, Fisheries Research Branch Tech. Report No. FRB 88/6, Report to the GBRMPA / Queensland Department of Primary Industries, 38p.

Sadovy, Y. 1990, 'The status of the red hind fishery in Puerto Rico and St. Thomas as determined by yield-per-recruit analysis', *Proceedings of the Gulf and Caribbean Fisheries Institute*, 42: 23–38.

Shapiro, D.Y. 1979, 'Social behaviour, group structure, and the control of sex reversal in hermaphroditic fish', *Adv. Study Behav*., 10: 43–102.

Shapiro, D.Y., Garcia-Moliner, G. & Sadovy, Y. 1994, 'Social system of an inshore stock of the red hind grouper, *Epinephelus guttatus* (Pisces: Serranidae)', *Environmental Biology of Fishes*, 41: 415–422.

Shapiro, D.Y., Hensley, D.A. & Appeldoorn, R.S. 1988, 'Pelagic spawning and egg transport in coral reef fishes: a skeptical overview', *Environmental Biology of Fishes,* 22: 3–14.

Turnbull, C.T. 1996, Domestic reef fishing industry assessment, *QDPI Information Series QI96106,*14p.

Warner, R.R. 1995, 'Large mating aggregations and daily long-distance spawning migrations in the bluehead wrasse, *Thalassoma bifasciatum*', *Environmental Biology of Fishes,* 44: 337–345.