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Management Options for Fish Spawning Aggregations of Tropical Reef Fishes: A Perspective

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Cover photo: Live Reef Food Fish Trade fish holding pens in Kavieng, Papua New Guinea.

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TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

Spawning aggregations are ephemeral and highly vulnerable events in the reproductive life history of some of the most commercially important tropical reef fishes. Numbering in the hundreds or even thousands of individuals, reef fish spawning aggregations (FSA) form at highly specific times and places over brief periods where all or much of their annual reproductive activity takes place. During these brief and impressive displays, fishers also gather to take advantage of the highly predictable nature of the aggregations and the relative ease of capturing large numbers of fish. While fishers have carried out these practices for centuries, recent changes in fishing cultures, technologies and economies have engendered widespread overfishing tied to the loss of innumerable spawning aggregations and fish population declines worldwide (Table 1). Along with reports of rapid increases in FSA loss, is a unified concern that spawning aggregations require immediate and full protection. Thus, the design and implementation of effective, meaningful FSA conservation and management protocols is of paramount importance to local societies dependent upon reef fisheries resources, and to the world community charged with protecting global marine biodiversity (e.g. Johannes *et al*. 1999, Rhodes and Sadovy 2002).

While a myriad of management options for FSA exist, few have actually been applied, particularly in a manner that eliminates the potential for FSA loss or decline (Tables 2 and 3). These management options are generally the same as those utilized in other stages of a fish's adult life history, e.g. area and temporal restrictions, size limits, quotas, and so on. Of the few FSA that are actively managed, success in implementation and enforcement has varied due to the complex cultural and economic conditions characteristic of many tropical developing island nations, the extensive geographic distribution of FSA and an incomplete understanding of species' life history and spawning dynamics. Given the significant variations in implementation context, there is not likely to ever be a 'one size fits all' conservation strategy (Sadovy and Domeier 2005) that tropical marine resource managers can use to provide the necessary level of protection to FSA. Instead, effective management of coral reef FSA will require careful consideration of local circumstances and flexibility in implementation, and likely involve shared management responsibilities between communities, governments and non-government organizations (Munro 1996; Ruddle 1996).

Regardless of the management option(s) chosen, all generally require, at a minimum, information on species-specific seasonal reproductive activity, adequate monitoring and strong, incorruptible enforcement and prosecution. As is the case in Western settings, a political willingness to back management, that at first may be unpopular with the local electorate, is the first key to success (Hilborn 2002). Once that aspect is achieved, all other steps toward providing effective management become easier. Much of the biological information needed for adopting effective management policy can be gathered by trained local marine resource staff or non-governmental agencies.

The primary aims of this article are to: (i) provide a characterization of FSA, (ii) give an overview of the dominant threats to FSA, (iii) review potential options for FSA management and the underlying biological concerns and scientific backing for their use, (iv) present examples where tropical FSA management options have been adopted, and (v) evaluate the realistic potential of success or failure of these options for FSA conservation. We also discuss the necessity for integrating biological concerns within the political, cultural and socioeconomic frameworks within which FSA management actions will occur. Although the paper's analyses are applicable to a variety of locales globally, the case studies will focus on the western Pacific and Caribbean. The rationale for choosing these locales relates to the significant biodiversity contained within FSA in these areas (e.g. Domeier and Colin 1997; Heyman *et al*. 2005), the relative magnitude of pressures being exerted on those resources, the existence of promising implementation experiences with FSA management, and an immediate need and expressed desire by local governments and communities for improved FSA management.

Based on our review, we recognize that the most effective option to achieve adequate FSA protection is through the total elimination of fishing on reproductively active fishes; specifically FSA and the (reproductive) migratory pathways that individuals use to reach these sites. We make this argument in light of the overwhelming evidence that exists on failed management policy and implementation toward effective FSA protection, the difficulties associated with aligning political, cultural and economic circumstances for effective FSA management, and the innumerable cases of past FSA loss and population-level damage associated with most levels of FSA fishing worldwide (Table 1)—even with certain types of management in place (Tables 2 and 3). We are not aware of any recorded FSA that is fished and unmanaged, yet maintaining or increasing its abundance. Finally, we assert that full FSA protection should not be delayed in lieu of data demonstrating negative fishing effects, since *all known current accounts of FSA fishing appear to be unsustainable* (Johannes 1998).

INTRODUCTION

REEF FISH SPAWNING AGGREGATIONS

Reef fish spawning aggregations (FSAs) are groups of con-specific fish gathered specifically for reproductive purposes (Domeier and Colin 1997; Colin *et al*. 2003). Two types of FSA are recognized among reef fishes that aggregate to spawn—resident and transient (Domeier and Colin 1997). While both types of aggregations are temporally predictable, resident FSA occur frequently throughout the year—daily or monthly—with individuals traveling relatively short distances (meters to 100s of meters) to reach FSA sites. In contrast, transient FSA typically form only a few months of the year and during specific lunar phases, with some individuals reported to travel up to 250 km or more to a specific site for some species (Carter *et al*. 1994; Luckhurst 1998; Johannes *et al*. 1999; Bolden 2000).

For species forming transient FSA, aggregation formation is site-specific with individuals gathering over several days in each of a few to several consecutive months of the year. Spawning may occur on the last day(s) of the aggregation period over a few brief hours (e.g. Johannes 1978; Domeier and Colin 1997; Johannes *et al*. 1999; Rhodes and Sadovy 2002; Pet *et al*. 2005) or over most days of the aggregation period (e.g. Heyman *et al*. 2005), with the spawning frequency generally dependent on the species. In each case, at the conclusion of spawning, aggregations dissipate and re-form at the time of the subsequent aggregation period (i.e. same lunar cycle in a subsequent month or season), when the concentrated adult spawning population again becomes vulnerable to fishing.

Although resident spawners remain vulnerable to the same threats as transient spawners and many of the same management options apply, the focus of the remaining discussion and examples center on transient FSA that are typically—but not exclusively—the targets of commercial fishing. For the purpose of this review, any fishing resulting in the total or partial sale of the catch is regarded as commercial.

THE VULNERABILITY OF FSA AND BIOLOGICAL IMPACTS OF FISHING

The vulnerability of FSA to overfishing lies in the predictable manner in which they form and perhaps more importantly that they are "bottlenecks"[1] in the life history of the population (Sadovy and Vincent 2002). Generally, fishers become aware of FSA sites and times through direct observation or passing knowledge from previous generations of fishers (e.g. Johannes 1981). More recent interest in FSA fishing by foreign commercial enterprise has resulted in technologically advanced methods for FSA site identification that appears to have accelerated FSA overfishing (Johannes *et al*. 1999; Sadovy *et al*. 2003). Similarly, many local subsistence fishers have turned to commercial capture following changes to local economies and cultures, population increase and transmigration, among others (Ruddle 1993; Munro 1996). Regardless of how sites are located or by whom, FSA quickly become targets of fishing owing to the relatively high catch volume per unit of time invested and potential for fast income (Johannes and Squire 1988; Rhodes 1999). Whereas low levels of fishing characteristic of subsistence fishing may not result in overall FSA abundance declines over time, moderate-to-heavy levels of fishing typical of most commercial efforts cause rapid overfishing and FSA loss or decline within only a few years (Johannes *et al*. 1999; Rhodes 1999; Sadovy *et al*. 2003; but see Hamilton and Kama 2004) (Appendix I: Case Studies).

Although a few FSA have shown signs of recovery once fished out, many others have not, despite adoption of closures and other management measures (e.g. Paz and Grimshaw 2001; Claro and Lindeman, 2003; also see Luckhurst 1996). There is no evidence to suggest that FSA recovery is guaranteed, and the dynamics of how FSA form and persist at any particular site is yet unknown,

[1] Here, "bottleneck" refers to the concentration of all or much of the adult population in a confined period and space.

which, in turn, creates substantial problems toward instituting certain types of management (e.g. quotas, access permits). Nonetheless, the few FSA that have been shown to re-form from near extinction have required decades to do so (Colin *et al*. 2003; Burton *et al*. 2005; The Nature Conservancy Meso-American Reef Program, unpublished data).

Although there are many possible reasons for the rapid decline of populations once FSA become targeted for fishing, perhaps the most important is that fish are generally taken prior to egg release, depriving the population a chance to maximize reproductive output and replenish individuals lost through natural and fisheries-induced mortality[2]. This is a particularly important point, since spawning within FSA likely represents all of the annual reproductive output for the species and because the entire adult spawning population may occur at a single FSA site (Bohnsack 1989; Shapiro *et al*. 1993; Sadovy and Vincent 2002). Secondly, and perhaps equally important in explaining FSA loss, is the fact that many FSA-forming species have complex life histories that increase their vulnerability to extirpation (Bannerot *et al*. 1987; Huntsman and Schaaf 1994; Sadovy 1997; Armsworth 2001; Huntsman *et al*. 1999; Coleman *et al*. 2000). Some grouper (Serranidae), wrasse (Labridae) and parrotfish (Scaridae), for example, have sexual patterns that allow adult individuals to alter their sex as adults. Known as hermaphrodites, sex change in these species results in either males changing to females (protandry, or male first) or females to males (protogyny, or female first) (Shapiro 1987; Sadovy 1996). The direction of change is such that the terminal (final) stage individuals (e.g. males in protogynous species) are typically larger (and often more aggressive toward bait), since they continue to grow and age following the transition (Sadovy and Shapiro 1987). Since some fishing gears target larger individuals (size selection), overall catch may be primarily composed of upper size, single sex individuals, thereby impacting the FSA sex ratio at the time of spawning to reduce reproductive success and diminish egg output (Coleman *et al*. 1996; Koenig *et al*. 1996; Vincent and Sadovy 1998). Indeed, recent models have shown even low levels of selective fishing across all male size classes of protogynous species results in population crashes (Alonzo and Mangel 2003). Additionally, larger females produce far greater quantities of eggs and larvae with higher survivorship potential than smaller females, such that selective removal can significantly impact overall reproductive output and future population persistence (Sadovy 1996; Berkeley, *et al*., 2004; Bobko and Berkeley 2004). For some hermaphroditic species that form leks— spawning groups with a single, large male (e.g. humphead wrasse, Cheilinus undulatus) or female and several smaller members of the opposite sex— the loss of the largest individual stops reproduction altogether until sex change in another individual within the reproductive group can be completed. Thus, during the period of sex change, all potential for reproduction is lost.

For other FSA-forming species, sex-specific differences in feeding or arrival times to aggregations may influence catch composition to alter sex ratio prior to spawning. For example, for camouflage grouper (*Epinephelus polyphekadion*), males arrive at the sites up to one week prior to females and feed up to the day of spawning (Rhodes and Sadovy 2002; Rhodes and Tupper unpublished data). Fishing throughout the aggregation period would thereby affect males over a 14-day period in contrast to a 5-7 day fishing period for females (Johannes *et al*. 1999). In other species, such as the squaretail coralgrouper, *Plectropomus areolatus*, females migrate to spawning sites in large groups along specific migration routes where they may be targeted and disproportionately removed, thereby altering the sex ratio within the aggregation even before individuals reach the site (Johannes 1989).

OVERFISHING: THE THREAT TO REEF FISH SPAWNING AGGREGATIONS

While there is potential to affect the loss of spawning aggregations through habitat degradation and other forms of non-reproductive stress, the greatest threat to FSA appears to be commercial

[2] It is not yet clear what level of self-recruitment to individual FSA occurs. Among other possible explanations for FSA failure following extirpation is that older fish, which are believed to lead younger spawners to FSA sites, are no longer available to do so. Nonetheless, the linkage between reproductive output and recruitment is well established, with severe reductions in reproductive output undoubtedly having a negative effect on local or regional population replenishment.

overfishing (Sadovy 1994; Luckhurst 2004). Table 1 illustrates the impressive yet disturbing geographic scale and scope of commercial fishing activities affecting FSA[3]. In the following sections, we detail the main sources of the effects of FSA fishing (Table 1) in each of the two main geographic regions covered in this review, but highlight that these enterprises, while different in origin and form, provide identical results—FSA loss and population decline.

We identify two major types of commercial fishing responsible for aggregation loss: (1) the Southeast Asia-based live reef food fish trade (LRFFT) and (2) localized commercial fishing. Although these two industries differ both in scope and scale, the outcome—the degradation or loss of FSA—is generally the same. The LRFFT entails a relatively small group of overseas companies importing fish from regional suppliers using a vast network of companies or individuals in practically every country in the Indo-Pacific. In contrast, localized commercial fishing is comprised of perhaps millions of independent operators fishing within a relatively confined region and selling to local markets or buyers. For localized fishing, much of the catch is presumed to be sold and consumed locally, although sales and potential export practices vary by region. Although we identify commercial fishing as the greatest threat to FSA persistence globally, we briefly discuss subsistence and recreational fishing, which until now have gone largely unnoticed in the debate, but whose impacts may be substantial overall and whose impacts should not be neglected (e.g. see Coleman *et al*. 2004). We also make note that commercial fishing may reduce the resilience of FSA to subsistence and/or recreational fishing following a reduction in abundance or change in spawning habitat after commercial activities. In these instances, subsistence and recreational fishing—even at low levels—may have the same detrimental effects as commercial fishing, owing to the compromised nature of the FSA.

The Live Reef Food Fish Trade (LRFFT)

In the Indo-Pacific, one of the greatest threats to spawning aggregations of coral reef fishes is overfishing by the live reef food fish trade (LRFFT) (Johannes and Riepen 1995; Sadovy and Vincent 1999; Sadovy *et al*. 2003; Warren-Rhodes *et al*. 2003). The trade primarily targets certain species of serranids (groupers) and labrids (wrasse) using both non-destructive (e.g. hook and line) and destructive (sodium cyanide, mechanical reef breakage, some types of traps) techniques and relies heavily on FSA to meet catch targets (Johannes and Riepen 1995; Barber and Pratt 1997; Sadovy *et al*. 2003). Although direct evidence of aggregation loss or decline in the Indo-Pacific from the LRFFT is scant (but see Johannes *et al*. 1999; Domeier *et al*. 2002; Sadovy and Domeier 2005) when compared with the Western Hemisphere, anecdotal and documented reports of FSA affected by the trade are mounting and suggest an equal if not greater specific impact (Johannes *et al*. 1999; Sadovy *et al*. 2003; Hamilton and Kama 2004; Pet *et al*. 2005; Sadovy and Domeier 2005; Rhodes personal observation).

The live reef food fish trade, with origins in Hong Kong in the 1960s, began providing live reef fish to the local upscale Asian seafood market by targeting nearby surrounding reefs. From Hong Kong, supply for the trade spread to the neighboring reefs of Indonesia and the Philippines in the 1980s. Today, the LRFFT operates throughout the entire Indo-Pacific (Sadovy *et al*. 2003). From its humble origins, the trade income in 2002 was estimated at $810 million yr-1 (from previous levels of over $1.5 billion) and imports from the Indo-Pacific total an estimated 30,000 mt of reef fish annually (Sadovy *et al*. 2003). Perhaps only 50% of the actual volume is represented by this figure, owing to reporting inadequacies and trans-shipment mortality. In this manner, the trade appropriates an equivalent of 100% of SE Asia's sustainable grouper production and 20-40% or the entire Indo-Pacific's finfish stock (Warren-Rhodes *et al*. 2003). The estimated demand of the entire trade (1997 data) on Indo-Pacific reefs is 2.5 times higher than its sustainable production (Warren-Rhodes, *et al*. 2003). The unsustainable nature of the LRFFT is readily apparent and its effects are likely growing as the number of FSA declines and subsequent loss of reproductive and recruitment potential.

[3] It is noteworthy that in the Indo-Pacific, where the live reef food fish trade operates and is known to target FSA, little direct data are available either for FSA or population status for affected locales. However, anecdotal reports suggest numerous FSA have been eliminated by the industry, which may equal or surpass the number of FSA lost in other locales worldwide.

Given its unsustainable nature, the LRFFT poses a significant threat to long-term local economic potential and activity (e.g. dive and fisheries-related tourism, local food security) in developing countries in the Indo-Pacific, both from the removal of FSA (Sala *et al*. 2001; Sadovy *et al*. 2003) and potential damage to reefs from destructive fishing practices, such as the use of cyanide (Cesar *et al*. 1997) and repeated anchoring on fishing locales (Rhodes personal observation). As such, the trade could now be considered as promoting a regional socio-economic crisis that requires considerably more oversight and intervention by international trade and aid organizations than is currently being undertaken. Although importers recognize that FSA fishing is unsustainable, both importers' and import countries' perception appear to be that supply countries should bear full responsibility for regulating the output volume and source of fish. However, a scenario under which developing export countries entirely regulate and manage LRFFT activities is an unrealistic one, since most supply countries are well short of the funding and manpower necessary to adequately monitor and enforce this well-financed, often secretive and rapidly moving industry. Moreover, the trade has been associated with a number of illegal activities in export countries that includes fishing outside permitted times and areas, which exacerbates the potential for effective enforcement and monitoring (e.g. Johannes *et al*. 1999; Ioanis, B. Pohnpei Department of Marine Resources and Development, personal communication; Birch, K. Yap State Government, personal communication). A full description of the trade, its activities and its impacts may be found in Sadovy *et al*. 2003 (also see Johannes and Riepen 1995; Barber and Pratt 1997; Bryant *et al*. 1998; Bentley 1999).

Localized Commercial Fishing

Although large-scale centralized commercial fishing, such as that exemplified by the LRFFT, represents the dominant threat to FSA in the Indo-Pacific, decentralized commercial fishing—comprising thousands to millions of individual fishing entities of relatively small-scale—is also playing an important role in the loss of and worldwide decline in FSA (e.g. Beets and Friedlander 1992; Luckhurst 1996; Rhodes 1999; Sala *et al*. 2001). Perhaps nowhere has decentralized commercial fishing had more impact than in the Caribbean and western Atlantic, where the greatest recorded loss to FSA has been shown to date (e.g. Butler *et al*. 1993; Sadovy 1994; Luckhurst 1996; Koenig *et al*. 1996; Beets and Friedlander 1998; Burton 1998; Aguilar-Perera 2004; Luckhurst 2004) (Table 1). Indeed, spawning aggregation overfishing in the Western Hemisphere, conducted mostly by small-scale, privately-owned fishing vessels (skiffs), is directly responsible for the decline of at least seven species of grouper (including the endangered goliath grouper, *E. itajara*) and five species of snapper (Luckhurst 2004) in the region. This decline includes the commercial extinction of Nassau grouper (*Epinephelus striatus*) within virtually all countries in the Caribbean (Sadovy 1999). A full one-fifth of all known Nassau grouper FSA has been lost primarily to localized commercial fishing, which has pushed the species to endangered status in much of its former range and necessitated the complete closure of its spawning grounds in some locales (Table 3) (Hunter and Mace 1996; Sadovy and Eklund 1999; Domeier *et al*. 2002).

Despite the critical lessons for FSA management from the Nassau grouper experience and the similarities in terms of biology and vulnerability for many other FSA species, the majority of FSA in the western Atlantic and Caribbean continue to be unprotected and commercially fished (e.g. Sala *et al*. 2001; Claro and Lindeman 2003). A substantial number of other fish families are or have also been affected by commercial FSA fishing (Luckhurst 2004), including both resident and transient-type spawning aggregations. In Belize, for example, Graham[4] (in review) recently estimated the seasonal loss of approximately 12,000 mutton snapper (*Lutjanus analis*) from a single aggregation site over a 3-year period of commercial fishing, with associated declines in mean size and catch-per-unit-effort.

In the Indo-Pacific, decentralized, small-scale commercial fishing is exacerbating the tremendous toll on FSA from the LRFFT. Although accounts of aggregation loss by local non-LRFFT commercial fishers in the Indo-Pacific is scant, recent observations of large-scale removal of spawning individuals from a single aggregation in Pohnpei show that local fishing can also have rapid and dire

[4] Graham, RT, Roberts, CM, Heyman, WD and Carcamo R. *In review.* The mutton snapper (*Lutjanus analis* Cuvier, 1828) spawning aggregation fishery at Gladden Spit, Belize , *US Fishery Bulletin*.

consequences. In this latter example, over the course of a few days, fishers removed 4,000 individuals—equivalent to 20-30% of the entire FSA—in a one-week period (Rhodes 1999). Monitoring of the site in 2005 suggests this FSA has yet to recover (Rhodes personal observation). Johannes *et al*. (1999) report the loss of four spawning aggregations in Palau, beginning in the 1970s, primarily associated with local fishing efforts[5]. Similarly, Hamilton and Kama (2004) attribute the loss of at least one aggregation in Roviana Lagoon, Solomon Islands, and the decline of other FSA in sites in proximity to local populations, from commercial fishing. Other examples of FSA overfishing come from Tuamoto, where Hooper (1985) reported the near disappearance of at least one grouper species from small-scale aggregation fishing, while Bell (1980) found the once-common leopard coralgrouper practically absent from reefs around populated areas of French Polynesia. Similarly, spearfishing is reported to be responsible for removing two species of grouper around certain reefs of the Cook Islands, and Squire (L. Squire, Cairns Marine Aquarium, Cairns, Queensland, Australia, personal communication) report black saddled coralgrouper (*Plectropomus laevis*) virtually absent from some sections of the Great Barrier Reef (GBR). Leopard coralgrouper FSA have been similarly removed or are declining from a number of reefs along the GBR—one of the most heavily regulated recreational and commercial fisheries worldwide (Domeier *et al*. 2002). The frequent occurrence of locally derived gravid individuals of FSA-forming species in a number of countries (Marshall Islands, New Caledonia, Palau, Pohnpei, Solomon Islands, Papua New Guinea) suggests a widespread and systematic targeting of spawning aggregations regionally by local fishers.

Subsistence Fishing

While past reports have generally suggested that subsistence-level fishing exerts a low impact on spawning aggregations, at least one recent report has shown the contrary. In a recent examination of subsistence-level fishing in Roviana, Solomon Islands, Hamilton and Kama (2004) report the 10-fold diminution of FSA of the orange-striped emperor, *Lethrinus obsoletus*, by subsistence fishing. These authors also report a shift in effort toward an FSA of a species previously considered unfit for consumption—white-streaked grouper, *Epinephelus ongus*, in relation to overfishing of the orange-striped emperor and fish resources in general. Throughout the world, this shift is a commonly experienced consequence of, and response to, commercial overfishing and is but one manifestation of what Pauly *et al*. (2002) coined as 'fishing down the trophic level.' While many of the technological advances affecting some regions have not affected the Solomon Islands, population increases and changes in traditional values (e.g. customary marine tenure) and the increase in commercialization (e.g., need for cash for school fees, church obligations, etc.) may explain these recent trends (e.g. Ruddle 1996; Foale and MacIntyre 2000). Nonetheless, the evidence clearly shows that even subsistence fishing—often characterized as low-impact—can have profound negative consequences. These impacts may be substantial on FSA that have reduced resilience to fishing, such as extreme sex ratio or diminished abundance, following commercial activities.

Recreational Fishing

The overall impacts of recreational fishing to FSA are not well documented for most FSA-forming species. However, recent reports clearly show that recreational fishing is not benign (e.g. Coleman *et al*. 2004) and should be included in any management assessments or actions. For example, although Sadovy and Eklund (1999) do not directly compare recreational fishing and commercial fishing effects, the authors do show that at least 1.25 million now-endangered Nassau grouper and 114,000 goliath grouper were removed by recreational fishers from US waters between 1979 and 1993. The report also suggests that peak recreational fishing activity and landings of Nassau grouper within many areas of the Caribbean and Western Atlantic occurred during spawning seasons (Sadovy and Eklund, 1999). More recent reports of the impact of recreational fishing on US fish stocks show a substantial impact overall, but links to spawning aggregation fishing were not clear (Coleman *et al*. 2004). Finally, Burton (1998) suggests that recreational fishers may be at least partly responsible for the demise of mutton snapper (*Lutjanus analis*) in at least on FSA site within the Florida Keys. Clearly,

[5] Two of the FSA in Palau are showing some signs of recovery (Colin *et al*. 2003).

the impacts of recreational FSA fishing should be viewed more closely and held to the same types and standards of management as commercial enterprises.

MANAGEMENT OPTIONS

Below and in Table 2, we provide an overview of many of the potential management options available for FSA protection. Our intent is to provide a summary of these options by briefly describing the option, its scientific justification, requirements for its implementation and some of the possible advantages/disadvantages of employing the option. We also provide some case studies where some of the management options have been implemented for FSA, where available. Lastly, from this set of options, we (i) identify those which we feel are most likely to attain the level of protection and conservation required of FSA to secure them from the overarching threat of overfishing, (ii) discuss certain aspects of the economic, political and institutional issues that must be in place/resolved in order for the option(s) to work, and (iii) provide "second-best" approaches in lieu of our overall recommendation of no fishing on FSA. We have divided the list into two sections—one that focuses on eliminating fishing on FSA entirely and a second that reduces or restricts catch (effort) on FSA.

SECTION I: MECHANISMS TO ELIMINATE FISHING ON FSA

Precautionary and Data-less management

Prior to discussing data- or labor-intensive management options, we first discuss the one option that should be considered requisite for all FSA fishery management scenarios—data-less and precautionary management. Precautionary management is "management that greatly reduces the likelihood of stock collapse or severe environmental degradation" (Johannes 1998). In regard to FSA, spawning aggregation loss and population decline from overfishing is outpacing our ability to identify, study and manage each FSA individually and sometimes collectively, particularly given the vast area and circumstances over which these FSA exist. Thus, precaution is adopted by taking a proactive and conservative approach—one that prevents fishing on FSA—in order to avoid the likely negative impacts of FSA fishing. For FSA, this approach is highly justified given the undeniable outcome of FSA fishing—diminished reproductive population and aggregation loss—and global failure of practically every management approach to curtail FSA loss.

One 'sub-set' of precautionary management is data-less management, or simply management conducted in the absence of supporting scientific data for the specific FSA of interest[6]. In the wide geographic and resource-deprived areas of the tropics, data-less management is in most cases the only feasible option and one that has been employed for centuries as part of customary marine tenure (see below). Certainly, where observations on resource depletions, changes in size or degradation of habitat are clear, (precautionary) management should not be delayed until a scientific survey is conducted.

Several examples of precautionary management are found throughout the tropics. Examples include the imposition of marine protected areas by local clan leaders in Palau (Ngerumekaol) (Johannes 1997), private landowners in Pohnpei (Kehpara Marine Sanctuary) (Rhodes 1999), and community leaders in Kavieng, Manus and Kimbe Province, Papua New Guinea (Hamilton *et al*., 2004; Hamilton *et al*., 2005). These few examples highlight the fact that action can be initiated and maintained based on common perceptions of resource degradation and not merely on FSA-specific scientific justification. In each case, improvements were made (or are being made) to existing data-less management through scientific or local community monitoring surveys (Johannes *et al*. 1999; Rhodes

[6] There is overwhelming scientific evidence to show that FSA fishing usually leads to population declines and FSA loss. While some level of fishing may be acceptable to maintain FSA abundance and function, each FSA and species is likely to respond to fishing differently. In most locales, individual assessments of fishing level on FSA are impractical, as is generalizing the level of fishing that may be acceptable to prevent overfishing.

and Sadovy 2002; Hamilton, Giningele and Kama unpublished data; Rhodes *et al*. 2005). These improvements include recommended changes in area management, such as temporary or permanent no-take zones, and greater linkage of temporal bans to scientifically determined reproductive seasons. While it is true that the surveys improved management, it is more important to recognize that the surveys would likely not have ever been conducted had local leaders not taken the initial step of managing these resources and highlighting both the existence of the FSA and its plight.

Requirements:

- Management actions must be supported through local authority and be provided some means of enforcement and punishment should violations occur.

Pros: Can be cost-effective in comparison to data-intensive measures, depending on the type of action taken. Reduced occurrence of conflict within cohesive communities given that management of this form is often community-based.

Cons: May require the same level of enforcement as other data-intensive management measures. Can create conflict between user groups and management authorities if the details of management are unclear, not unanimously agreed upon or if there is little respect for those authorizing management action.

Area Conservation Strategies: Marine Protected Areas (MPAs)-Marine Reserves

The IUCN (International Union for the Conservation of Nature) defines an MPA (marine protected area) as "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the of the enclosed environment." Marine reserves, or no-take zones, are a sub-set of MPAs and are defined as restricted areas within the marine environment in which human activities, principally extractive fishing, are forbidden (Roberts and Polunin 1991; NRC 2001) and are what we prescribe as needed for effective FSA protection. Marine reserves can be either temporary, seasonal (e.g. no fishing May-October in proscribed area) or permanent closures (no fishing at any time in proscribed area), depending on the purpose and scope of management. First considered in the West for fish protection around the mid-1900s and used elsewhere for centuries as part of customary marine tenure (CMT), area closures, such as marine reserves, are now being considered, or currently used, at multiple ecological levels and for a variety of purposes, including reducing user group conflict, stock improvement, promotion of recreational and scientific opportunity and biodiversity protection, among others (Murray *et al*. 1999; Mackie 2000; McClanahan and Mangi 2000; Coleman *et al*. 2004; GBRMPA 2004; Russ *et al*. 2004). Evidence of the benefits of marine reserves is rapidly growing (e.g. Roberts and Polunin 1991; Polunin and Roberts 1993; Beets and Friedlander 1998), although there is still substantial discussion on their use and design (e.g. Sladek Nowlis and Roberts 1999; Mora and Sale 2002).

While marine reserves may be more widely known for protecting biodiversity at the ecosystem level, they can also be used effectively on smaller scales and for narrower, though equally important purposes, such as to protect essential fish habitat and individual life history stages (Plan Development Team 1990; Beets and Friedlander 1998; Sadovy 1998; Johannes *et al*. 1999; Warner *et al*. 1999; Rhodes and Sadovy 2002; Pet *et al*. 2005; but see Foale and Manele 2004). Such is the case for FSA-based marine reserves that function to protect reproductively active fish at and en route to spawning aggregation sites. Specifically, spawning aggregation-based MPAs act to protect spawner stock biomass in order to enhance reproductive output, while providing added benefits to habitat and non-target species (e.g. Bohnsack 1989; Plan Development Team, 1990; Roberts and Polunin 1991; Sadovy 1998).

Within the tropics, only a few marine reserves (also referred to as marine sanctuaries) have been established specifically for FSA (e.g. Belize, Pohnpei, Palau, Puerto Rico, Indonesia, US Virgin Islands) (Rhodes and Sadovy 2002; Johannes *et al*. 1999; Pet and Muljadi 2001;

http://www.caribbeanfmc.com), and fewer still have been assessed adequately and over sufficient time to determine whether stock-level improvements, such as increased spawning stock, improved sex ratio (post-fishing) or enhanced reproductive output, have occurred [7] (Appendix: Case 1- Puerto Rico). The potential for marine reserves to produce positive results rests on active monitoring, effective enforcement and strong punitive capacity, as well as adequate protection of other life history stages both locally and regionally—challenging tasks even among developed nations. A failure to actively enforce closures, i.e. the creation of 'paper parks', creates a false sense of accomplishment and protection, while allowing for the continuation of spawning population exploitation and FSA declines, which in turn fuels the potential for future conflict among user groups and management. In addition to enforcement issues, cultural and historical conditions must be considered when examining management options, particularly where CMT has played a predominant role in fishery management (Foale and Malele 2004). Finally, any FSA-based marine reserve should be part of a larger regional MPA network that takes into account issues of larval dispersal and connectivity, since localized, small-scale FSA-based reserves will not alone likely result in local population resiliency (Warner *et al*. 2000; Mora and Sale 2002). Moreover, FSA management should be an integral part of a broader fisheries management framework that incorporates all life history stages.

Examples of permanent multi-species FSA conservation areas include Ngerumekaol[8], Ebiil and Western Entrance (Palau), Kehpara Marine Sanctuary (Pohnpei), Hind Bank Reserve (USVI) and 11 sites in Belize, including Gladden Spit, Caye Glory (Emily), and portions of Lighthouse, Turneffe and Glover's Reefs. The Cayman Islands Government in 2004 issued permanent closures for eight sites that targeted Nassau grouper, but which are essentially multi-species FSA closures (Bush, P. Department of Environment, personal communication). Seasonal area closures may be found in the USVI (Lang Bank, St. Croix), Bermuda, and Puerto Rico (Abrir la Sierra Bank, Bajo de Cico, Tourmaline) for red hind, USVI (St. Croix) and US (Riley's Hump) for mutton snapper and Bahamas (High Cay and Long Island) for Nassau grouper (Luckhurst 2004; Burton *et al*. 2005).

Although we focus on and recommend permanent area closures, we recognize that in some cases permanent closures may not be culturally acceptable (e.g. Case Study 6). Such is the case in all or many parts of the Solomon Islands, where area closures combine with customary marine tenure to protect FSA. In these instances, area closures are instituted to allow FSA time to recover subsequent to periodic harvesting—a form of pulse fishing. While this measure is superior to no management, there is still an inherent danger in losing the FSA even after prolonged closure, since each FSA will be unique in its abundance and species composition and each will have had a unique fishing history. Consequently, each will have been compromised differently in terms of sex ratio and abundance and target species and will respond to renewed fishing differently. As such, each FSA will require close monitoring within and following open fishing periods and will likely depend on non-scientific monitoring to determine when FSA are subject to openings and closures.

Requirements:

For area closures to be effective in meeting conservation objectives, resource managers must have, at a minimum:

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[7] The Ngerumekaol spawning aggregation site closure was established in 1994 and is actively monitored and patrolled by the Koror State Rangers. The site was first closed under national law for four months of the year, then later closed permanently. Ebiil was first closed under traditional law through a *bul* and later closed for 5 years by state law. Western Entrance is closed on four months of the year through a traditional *bul*. The Kehpara Marine Sanctuary (Pohnpei, Micronesia) was originally established in 1998, expanded in 1999 and is actively enforced by the Pohnpei State Department of Land and Natural Resources. In Belize, 11 of 13 known FSA sites for Nassau grouper (*Epinephelus striatus*) have been protected since 2003. Only one of the 13 sites, Gladden Spit, is actively patrolled for enforcement. FSA within MPA sites in Pohnpei and Belize are routinely monitoring by various non-government organizations (NGOs).

[8] Initially formed as a *bul*, or area closed by customary marine tenure.

- Knowledge of the location(s) of all potentially affected FSA sites and migratory pathways. A failure to identify all sites and pathways may lead to unintended shifts in fishing pressure to both known and unknown (by managers) sites or the removal of spawners prior to reaching FSA sites;

- Ability to spatially assess (using underwater techniques) and document all FSA sites of interest to conservation. A failure to accurately identify aggregation dimension can lead to failed protection (see Case Study 2);

- For seasonal area closures, a clear understanding of reproductive season and inherent variability for target species (also see Temporal Closures, below);

- Ability to actively monitor and enforce protected areas during all periods within the reproductive season;

- Strong punitive system to punish and deter violations;

- Manner and resources to identify and verify changes to populations following a ban implementation.

Pros: Marine reserves protect spawning stock biomass and promote maximum reproductive output through maintained sex ratio, size maintenance to enhance fecundity, and normalized reproductive behavior. Other benefits may include providing spillover of larvae and adults to adjacent habitats, habitat protection, increased overall biodiversity, maintenance of genetic diversity and enhanced recreational, tourism and scientific opportunities with potential economic benefits (Roberts *et al*. 2001; Ruitenbeck 2001; Luckhurst 2004; Russ *et al*. 2004; Polunin and Roberts 1993). If FSA sites are limited in number and enforcement is strong, area closures may provide the most direct and cost-effective method of protection for spawning aggregations. Under co-management or CMT arrangements, marine reserves may produce a viable and cost-effective alternative to strictly government-run management. Many FSA sites are multi-species in nature and are, therefore, used by a variety of (commercially important) fish throughout the year. Thus, the protection of a site for one target species often provides protection for other spawning species. In contrast to other management options, may require less rigorous and frequent collection of information (Huntsman *et al*. 1999).

Cons: FSA-based marine reserves require knowledge of the specific location and extent of FSA as well as active monitoring and enforcement of the reserve throughout the spawning season(s) or entire year. These requirements may necessitate considerable manpower and resources, particularly when sites are widely dispersed and numerous. With limited resources and funding, monitoring and enforcing area closures becomes challenging, unless effective co-management or customary marine tenure agreements are in place that share costs and effort. When sites are widely dispersed, options for reserves are to focus on areas most significant, for example in terms of future commercial value and/or biodiversity, or those perceived as most threatened—e.g. those closest to population centers or those that have historically been overfished. The latter strategy has the potential to shift fishing effort to more distant and previously unfished FSA sites, depending on fisher resources. The removal of FSA from the fishery through area closure is likely to create opposition and be politically unpopular unless positive results can be shown over time. Area bans may place additional pressure on non-target species, may increase conflicts between management and fishers and may reduce fisher income during spawning seasons if no alternative fishing or vocation is available. Seasonal area bans may incur increased fishing pressure on fish during non-spawning periods—i.e., fishing extra hard to make up for 'lost time'—such that annual total volumes of fish remain constant (see below for Mahahual seasonal ban).

Temporal Conservation Strategies

Temporal, or seasonal, conservation strategies indirectly protect spawning individuals at or en route to FSA by closing the fishery coincident to the reproductive season, but leave the FSA area and the adult population open to fishing at other times of the year. The scientific justification for temporal bans on FSA fishing is similar to that for marine reserves—to protect spawner stock biomass and maximize reproductive output—but without the added site-based benefits described above, such as habitat protection, spillover or large-scale improvements to biodiversity. Although these types of bans do not always provide direct protection of spawning individuals at FSA sites, the bans may minimize catch during spawning season(s) since all forms of commercial activity or possession are prohibited. One of the greatest potential benefits of temporal bans is that they provide indirect protection for all spawning sites, whether known or protected by management, since commercial catch, sale or possession of FSA-derived fish cannot take place. Given that all or the majority of spawning individuals are thought to be at FSA sites during the reproductive season, possession during the spawning season virtually ensures that fish have been caught from aggregations.

Temporal bans can take the form of sales, catch, possession, or export bans that coincide with the spawning season for target species (e.g. Johannes *et al*. 1999; Rhodes and Sadovy 2002) (see below). Although both spatial and temporal bans have the potential to work alone, a combined approach is an option that provides both site-based protection to prevent fishing and a mechanism to prevent catch and or possession during the spawning season at all spawning sites. It should be noted that when variability in spawning times occurs, placing bans only during months where spawning is common between years may be insufficient to prevent FSA overfishing (see Case Study 3). Moreover, certain species, such as squaretail coralgrouper (Plectropomus areolatus) may form aggregations monthly throughout the year. In these instances, temporal bans may require linkage to area closures or species-specific restrictions to prevent overfishing[9] and to allow fishers some percentage of catch from the population away from FSA sites (and migratory pathways).

A number of tropical countries have implemented temporal bans in various forms to stem FSA loss and prevent population decline (Table 3). For example, the British Virgin Islands (BVI) has a seasonal ban on red hind (January-March) and both Pohnpei and Palau have seasonal closures on camouflage grouper, brown-marbled grouper and squaretail coralgrouper from 1 March-30 April and 1 April-31 July, respectively (Johannes *et al*. 1999; Rhodes and Sadovy 2002; Luckhurst 2004). Owing to a failure to link bans to species-specific spawning season(s), bans such as those for Pohnpei and Palau are only partially effective in preventing FSA overfishing, since some months for some aggregating species are not inclusive in the ban[10]. A similar case is shown for spawning season closures in southeast Florida for mutton snapper (*Lutjanus analis*) and greater amberjack (*Seriola dumerili*), where fishermen have responded to seasonal restrictions on fishing by redoubling efforts outside the closure period, such that total landings have remained essentially constant (Burton 1998). We support catch bans for all locales with species listed under CITES, such as humphead wrasse and Nassau grouper.

Requirements:

- Accurate information on the spawning season and potential variability within and among sites and species are the most important requirements for developing meaningful temporal management protocols;

- Information on, and access to, sites where all or the majority of fish are captured (catch or possession bans), sold (sales or possession bans) or exported (export or possession bans) are needed for adequate enforcement;

- Ability to monitor and enforce at all points of catch, possession, sale or export.

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[9] Monthly aggregation formation has been shown for some areas of Melanesia and Palau. We do not yet know whether these monthly aggregations are reproductive and there is some suggestion that all are not, i.e. support only males. Regardless, because of the predictable nature of these gatherings, the fish(es) within them remain highly vulnerable to overfishing and their removal may affect future reproductive success.
[10] These bans were initially based on local knowledge that hadn't been fully verified by scientific investigation.

- Strong punitive system to punish and deter violators;
- Licensing requirements and punitive measures for market and restaurant owners, etc., as well as fishers, violating sales and possession bans;
- Methods and resources to verify changes to populations following a ban implementation.

Pros: Temporal bans have the potential to maintain or increase reproductive output and may provide a more cost-effective enforcement option to area closures when sites of commercial activity (e.g. docks, markets) are centralized or otherwise easily accessed and FSA sites are otherwise widely dispersed geographically. Temporal bans are also simple to understand by all parties: protection of the fish occurs during the times and at places where the fish are reproductively active—i.e. when they are most vulnerable. Seasonal bans can act effectively for numerous species, but only if ongoing monitoring and enforcement is active. Temporal bans can be linked with area closures to provide added effectiveness or can be tied to licensing requirements, for example, for exporters and market owners. Enforcement of catch and possession bans can occur at any point from catch to sales. Fines may provide added revenue to further support enforcement activity. Seasonal market-based bans may not require marine transport to distant spawning sites and associated fuel cost and are not impeded by weather if enforcement is at the point of sale, trans-shipment, etc. Catch bans also prevent fishing on non-reproductively active adults and juveniles during the spawning season to ensure greater potential overall stock protection and replenishment.

Cons: Temporal bans/seasonal closures may not be suitable for locales with spawning seasons that vary widely for the same species over short distances (e.g. 20 km), therefore, requiring highly site-specific seasonal bans (e.g. Papua New Guinea, Solomon Islands, Palau). The bans also require centralized commercial facilities (point of sale, export, etc.) or, alternatively, access and resources for enforcement at (potentially) widely distributed facilities or catch locales. Temporal bans may place additional pressure on non-target species, may increase conflicts between management and fishers and may significantly reduce fisher income during spawning seasons if no vocational or fishery alternative is available. Consequently, closures may result in a shift (or redoubling) in effort outside the closed period, or in a rise in discards/mortality if prohibited fish are captured (Burton 1998; Coleman *et al*. 2000; Lindeman *et al*. 2000). Requires knowledge of species identification by enforcement and commercial staff. Prohibition on commerce during extended time periods (e.g., 3-4 months) places economic hardship on fishers and may be politically unpopular. Since they are usually species-specific, temporal bans do not provide blanket protection for sites that may actually be multi-species, year-round spawning sites for a number of commercially and artisanally important species.

Seasonal Sales Bans

Seasonal sales bans provide benefits to FSA when the main purpose of fishing is for local sale of catch and where markets can be easily monitored and enforced. From a management viewpoint, sales bans require sufficiently knowledgeable staff to monitor and enforce all markets and other points of sale (e.g. restaurants) during spawning periods. Where markets are highly centralized, a single staff member would generally suffice to conduct all the necessary monitoring. Examples where seasonal sales bans are enforced to protect FSA species during all or a portion of the reproductive season are Pohnpei (Rhodes and Sadovy 2002), Palau (Johannes *et al*. 1999), USVI and Puerto Rico (Sadovy 1994; Beets and Friedlander 1998), US (March-April: gag and black grouper), Dominican Republic (Sadovy and Eklund 1999) and the BVI (Luckhurst 2004). While some success has been shown in the locales where enforcement is active (e.g. Palau, Puerto Rico, USVI), poaching at the FSA sites appears to continue at least in one locale—Pohnpei— where inadequate enforcement and prosecution hinders both the area and temporal bans that are in place.

Requirements:

- Ability to access, monitor and enforce at all points of commercial activity;

- Clear understanding of the seasonal patterns of reproduction for target species across all management areas;
- Strong punitive system to punish and deter violators.

Catch Bans

Catch bans in association with spawning seasons assist managers in preventing FSA overfishing by protecting spawning individuals at any location, including FSA sites and migration pathways, even when site-specific area closures are not in place. From a management perspective, catch bans are potentially more labor-intensive since they require on-site enforcement and monitoring that may be impractical in regions with wide geographic jurisdictions or FSA, and with limited management infrastructure. Seasonal catch bans are in place in Australia (recreational: three 9-d periods around new moons during spawning seasons for several coral reef species; adjusted annually), US for mutton snapper (May-June), black grouper and gag (March-April), red hind in Bermuda (May-August), Pohnpei for three aggregating grouper species (see above), Palau for camouflage grouper, brown-marbled grouper, squaretail coralgrouper, black-saddled coralgrouper and leopard coralgrouper during five months of the year[11] (Graham 2001) and Nassau grouper for at least eight sites in the Cayman Islands (see above and Table 3). The Dominican Republic prohibits the catch of ripe female Nassau grouper during the spawning season and Bermuda instituted a moratorium on the catch of Nassau grouper in 1996 (Sadovy and Eklund 1999). Baldchin grouper (*Choerodon rubescens*) is banned from catch from Western Australia to protect spawning aggregations from 1 November-31 January (Western Australia Department of Fisheries <http://fish.wa.gov.au>).

Requirements:

- Ability to monitor and enforce at all points of catch;
- Clear understanding of the seasonal patterns of reproduction for target species across all management areas;
- Strong punitive system to punish and deter violators.

Possession Bans

Possession bans prevent fishers, market owners, restaurants and exporters from possessing any species held under the ban within the reproductive period. This type of ban is most effective in preventing poaching and storage of FSA species during spawning periods for subsequent sales, export or use outside ban periods. One especially useful application of this type of ban may be in areas where the live reef food fish trade operates, since fish are often taken from aggregations and held in cages prior to shipment. The ban would prevent traders from holding FSA-derived fish and then exporting them once the ban period is passed. These same bans could be applied elsewhere where fish are stored prior to export or sale. When combined with other types of bans, such as export (see below) and catch bans, possession bans are useful tools in preventing FSA overfishing. For management, possession bans require some additional effort in monitoring points of catch, sale and/or possession, such as restaurants, markets, holding pens or docks. Some examples of locations where possession bans are in effect for reproductively active grouper are Palau and Pohnpei (*Epinephelus polyphekadion, E. fuscoguttatus, Plectropomus areolatus*), the US and its territories (goliath and Nassau grouper), Belize (Nassau grouper) and British Virgin Islands (red hind).

Requirements:

- Ability to monitor and enforce at all points of catch, sale or possession;

[11] 27 PNCA 1204.

- Clear understanding of the seasonal patterns of reproduction for target species across all management areas;

- Strong punitive system to punish and deter violators.

Export Bans

Export bans are generally established to preclude the large-scale export (or over-export) of FSA-derived or reproductively active fish during spawning times. This type of ban would affect both the live reef food fish trade and locals wishing to export smaller quantities of fish to local or regional markets (e.g. Micronesia to Guam or Hawaii). Export bans during the spawning season would only prevent FSA overfishing when combined with a catch and possession ban, since an export ban alone cannot prevent FSA fishing. From a management resource perspective, export bans require minimal staff if points of export are centralized (e.g. Pohnpei, Chuuk), but may prove ineffective if export locations are widely dispersed, such as those of the LRFFT in Papua New Guinea or the Solomon Islands. Solutions to overcoming widely dispersed points of export in relation to monitoring and enforcement include an export licensing requirement to trans-ship all catch through a centralized point of export. Only the Maldives, Seychelles and Papua New Guinea currently have known export requirements (Sadovy *et al*. 2003). However, the bans only control export volumes and are not directly tied to spawning seasons or FSA. Therefore, they do not directly control FSA overfishing. Examples of export bans include humphead wrasse from Palau (Palau, domestic Fishing Laws 1998, 27 PNCA 1024) and all reef fish from the Cayman Islands (Bush, P, Dept. of Environment, Cayman Islands Government, personal communication).

Requirements:

- Ability to monitor and enforce at all points of export for target species;

- Punitive system to punish violators, such as license revocation and confiscation;

- General requirement for exporters to report to one or several centralized export facilities prior to export for inspection and recording catch.

Species Bans

Species bans provide total protection and potential recovery for species that are highly endangered or vulnerable to extinction, including from FSA overfishing. Such species are typically found on the Conservation for International Trade of Threatened and Endangered Species (CITES) (http://www.cites.org) list of appendices for voluntary removal of species from trade or The World Conservation Union (IUCN) Red List (http://www.redlist.org), assuming sufficient evidence is available to evaluate the relative extinction risk. Species forming FSA that are currently listed include the humphead wrasse (*Cheilinus undulatus*), giant grouper (*Epinephelus lanceolatus*), goliath grouper (*E. itajara*), Nassau grouper (*E. striatus*) and cubera snapper (*Lutjanus cyanopterus*), among others. Many of the species listed have high tourist potential, such that their recovery may elevate tourism interest and revenue (e.g. Mexico, Palau, Belize). Still others are likely to be listed, as more information on their status becomes available, including those with narrow geographic distributions and complex reproductive life history, such as humpback grouper, *Cromileptes altivelus*, for example. Regardless of whether a species is formally listed, in some areas, both fishers and managers are aware of substantial changes in the number or size of catch, or loss of FSA of certain fish species. In these instances, management in the form of species, catch, possession, export, sales bans and/or area closures is justified under precautionary management principles.

A number of countries have imposed species-specific bans following substantial regional changes to populations. Perhaps the most widely banned species in the Western Hemisphere are the Nassau grouper (US, Puerto Rico, USVI, Belize) and goliath grouper (US, Puerto Rico, USVI, Cayman Islands) (Sadovy and Eklund 1999; Bush, P, Dept. of Environment, Cayman Islands Govt., personal communication). Both species are listed on the IUCN Redlist. In Australia, humphead wrasse, potato cod, humpback grouper and giant grouper are prohibited from catch (Queensland Department of Primary Industries and Fisheries 2004; http://www.dpi.qld.gov.au/fishweb/131510.htm). Humphead wrasse is also prohibited from catch in the Maldives (Shakeel 1994; Anderson and Waheed 1997) and Niue (Niue Domestic Fishing Regulations 1996). Each of the aforementioned species is characterized by having a complex reproductive pattern and in most cases, slow growth, late maturity and the formation of relatively small spawning aggregations. It is noteworthy that many of the above species, such as Nassau and goliath grouper and humphead wrasse, that have already been placed on these lists continue to be fished in many countries, despite their decline or extinction in other areas.

Requirements:

- Historical and current information on fisheries, life history and/or population trends, including catch-per-unit-effort, mean individual catch size, distribution area or size at maturity;
- Historical and current information on FSA locations, areas and abundance;
- Ability to actively monitor and enforce from point-of-catch to landing, sales or export;
- Ability to enact necessary changes to landings, such as requiring fish be landed whole;
- Strong punitive system to punish violators;
- Manner and resources to verify changes to populations following a ban implementation.

Pros: Can be simple to implement, monitor and enforce when points of landing or sale are centralized or FSA are few and can be routinely assessed. User groups may reach consensus on restrictions when species are in obvious decline.

Cons: Where species are culturally significant (e.g. humphead wrasse, white-spotted grouper, *Epinephelus caeruleopunctatus*), implementation of such a ban can prove politically unpopular. Species bans are difficult to enforce when the fishery is geographic dispersed and no active monitoring of catch areas is taking place. May require additional changes to fishery regulations if fish are landed as fillets (e.g. Belize), thereby creating greater opposition among fishing interests.

Customary Marine Tenure [12]

Customary marine tenure (CMT) is "a locally specified entitlement to marine territory and resources exercised by 'guardians' of those territories and resources" usually an elder council, individual under a specified lineage, or monarch (chief or king) (Hviding 1996). In many areas of the central and western Pacific, CMT has been practiced for generations to 'manage' both fish and invertebrate stocks (e.g. Johannes 1981; Johannes 1998). While there is little in the way of formal scientific backing to justify a CMT approach, the principles— developed perhaps centuries prior (e.g. Johannes 1998)—rely on the same concepts as Western management, such as stock increases through area and seasonal closures, species bans or minimum size limits.

In contrast to Western style management, CMT may have far greater potential for success in protecting FSA—since it relies on active participation of the community and those most affected by management, including fishers—particularly where conventional management resources at the national scale are scarce or insufficient (e.g. Melanesia) or have a history of failure. The latter should not imply that CMT, left to its own devices, is the ultimate solution to FSA management. Indeed, all management, including CMT, would greatly benefit from greater awareness of FSA vulnerability and

[12] Here we include CMT as a management option to eliminate fishing on FSA, although CMT is and can be used as an effort reduction mechanism as well.

target species life history. Therefore, there remains a need for greater scientific input into the system to justify and succeed in CMT-style management, with case studies serving to promote these changes.

The use and effectiveness of CMT as a conservation technique to sustain or promote stock abundance is somewhat controversial. While some researchers have viewed it as a conservation tool to provide sustainability to stocks (e.g. Johannes 1991; Hviding 1998), others see it as a method of regulating stocks for exploitation without regard for sustainability or long-term stock enhancement (e.g. Foale and MacIntyre 2000[13]). For example, in many regions of the central and Western Pacific (e.g. Papua New Guinea, Vanuatu and Solomon Islands) area closures serve only as a short-term means to build up stocks for harvest in association with festive activities, such as funerals or circumcisions. They are not typically instituted to build up stock biomass for long-term population expansion or sustainability per se. As mentioned, while CMT utilizes species bans, gear restrictions, seasonal closures and size restrictions, it is rarely for periods greater than a few months (e.g. Johannes 1998) and is typically infrequent over longer time periods.[14]

Thus, whether CMT has the potential to be re-structured or re-instituted on a large scale or long-term for FSA conservation is uncertain. Nevertheless, the use of CMT on the area scale of FSA remains feasible, although the overall benefits to the local target species population will likely be minimal unless self-recruitment or natal homing is high or CMT is enacted on a wider geographic scale within a particular region. The latter would generally require cooperation among numerous groups of landowners. To institute any such long-term protection at the scale of FSA (km^2), owners must also change the way in which they view benefits (e.g. to provide short-term build-up for exploitation), which can only come through educational awareness.

In at least two recently reported incidents, educational awareness has provided the impetus for CMT to be used for stock enhancement or FSA protection using a modified CMT approach. In Vanuatu, for instance, educational awareness resulted in longer catch ban periods or area closures for some species through ongoing government awareness campaigns (Johannes 1998). A second example is shown for Kavieng, Manus and Kimbe Bay in Papua New Guinea, where several formerly fished FSA in each region were closed to fishing, following an awareness presentation on spawning aggregations, in order to rebuild spawning stocks (Hamilton *et al*., 2004; 2005).

Similar to Western management strategies, CMT has flexibility in response to ever changing internal and external cultural, political and economic forces (Graham and Idechong 1998; Hviding 1998). In contrast to Western approaches that often get bogged down in political processing resulting in a management response that is outdated by the time of its implementation, CMT can have a rapid response time (e.g. immediate area closures in response to a death).

In the Pacific, many island communities have abandoned traditional CMT, in practice for centuries, in response to the promotion of Western management practices (e.g. Pohnpei), although some have held more closely to CMT traditions (e.g. Yap, Solomon Islands, Papua New Guinea). Still others are reinvigorating the use of CMT to assist government for resource management (e.g. Vanuatu). Given the lengthy track record of failure of Western management in managing a multi-gear, multi-species fishery in the tropics (Sadovy 1994; Luckhurst 1996), CMT should at least be viewed as one potential option to conserve FSA, (and in some areas the only effective way), with those areas still utilizing effective CMT effective[15] serving as case studies. What is now needed is clear evidence that the institution of CMT will benefit FSA to a greater extent that Western styled management. In regards to site based management of FSA in Melanesia, western management is often clearly not a feasible

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[13] Hamilton, R.J. and A.J. Smith. 2005. Supporting community-based inshore fisheries management in Melanesia to achieve conservation goals. A paper presented at the 7th Indo-Pacific Reef Fish Conference, Okinawa, Japan, May 2005.
[14] In Melanesia ban for invertebrates are typically in the order of years not months (e.g. Hamilton, 2003; Hamilton *et al*., 2004)
[15] CMT is most effective when reinforced by supporting legislation at the most appropriate level of government.

option in most cases, but in the correct circumstances CMT can be a viable management structure. However, where Western management has failed, CMT may be advantageous—perhaps the only option—given the greater understanding local communities possess of resource needs, local political circumstances and management opportunities (Foale and MacIntyre 2000).

Requirements:

- Cultural and political background or other form of local reef ownership for the use of CMT;
- Ability to limit access to FSA sites to local user groups by CMT councils;
- Strong monitoring, enforcement and punitive system to punish violations;
- Ability to monitor and rapidly respond to changes in FSA;
- Knowledge of FSA locations within the CMT jurisdiction;
- Community involvement is central to CMT, thereby integrating key stakeholders into conservation and management plans and implementation.

Pro: CMT and community based management can be used to respond rapidly to overfishing at FSA. Reef owners usually have long-term awareness of the general status of the resource and may be better able to judge when community based management measures are necessary. This local control of resources can minimize costs and effort to national management authorities and potential conflict between local and national government entities.

Con: Small-scale area closures may not provide localized population build-up for target species. In many areas, national governments have ultimate authority over marine areas that may conflict with the effectiveness of CMT measures. CMT measures may be temporally insufficient to be meaningful. CMT implementation without sufficient understanding of target species life histories or ability to detect changes in FSA size or distribution may result in continued population decline. Can result in conflict between reef owners and government resource managers if CMT owners are 'oversold' on the concept and potential outcome of FSA protection, i.e. have false expectations. CMT officials' goals may not be solely, or primarily, conservation-oriented, these individuals may lack sufficient authority to enforce or prosecute violations effectively or may clash with other CMT owners or other management authorities when fish stocks overlap or migrate between areas. May require labor-intensive monitoring during and after pulse fishing periods to reduce the potential for stock collapse. Certain negative consequences of fishing during open fishing periods, such as sex ratio imbalance may go unnoticed by CMT monitors, leading to FSA loss or severe declines in reproductive output. Changes to reproductive output may go unnoticed for years by non-scientific observers.

SECTION II: MECHANISMS TO REDUCE OR REGULATE FISHING ON FSA

Quotas and Bag Limits

Quotas (also total allowable catch, or TAC) allow fishers to extract fish at a predetermined fishing level (e.g. maximum sustainable yield) on a population of 'known' (i.e. predicted) size. Bag limits, typically targeting recreational fishers, work in a similar fashion by theoretically controlling the total amount of fish to be extracted and are also based on stock size maintenance. Generally, both quotas and bag limits require sound knowledge of the fishery, such as catch-and-effort, catch mortality rates and real-time changes in stock size and cohort (age-class) contribution. Obviously, quotas require substantial data input, labor and cost, both for acquiring and analyzing the data and for ensuring quotas are managed efficiently.

For most tropical marine reef fishes in practically all locales, neither the type of biological or fisheries information needed nor the resources to pursue enforcement of quotas or bag limits is available, nor is it likely to be available in the near future. Moreover, the complex reproductive biology, inherent inter-annual variability in stock and FSA size (also inter-monthly) and poorly understood biology of most FSA-forming species preclude the use of these management options for many tropical species (Munro 1996). Finally, numerous FSA likely exist in each locale, and each requires independent assessment, monitoring and enforcement for quota establishment—a serious burden in areas affected by scarce economic resources. For this reason, few locales have attempted to use quotas on FSA-forming species (Cuba, Bahamas, US, Belize, Bermuda, Australia, Seychelles and Papua New Guinea) and success has generally been poor (e.g. Sadovy and Eklund 1999). Belize, for example, imposed quotas on the catch of Nassau grouper at Glover's Reef, but a failure by management to monitor and enforce resulted in continued overexploitation of the resource (Sala *et al*. 2001) and a subsequent total closure of Nassau grouper to the fishery through marine reserves (Government of Belize 2003). Continued declines of Nassau grouper following the imposition of quotas for all groupers in US waters in 1989 resulted in a total fishery closure for the species in 1991 in the US Atlantic and in 1997 for the Gulf of Mexico (Sadovy and Eklund 1999).

The likelihood that quotas are or can become a practical management tool for FSA in the developing tropics is slight at best. Indeed, even in temperate areas with sufficient resources to implement and evaluate quotas, their application has failed in most instances (e.g. Myers *et al*. 1997; Daan 1997). The use of quotas for FSA fishing would likely lead to overfishing and possible extirpation, given the likely shortcomings in resource availability for enforcement and monitoring (albeit with potentially less impact in the short-term than unregulated, open access fishing). Some examples of FSA-forming species that are currently under some form of quota management scheme in US waters include yellowedge and Warsaw grouper, speckled hind and scamp (US Department of Commerce 2004). Bag limits are in place for some species, including coralgrouper (*Plectropomus* sp.) and other serranids in western Australia (2004), Warsaw and red grouper, speckled hind (limit = 4), black grouper and gag (2 person per trip) and some other snapper (10 limit) in the US (US Department of Commerce 2004) and red hind (10 per boat) and black and yellowmouth grouper (1 per boat per day) in Bermuda (Luckhurst 2004). The Cayman Islands restricts the take of Nassau by spear to 3 fish (Bush P, personal communication).

Requirements [16]:

- Monitoring and enforcement at all points of catch, landing and sale;
- Real-time information on the fishery and affected population or stock;
- Knowledge of all affected FSA sites and changes therein;
- Potential to collect and analyze fisheries information and respond to changes in the fishery or FSA based on this information;
- Political and cultural flexibility to alter quotas annually or as required by the data;
- Strong system of jurisprudence and political willingness to punish violators;
- A sufficient understanding of the life history of the species under consideration.

Pros: Since quotas, in practice, would provide some access to FSA and removal of at least some portion of the spawning population, fishers are more likely to support quotas over total exclusion of the resource.

[16] Quotas should be set for individual species to be effective in preventing overfishing on FSA.

Cons: Active enforcement is necessary at all points of catch, landing and sales, requiring substantial cost and effort on the part of enforcement agencies (King 1995). Quotas and bag limits require up-to-date knowledge on the state of the fishery and status of the population of each species, which is generally not economically or logistically possible in most areas of the tropics. Many FSA are multi-species, and thus the potential for by-catch of non-target spawners is great and likely to require management of all species within the FSA or managed area. Quotas impose a risk of underestimating fishing mortality, overestimating stock abundance and providing misplaced optimism about a stock's condition (Walters and Hilborn 1992; Walters and Maguire 1996; Myers *et al*. 1997 in Coleman *et al*. 2000). Given the degree of uncertainty that exists for both the fishery and target species, the likelihood that such quotas will be exceeded is generally great. The use of quotas often catalyzes a 'run' on the fishery to maximize the amount of catch before the quota limit is reached, again providing the impetus for overfishing. Bag limits may be ineffective if fishers respond by increasing the number of trips or individuals fishing (Coleman *et al*. 1999). Overall, the current understanding of FSA population dynamics is insufficient to establish meaningful quotas. In the case of the LRFFT, small quotas (on FSA sites) would also make the LRFFT fishery operations in remote regions largely uneconomical (Thomas, 2001).

Access Permits

Permits provide restricted access to FSA and require many of the same data needs as other types of management, such as for quotas or bag limits. In other words, permitting requires data on the current and (potential) future abundance and condition of the spawning population (e.g. cohort condition, sex ratio, dynamics) and the variability therein, which is often not attainable within developing island resource agencies. The intent of permits is to restrict the impact of fishing on the spawning population by reducing, for example, the number of fishers using a site, the number of sites open to fishing, the number of days sites are open to fishing, or some combination of these. Although similar in many ways to licensing, permits can be greatly restricted in number and access to sites, can be tradable between fishers, can be issued through a lottery system or other means to reduce bias and can be altered depending on stock or FSA condition. Permits can be used alone or in combination with quotas. There is no known use of access permits on FSA.

Requirements:

- Ability to determine the sustainable level of fishing possible on an affected FSA, based on the fishery (e.g. catch mortality, catch-per-unit-effort, etc.) and status of the FSA (e.g. abundance, cohort or size distribution, sex ratio, etc.);
- Administrative capacity to issue permits;
- Political willingness to restrict access to sites;
- Ability to determine the number of permits possible based on fishery and FSA data;
- Active on-site enforcement at all affected FSA sites;
- Strong punitive system in place to deter and prosecute violators.

Pros: Like quotas, provides some access to the resource, which may minimize conflict between fishing communities and government. Given the dynamics of the spawning population is well known and adequate enforcement is in place, may limit the impact of FSA fishing in comparison to open access.

Cons: Access to the resource by a sub-group of the fishing community may cause conflict between deprived fishers and government or permitted fishers. Opening the fishery may promote overfishing or poaching, particularly where monitoring is weak or where the condition of the FSA is not adequately understood (i.e. overestimated). Likely requires substantial enforcement, economic input and administrative capacity. Requires a detailed understanding of the FSA and the fishery that is typically costly and time-consuming to obtain and which is generally not feasible for most developing tropical island governments or communities. Generally would require a combined management approach such as the implementation of other types of restrictions (e.g. bag limits) to minimize overfishing potential.

The Cayman Islands currently provides access permits to the public to fish some marine protected areas established to protect FSA (including the endangered Nassau grouper), although no permits are currently being issued (P. Bush, Dept. of Environment, Cayman Islands, Govt., personal communication).

Size and Weight Limits

Size and weight limits in the context of fisheries management allow individuals to mature and reproduce a minimum of one year prior to capture, thereby providing some assurance of population maintenance through enhanced reproductive output. These measures reduce growth overfishing and help to increase the yield (reproductive output) per recruit. However, among FSA-forming species, size limits as a management measure have rarely been implemented (e.g. US, US territories and Cayman Islands). This owes in part to a paucity of size-at-maturity data for multiple species, the species and sex-specific variation in growth rate and complexity in determining meaningful size limits on sex-changing species and the resource needs required to enforce size limits in a multi-species fishery. For example, for some hermaphrodites, males and females mature at vastly different sizes (and ages). As such, setting a minimum size-at-catch may only ensure that some first-year females spawn, while allowing catch on all size classes of males. A variation of size limits are slot limits, which allow catch on individual within a certain size range (e.g. some size range in the middle of all possible adult size ranges) that usually excludes catch on the smallest and largest adult size classes in the population. Furthermore, size at sexual maturity may vary among regions, such that certain size restrictions may only be relevant to specific sites or regions. Finally, barotrauma-induced mortality often precludes the effective release of undersized individuals, particularly among deeper water species (e.g. black grouper, giant grouper).

Regardless of the aforementioned difficulties, a number of countries have instituted size limits. For example, in the US and the Bahamas, yellowfin grouper have a 3 lb (~1.3 kg) weight minimum, while other grouper species have a 12-20 in TL size minimum (Sadovy 1994; also Luckhurst 1990). Various limits have been attempted for Nassau grouper in the US (Sadovy and Eklund 1999; Case Study 4). Cubera snapper are protected by a 30 cm TL size limit in US waters and Nassau grouper are afforded a 25 cm TL minimum size requirement in the Cayman Islands. All commercially and recreationally important serranids are protected by size limits in Australia including potato cod, camouflage grouper, as are humphead wrasse (Queensland Department of Primary Industries and Fisheries; http://www.dpi.qld.gov.au). Similarly, in Australia, leopard, black-saddled and spotted coralgrouper have a 38 cm TL minimum size at catch requirement. Palau and Papua New Guinea restrict the capture of humphead wrasse smaller than 65 and 64 cm TL, respectively (Palau Domestic Fishing Laws 1998, 27 PNCA 1024); National Gazette No. G99, June 17, 2002). Additional size and weight minima may be in place elsewhere.

Requirements:

- Clear knowledge of the minimum size at maturity for each species within each affected area;
- Information on each species reproductive life history (i.e. gonochore, vs. hermaphrodite) and associated sex-specific variations in size at maturity;
- Ability to monitor and enforce a size-based management protocol at all points of catch, transport, sale or export;
- Prosecutory capacity to deter violators and ensure management objectives are met.

Pros: Size and weight limits have the potential to maintain populations by permitting all individuals an opportunity to reproduce at least one year and, thereby, replenish some portion of the population lost through fishing or natural mortality. May provide good protection against growth overfishing when fish are required to be landed at central locations for inspection or enforcement is active at the point of catch or transport. Requires fishers to measure fish at the point-of catch, reducing the potential for claiming ignorance of illegal catch.

Cons: Requires species-specific information on size and maturity (and/or sex change) for target species, many of which are unknown and difficult to obtain. Requires enforcement agents to identify, handle and measure (or weight) all suspected under-sized individuals. Requires monitoring and enforcement between point-of-catch and landing, sale or export. Potentially costly unless monitoring and enforcement activities can be centralized, such as requirement for landing fish at centralized locales. Many undersized fish may subsequently die following release due to barotrauma-induced mortality. Those that do die cannot be kept and are, therefore, wasted. Moreover, since a number of FSA are multi-species, the likelihood of catching other reproductively active fish is high.

Gear Restrictions

Gear selectivity in altering populations of fishes has long been established (Beverton and Holt 1957). For FSA, certain types of gear have had dire consequences, including fish pots (Case Study 5) and traps (Luckhurst 1996; Beets and Friedlander 1992), spearguns (Aguilar-Perera and Aguilar-Davila 1996; Bush, P, Department of Environment, Cayman Islands Govt., personal communication), hook and line (Koenig *et al*. 1996), nets (Ioanis, B, Department of Marine Resources, Pohnpei, FSM, personal communication) and more recently, sodium cyanide (Johannes and Riepen 1995; Pet *et al*. 2005). As a result, several countries have banned certain types of gear to alleviate problems associated with overfishing (Table 2). Collectively, these gears have resulted in mean size reductions, aggregation loss, altered sex ratios and FSA loss. The justifications for banning certain gear types are to reduce selective fishing (hook-and-line, spear), halt indiscriminant fishing (traps, nets) and reduce habitat degradation (explosives, chemicals).

Perhaps the most destructive fishing gear currently in use for FSA is sodium cyanide, which is widely used by the Southeast Asia-based live reef food fish trade (Richards 1993; Johannes and Riepen 1995; Barber and Pratt 1995; Bentley 1999). Although cyanide is specifically banned from most countries where it has been used, enforcement is limited or ineffective (e.g. Pet *et al*. 2005). Poisons are specifically banned in most countries, including the US and its territories, Australia, Pohnpei, Maldives, Tonga, Vanuatu, Turks and Caicos and Palau, to name but a few.

In addition to cyanide fishing, many countries (US, US territories, Caymans, Cook Islands, Pohnpei, Turks and Caicos, and BVI) have banned the use of spearfishing on SCUBA (i.e. Hawaiian sling, spearguns) and exploding power heads (e.g. US territories, Cayman), either totally or during spawning seasons (e.g. Cayman Islands for Nassau grouper). The primary rationale for banning spears and SCUBA is that fishing with these techniques promotes overharvesting (e.g. Aguilar-Perera and Aguilar-Dàvila 1996) and can be both size selective as well as disruptive toward spawning behavior. For obvious reasons, most countries listed have also banned the use of explosives for extracting fish owing to its non-selective nature and because of the mechanical damage it inflicts on coral habitat.

Requirements:

- Ability to monitor and enforce prohibitions on the sale, possession and use of banned instruments (e.g. spears, explosives, etc.);
- Ability to patrol and monitor fishing areas to inspect catch methods;
- Legal framework to board and inspect boats for illegal gear;
- Strong legal and judicial framework to punish and deter violations.

Pro: The abolition of the use of explosives, poisons, spearguns and powerheads, for example, prevents the potential for overharvesting of both target and non-target species and damage to critical habitat. Fines or sale of confiscated gear and catch can be used to support enforcement and conservation activities. Usually has broad support from the fishing community. Detection of some fishing methods, such as explosives or powerheads, can easily be made upon inspection of catch.

Cons: Usually requires enforcement at the point of catch, which can be costly, depending on the area of jurisdiction. Boarding and inspecting boats is usually required, which may be unpopular in some areas. Illegal fishers are often armed or fitted with powerful motors, which complicates enforcement opportunities. Detection of certain types of gear, such as sodium cyanide, is often a daunting task, since fishers using these methods are well versed in hiding/storing/discarding illegal gears. Detection of fish captured with certain types of gear, such as cyanide, is often difficult away from the point of capture.

Licensing

Licensing can be used to regulate and monitor fishing activities, deter illegal fishing on FSA, and promote effective management and conservation by providing income to resource agencies, both from license fees and fines. In this way, licensing may be considered a ‘delivery mechanism’ to achieve each of the aforementioned management options. For example, for commercial enterprises targeting FSA, such as the LRFFT, licensing can be used to limit the number, size or purpose of fishing vessels, restrict the number of fishers, regulate access to certain areas, and create resource ‘rents’, whereby money from licensing fees goes to conservation and management efforts. Conditions of licensing can also be imposed, such as reporting of catch, gear, effort, etc. to assist management agencies in auditing both fisheries and resources. Although commercial fishing on FSA is strongly discouraged, licensing at least provides potential revenue for enforcement and monitoring of the fishery.

For local small-scale commercial and artisanal FSA fisheries, licensing is somewhat impractical owing to the cost and resource requirements necessary to implement and direct licensing procedures and the wide geographic range over which monitoring and license inspection is required. Nonetheless, several tropical nations require some form of licensing either for fishers, vessels, gears or all of the above. These include the US and its territories, Australia, Turks and Caicos Islands, Vanuatu, Tonga and British Virgin Islands. In Palau, Koror State requires fishing licenses for recreational (non-Palauan) and commercial (Palauan) fishers.

Requirements:

- Ability to monitor and enforce possession-of-license requirements and adherence to conditions at all points of catch, landing and sale;
- Strong institutional cooperation among resource management, enforcement, judiciary and administrative agencies;
- Ability to administer licensing procedures, i.e. issuance, fee scheduling, etc;
- Ability to prosecute violations.

Pros: Potentially provides additional monetary resources to enforcement agencies through license fees and fines, provided licensing fees are sufficient to cover associated costs (e.g. enforcement, distribution, printing, administration, etc.). Provides managing agencies with an additional method to regulate fisheries and provides rationale for making necessary changes to management, such as reducing the number of licensing to limit or maintain a certain level of fishing pressure on stocks. Licensing provisions should also include providing information (data) on the fishery and fish.

Cons: May be difficult to enforce where fishing activities are geographically dispersed. May be politically unpopular even where sufficient awareness of the worth of the program is provided. To be effective, FSA and landing sites (e.g. markets, docks) must be actively monitored and enforced and violations of license requirements must be punishable, requiring substantial resources that are often unavailable to developing island governments.

DISCUSSION

Reef fish spawning aggregations are experiencing dramatic declines in much of their range in both the Indo-Pacific and Western Atlantic/Caribbean regions. The major cause of this decline is commercial overfishing, in centralized, large-scale and decentralized local-scale forms. In particular, these fishing entities concentrate their efforts at and around FSA sites during reproductive periods when fish are most vulnerable to rapid extirpation. From our review and those of others (e.g. Domeier *et al*. 2002; Sadovy *et al*. 2003), it is clear that there is 1) significant and documented world-wide commercial overfishing of FSA, 2) large biological uncertainties in the life histories and spawning dynamics of aggregating fish, 3) important cultural, political and socioeconomic differences and ubiquitous resource shortages amongst nations that affect FSA management success, and 4) common and persistent failures amongst countries to overcome political pressures and short-term decision timeframes in their management of reef fisheries (versus long-term sustainable use). Given these conditions and the inherent biological vulnerability of FSA to fishing, we conclude the best way to conserve FSA is *to close spawning aggregations and reproductive migratory pathways to fishing* in whatever manner suited to local circumstance.

This position is justified by the observed global loss of FSA everywhere that commercial FSA fishing occurs and the overwhelming evidence that most tropical reef FSA are highly susceptible to rapid depletion under all but the lightest fishing pressure (Sadovy 1994; Colin *et al*. 2003; Sadovy *et al*. 2003; Luckhurst 2004; Beets and Friedlander 1998; Hamilton and Kama 2004). As discussed above, the vulnerability of FSA stems from the concentration of substantial portions of the reproductive population in a relatively small, predictable and readily accessible area and over brief periods[17] that make possible the rapid removal of entire adult populations[18]. While the timeframe to extirpation varies among sites and species, our review indicates that the eventual outcome from commercial fishing has generally been the same throughout the Indo-Pacific and Western Atlantic/ Caribbean—population decline, reproductive failure, and ultimately, loss of the FSA (e.g. Table 2). Consequently, we submit that any management decision that allows fishing on FSA, whether commercial or subsistence, will likely result in its decline and eventual demise[19]. We also note here that eliminating FSA fishing will not guarantee the decline or loss of target fish populations if other life history phases are excluded from management (e.g. larval, non-reproductive adult, nursery) or if the FSA protection

[17] Although not thoroughly investigated to date, FSA occurring over short reproductive seasons (e.g. 2-3 months) may be more susceptible to rapid overfishing than those that occur monthly. In addition, species that spawn daily over the entire course of each individual aggregation period (i.e. snappers) may be more resilient to fishing than those that spawn over 1 or 2 days at the end of each reproductive period (i.e. groupers).

[18] While clearly a few FSA have been maintained under light levels of subsistence) fishing (see also Footnote 17), countries experiencing commercial FSA fishing show rapid reproductive population declines within over relatively short periods (e.g. 3-20 yrs), or alternatively population-level changes, such as an imbalance in sex ratio that results in lowered reproductive output. Thus, we maintain that the likelihood of complete FSA loss is high, particularly when fishing is high relative to the size of the FSA and recommend, whenever possible, that FSA fishing be banned.

[19] While we acknowledge that some forms of subsistence fishing have not resulted in substantial negative impacts to some FSA, we also recognize that sustainable subsistence-level fishing often occurs under special circumstances that are increasingly rare. These circumstances include the combination of (1) non-technical transportation and catch methods, such as individual hook-and-line and non-motorized canoes or dugouts; (2) a small number of fishers relative to the number of fish in the FSA; (3) uncompromised FSA (i.e. not previously fished by commercial entities); and 4) fishing that occurs within a subsection of the aggregation period or season.

does not also focus on reproductively active fishes away from spawning sites (e.g. migratory pathways).

As reviewed above, numerous management options are available to protect and manage spawning aggregations. Based on our review and the lessons (failures and successes) of past management that the review has highlighted, we suggest that the strategy most likely to succeed in protecting tropical reef FSA is a *precautionary and data-less management approach that employs a combination of area closures and temporal bans* (catch, possession, sales and export). This insight is a natural outcome derived explicitly from the following issues that arose time and again during the review. First, that FSA decline rapidly under fishing pressure and at time scales (years to decades) faster than that typically necessary to obtain conclusive scientific evidence for management decisions. Second, that political and community will and decision-making processes necessary to protect FSA were usually the first and most crucial step for FSA management, but were often too slow (or did not occur at all) in time to offset the pace of overfishing and FSA loss.

Moreover, following the review, we advocate area closures and temporal bans over other measures for two main reasons. First, we observed that many countries initially tried to institute measures less stringent or comprehensive than full closure and bans (i.e. that enabled at least some, albeit restricted, fishing to continue on FSA, such as quotas or gear restrictions), while reproductive populations continued to decline. Thereafter, most eventually adopted complete FSA fisheries closure, usually following substantial aggregation loss or population decline. Second, it became evident that, in contrast to management actions that allowed limited FSA fishing, area closures and temporal bans have been relatively successful in the areas where they have been adopted for tropical FSA (e.g. Beets and Friedlander 1998; Burton *et al*. 2005). Our review also clearly highlighted the current lack of, and serious need, for additional scientific case studies that demonstrate the potentially positive benefits of area closures and temporal bans for FSA (as well as a systematic scientific investigation of the negative consequences of the LRFFT). Nevertheless, where other types of described management options have been used (e.g. US and US territories), management failures have consistently ensued, resulting in the eventual institution of complete catch bans, usually following commercial extinction for some species (e.g. Nassau and goliath grouper) or large-scale population declines (e.g. Sadovy and Eklund 1999; Coleman *et al*. 2000; Sala *et al*. 2001).

Analysis from the review also reiterated the importance of several critical factors that must accompany a proactive and precautionary strategy that relies on area closures and temporal bans: (1) managers must have a firm and complete understanding of the reproductive season of each of the specific FSA species, (2) site-based scientific and community monitoring and data analysis is necessary to track management success (important for community support) or highlight the need for changes and improvements and (3) strong, active enforcement (whether by the community or political institution) is requisite.

PRECAUTIONARY, DATA-LESS AND COMMUNITY CO-MANAGEMENT

No less than a paradigm shift in fisheries decision-making and management must take place in the new century. It is a time in which the oceans are no longer viewed as inexhaustible and prolific but rather as finite resources that have essentially reached near to full fishing capacity. This sea change in thinking and action is equally important for the perpetuation of tropical reef FSAs. While we still have a lot to learn in terms of their biology and dynamics, current circumstances are outpacing the ability of scientists to provide detailed biological data for FSA in time for deliberate policy and decision-making. Population growth coupled with sophisticated technology and opportunistic and dynamic fishing entities ensure that demand for tropical reef fish is quickly outstripping supply (e.g. Warren-Rhodes *et al*. 2003). This reality necessitates that the choice to protect FSA must come before, not after, the availability of sufficient scientific data.

As we have described in this review, the rapidity of past and current loss and decline of FSA is likely accelerating for the above reasons, and the solution requires that communities and governments make a concerted decision to protect FSAs as an insurance policy in the absence of irrefutable FSA-specific scientific or economic data. We and other authors strongly support the adoption of an immediate, precautionary and data-less management approach, in lieu of traditional data-dependent fisheries management, whereby all fishing on FSA and FSA-associated species during their respective spawning seasons is eliminated entirely (Johannes 1998; Sadovy *et al*. 2003; Luckhurst 2004; Sadovy and Domeier 2005).

It should be noted that the time factor is not essential to our argument. It is evident from our review of past experience, that even when managers are armed with strong scientific evidence for the decline of FSA from overfishing, and for the need for particular management choices—which usually took years-to-decades of scientific analysis or the collapse of a fishery (red hind, Nassau grouper, goliath grouper, red snapper, etc.) and hindsight to observe—this data was not necessary for, and may only be marginally more helpful in deciding to conserve FSA and/or the selection of particular management protocols (e.g. Palau, Johannes 1998). Indeed, we still arrive at the same place: that individuals, communities and governments must accept the unpalatable fact that fishing effort must be curtailed, and in the case of FSA, eliminated. Awaiting the complete scientific picture just delays this inevitability, usually accompanied by the loss of FSA and substantial population declines.

POLITICAL AND COMMUNITY WILL

One fundamental condition underpinning the successful protection of FSA in several case study countries and a necessity for the adoption of the precautionary, data-less management approach, is a recognition by critical stakeholders, be they tribal elders, elected legislators, or fishermen themselves, of the need for FSA management and the responsibility and authority to actively participate in all phases of the decision-making, management design and implementation process. In our review, we observed that a key and perpetual problem that explained the declines and losses of FSA, irrespective of location, was the denial of reality and lack of political or community will to place the long-term needs of management of a community or state resource—reproducing fish—over the short-term gains of an individual (whether a fisher or elected official).

Perhaps the most classic case is of the Nassau grouper in the Caribbean. For decades and across nearly 15 countries, scientists studied, documented and warned of the decline of Nassau grouper FSAs in response to commercial aggregation fishing (Sadovy 1993; Sadovy and Eklund 1999). Yet, the typical reaction by fishing entities of Nassau grouper (and currently for other FSA-forming species) was to deny, ignore or marginalize scientific findings and continue to target FSA. In contrast, in some countries, managers, fishers, or both, recognized the need for change and instituted limited regulation, such as short-term seasonal closures or bag and size limits. This was by far the exception to the rule. The final outcome in the Nassau grouper case is incontrovertible: from the 1970s to 1990s the majority of Nassau grouper FSAs experienced declines or disappeared altogether, such that by 1996 they were commercially extinct throughout the Caribbean and listed on the IUCN Red list (Hunter and Mace 1996). While perhaps too little too late, complete fishery bans for the species have now been instituted in many Caribbean locations, including the Gulf of Mexico and South Atlantic, with some showing signs of recovery (Table 3) (The Nature Conservancy unpublished data).

In the above scenario, fisheries authorities, legislatures, political officials, scientists, fishers and fishing lobbyists all share blame for the commercial extinction of Nassau grouper in many areas of the Caribbean. In other instances, it is the failure of community or tribal leaders, and those advising them, to recognize the problem and take action. In many areas, fishing rights and prerogatives are held by a small, but vociferous and sometimes defiant, group of individuals. When these minorities are allowed to dictate management and survival of FSA for the entire country and future generations, this speaks to a failure at the community and government authority levels to recognize the problem, which may speak to education by scientists and fisheries managers, and/or to take political responsibility and provide leadership in managing the problem. In sum, what the cases and lessons highlight is that until political and/or community will is engaged in the desire, and integrated in the design and management process, to protect FSA resources, countries are doomed to repeat the management mistakes of the past, which have led to the current declines and losses of FSA in virtually all countries in the Caribbean/western Atlantic and Indo-Pacific regions.

FSA AREA CLOSURES AND TEMPORAL BANS AND WHY LESS COMPREHENSIVE MEASURES TYPICALLY DON'T WORK

Another lesson readily apparent from our review is that, while a multitude of options other than area closures and temporal bans exist, these have seldom been sufficient in their own right to stem FSA declines or losses. For those agencies advocating less comprehensive measures that fall short of permanent elimination of fishing on FSAs (gear restrictions, size limits), a review of Nassau grouper, lane snapper (Lutjanus griseus) or red hind management history in the Caribbean or LRFFT in SE Asia is instructive. In these cases, the typical scenario was initial management through less restrictive measures, such as a size limit, gear restriction, or incomplete seasonal closures. In each case, new and more prohibitive measures were subsequently added, with limited-to-no recovery achieved (Luckhurst 1996; but see Beets and Friedlander 1998). In all cases, permanent closure were eventually advocated and adopted, but only after severe fisheries declines and, in some cases, FSA loss.

FSA MANAGEMENT EXISTS WITHIN A TOTAL MANAGEMENT FRAMEWORK

Our recommended FSA management strategy does not exist within a management vacuum. It is a self-defeating cause to protect FSA during spawning periods if, for example, an equal or greater proportion of the stock is then removed during non-reproductive periods (Horwood *et al*. 1998; Burton, 1998). Thus, FSA options should be adopted in combination with other fisheries management and effort reduction measures, including the identification and protection of recruitment and nursery habitat. We recognize that FSA are a critical life history phase that must be totally protected, as a minimum, to maintain populations. However, in the event that other stages in life history are not considered and protected, FSA persistence is not assured. Closure "may be valuable but must be viewed just part of an overall, multifaceted conservation plan which should be implemented in a complex, multi-species fishery" (Beets and Friedlander 1998).

WHAT ARE SOME OF THE ISSUES WITH MANAGEMENT OF FSA?

For tropical coral reef FSA, the effectiveness of any management option must be tightly linked to the economic and cultural circumstances under which the protocols are instituted (Munro 1996; Ruddle 1996). Indeed, protecting FSA will likely depend on an innovative approach of combined management protocols and co-management, as reviewed above, agreements among local, regional and national agencies for implementation, monitoring and enforcement (Ruddle *et al*. 1992; Adams 1996; Munro 1996). Moreover, for most developing island nations, long-term technical and financial commitments from donor and non-governmental organizations will be required for FSA protection to be effective. From our review, we see several main issues related to the successful management of FSA and conditions that must exist for all, and for each specific, option to be applicable in tropical developing countries. Where those conditions do not exist, difficulties in providing effective management protection of FSA, particularly from a top-down perspective, will be great.

Another issue critical to the success of FSA area closures and temporal bans is enforcement, whether it originates within the community, official government authority, or both[20]. In the tropical developing world, practically all government agencies tasked with protecting marine resources over vast areas of ocean face great economic and logistic difficulties. In addition, most communities within developing nations are highly dependent on fishing for both food and income, such that the enactment of any regulation banning or limiting catch will be politically distasteful. For these reasons, many national governments choose to do nothing to reduce the risk of conflict, economic hardship and loss of power. To reduce the burdens on government, one alternative is co-management or shared management,

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[20] Here, enforcement refers to enforcement authority, legal framework(s), enforcement capacity and willingness, and any other associated legal administrative entities common to the site, state or region.

whereby national governments share responsibility or provide management advice to local communities, which otherwise conduct all forms of management. Such a system has the potential to reduce community and national government conflicts and allow communities authority to protect the resources on which they are most dependent. To ensure co-management operates effectively in protecting FSA and to guarantee communities know why management is important, educational awareness is key.

As one example, co-management of FSA resources is currently being practiced in Belize, where several non-government community-level organizations (NGO) patrol the 11 FSA-based marine reserves within the state. These efforts followed several years of stepwise negotiations between non-government, government and community members prior to its implementation. Enforcement for any of the sites is still incomplete and poaching has continued for at least one site as a result. In short, co-management, while a viable option to improve FSA protection, is a complex, challenging and often lengthy process.

In addition to co-management protection of FSA, some additional methods of reducing fishing pressure may be brought about by providing and promoting alternative livelihoods to fishing the local environment. Currently, the tourism industry is the largest and fastest growing industry worldwide. While every nation has different potential to create and sustain tourism, many options still exist, such as dive tourism, recreational fishing, research assistance and entertainment. In Belize and Palau, for instance, vocational alternatives, such as dive guiding, fly fishing, boat captaining, and even assisting scientists in marine research have helped reduce fishing impacts in these countries. However, in many areas, there is currently no basis and no infrastructure to facilitate the alternatives listed and in those places (e.g. Melanesia) where alternatives have been tried in the past, none have had long-term success (e.g. Foale 2001). Nonetheless, other non-destructive[21] vocational alternatives should be explored to assist fishers displaced by restricted or eliminated fishing on FSA by management, even though the scale of the vocational shift is unlikely to equal the number of fishers displaced by new management regimes. However, where feasible, these options should be pursued, which tend to bring a greater sense of awareness and responsibility to reefs and resources.

CONCLUSIONS

The targeting and overfishing of tropical reef fish spawning aggregations is not a new phenomenon. Craig (1968) described this practice by Belizean fishermen for Nassau grouper at Caye Glory nearly 40 years ago. At the time, Craig warned of the potential for the loss of the aggregation at the heavy fishing levels the FSA was then experiencing. At the time of Craig's report the Caye Glory FSA hosted more than 10,000 individuals and a catch of 1,200-1,800 Nassau grouper per boat per spawning season (~3 months). By 2000, the Caye Glory aggregation had dwindled to only a handful of individuals and was considered commercially extinct (fishers captured nine fish during the 2001 spawning season). A similar, repetitious and unnecessary picture is painted for FSA in virtually all countries in the Caribbean countries, as well as innumerable ones in the Indo-Pacific, for a number of FSA-forming species. Nonetheless, few countries affected by FSA overfishing have recognized the potential for FSA loss and taken the actions we deem necessary for their persistence—a total FSA fisheries closure.

In contrast, the decline and commercial extinction of grouper FSAs has prompted some locales, notably Belize and Palau, to recognize the importance of FSA protection and has spurred legislative and management action. These changes, however, have not come about overnight, but through the long-term process of (1) recognition of failed management and resource declines, (2) educational awareness and training, and (3) the promotion of eco-tourism. And while there is still room for improvement in terms of enforcement, the Belize government, together with local fishing communities

[21] We use non-destructive, as many fishers (displaced otherwise) often switch to logging or mining in many areas of the Indo-Pacific as a more lucrative vocational alternative, which we consider destructive.

and non-government organizations, summoned the political will in 2003 to close 11 of 13 known spawning aggregation sites to fishing with regular monitoring of both fished and unfished sites (Case Study 8). Years before this action, Palau had supplied meaningful FSA protection at the local and state level in recognition of FSA vulnerability to loss (Case Study 7). It is hoped that other countries will follow suit in their own way and that cases like Belize or Palau become the rule rather than the exception for tropical reef management, and a blueprint for future success in marine resource and FSA protection.

While the opportunity cost of FSA decline in terms of lost eco-tourism potential and revenues is readily apparent for countries such as Belize and Palau, the economic worth and potential monetary loss from FSA overfishing is also high for those countries not heavily dependent (at least currently) on tourism. Although the reported worth of the LRFFT is $810 million over the entire Indo-Pacific, and that of fish exports from the Caribbean $1.9 billion (including crustaceans and highly migratory species) (Bryant *et al*. 1998), the current and long-term economic cost to the world's coastal regions dependent on reef fishes from FSA loss and declines is likely far greater. Reef fisheries constitute the basis of local and regional industry in coastal areas and are the primary protein source for the millions of coastal villages lining the world's oceans. For example, reef fish supply 10-25 % of the fish protein to coastal Southeast Asians and constitute the entire protein source for many nearby communities (Ruddle 1996). In other areas of Southeast Asia as much as 25 % of the national fish catch comes from coastal reefs (McManus 1988). These small-scale industries also contribute substantially to the annual local income and employment of coastal villagers who are increasingly reliant on the global cash economy (Munro1996). Since FSA are the primary source of new recruits to reef ecosystems and because many of the species forming FSA are top predators, their persistence helps maintain stability to both the ecosystem and to fishing communities that depend upon them. In other regions FSA and FSA species are an integral part of the growing and economically prosperous dive industry that also fuels vocational alternatives to fishing in some areas. Indeed, recent estimates have shown a single live grouper to be 20 times more valuable alive than dead from an eco-tourism perspective (Sala *et al*. 2001). This figure is likely to climb substantially in the future, as top predators, large fish and pristine reefs become increasingly scarce, and thus in greater demand. Clearly, the protection of FSA for long-term socioeconomic health far outweighs the short-term monetary gains from heavy exploitation of these resources.

In this review, we have presented clear evidence of the global fragility of FSA to fishing. We have also presented several management options, along with eight case studies that highlight where and how some of these management options are being used. In each of these cases, however, overfishing of FSA is ongoing because these (and other) countries have failed to provide what we consider to be the only viable option to prevent population declines and FSA loss—a comprehensive fisheries management plan that permanently excludes fishing on reproductively active fishes at FSA and along reproductive migratory pathways. And, while we recognize the impracticalities of this recommendation in some locales, we also suggest that anything short of this action has the potential to result in the undesirable reduction in fish population abundance and the demise of the FSA. Therefore, we urge all countries currently practicing or considering FSA to fishing to implement the precautionary principle in managing FSA fishing in light of past FSA fishing examples and fully protect FSA with whatever means are locally feasible.

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Table 1: Reported Status of Some Key FSA-forming Species

Location	Species	Fishing effects
Antilles	Nassau grouper	Declines (~20y)[1]
Australia	*Plectropomus leopardus*	Declines
Bahamas	Nassau grouper	Declines of FSA[1]
Belize	Goliath grouper Nassau grouper Red Hind Snappers	Declines[1] FSA loss[4] and Declines (50% from late 1970s to 1980s)[1] Declines (anecdotal) Declines (anecdotal)
Bermuda	All grouper Nassau grouper Black grouper Red Hind Snappers	Declines from 205 to 58 t (1975 to 1982); several important species commercially extinct (CE)[2] FSA loss1;CE (~10-40 y)[2,5]; Declines from 33 to 1 ton (1975 to 1981) and no recovery to 1993; no FSA remain by 1990s.[2] Declines from 39 to 6 t (1975 to 1982)[2] Past declines, current status unknown[5] Collapse in fishery[2] (red)
Cayman Islands	Nassau grouper	FSA loss, Declines[11]
Cuba	Nassau grouper Black grouper Yellowfin grouper Snappers	Decline and loss of FSA (From 21 FSA in 1884 to 1 by 1997; from 2000 t per yr (1960s) to <100 t per yr (1990s)[1, 6, 21] Declines[6] Declines[6]–catastrophic overfishing (lane)[6] Declines[6] (mutton, cubera, dog, gray)
Dominican Republic	Nassau grouper	Declines, possible FSA loss[1]
Honduras	Nassau grouper	Declines (1 FSA from 20,000 to 500 fish from 1988 to 1991)[1] or CE[10]
Indonesia	Commercial grouper	Declines[18], likely FSA loss[22]
Jamaica	Nassau grouper	Unknown, but presumed FSA loss, declines
Mexico	Goliath grouper Nassau grouper	Unknown Declines, CE and loss of FSA (Yucatan): fished since 1920s, 1950s 24t/y by 1988-1992 2-4t and by 1997 <100 kg[3]
Micronesia	Commercial grouper	Declines, FSA loss[17]
Palau	Commercial grouper	Declines19,20, FSA loss[19]
Papua New Guinea	Commercial groupers	Declines, FSA loss[16]
Puerto Rico	Nassau grouper Tiger grouper Red Hind Snappers	CE (~20+y), no FSA remain[1] Declines[14] Declines[14] Declines (mutton)[15]
Solomon Islands	Commercial grouper	Declines, some dramatic[16]
US	Goliath grouper Nassau grouper Black grouper Gag grouper Scamp Yellowedge grouper Snappers	CE; FSA loss[1] CE[1] Declines[7] Declines[9, 23]; FSA loss; Sex ratio imbalance[9] Declines; FSA loss[23] Declines[24] Declines[8] (mutton)
USVI	Nassau grouper Red hind	CE; FSA loss (~20+y, no known FSA remain)[1,12, 13] Declines (late 1980s)[13]

[1] Sadovy and Eklund, 1999; [2] Butler *et al*., 1993; [3] Aguilar-Perera and Davis, 1996; [4] Sala *et al*. 1991; [5] Luckhurst 1996; [6] Claro and Lindeman, 2003; [7] Eklund *et al*. 2000; [8] Lindeman *et al*. 2000; [9] Coleman *et al* 1996; [10] Fine, 1992; [11] Bush *et al*. in review; [12] Olsen and Laplace 1976; [13]Beets and Friedlander 1992; [14] Matos-Caraballo 1997; [15] Garcia-Moliner 2000; [16] Hamilton and Smith 2005; [17] Rhodes and Sadovy 2002; [18] Pet *et al*. 2005; [19] Johannes *et al*. 1999; [20] Graham 2001; [21] Sadovy and Domeier 2005; [22] Sadovy and Liu 2004; [23]Koenig *et al*. 2000; [24]Cass-Calay and Bahnick 2002

Table 2: Overview of FSA Management Options

(YR = year-round)

Management Option	Description	Scientific justification	Strengths	Weaknesses	Where Adopted?
Area closure (marine reserve as no-take zone), permanent (year-round and long-term) or temporary (seasonal and/or short-term)	Close off spawning areas and migration routes to fishing (at a minimum) during spawning season	• Maintains/allows increases in spawning biomass • Aids in maximizing reproductive output • Prevents selective fishing • Protects habitat Helps maintain biodiversity	• Requires closure only during spawning season • If closure area is near local community, potential for co-management or local enforcement	• Requires data on location and spatial extent of FSA and migration routes • FSAs may be too numerous or widespread to protect all FSA • Area to be closed may be too large/remote for effective monitoring/enforcement • 24-hr or random monitoring necessary, since poaching often at night • Potentially costly to maintain and enforce	US (mutton snapper; Sadovy 1994), Pohnpei (two YR marine reserve), Palau (5 spp. grouper); Belize (eleven YR marine reserves), Puerto Rico (three marine reserves), Komodo, Indonesia (several multi-use marine reserves), Papua New Guinea (3 spp. grouper), Solomon Islands (one YR marine reserve); USVI (1 YR, 1 seasonal marine reserve); Bahamas (1 site)

Management Option	Description	Scientific justification	Strengths	Weaknesses	Where Adopted?
Seasonal Closures	Prevents capture, sale, possession or export of fish during spawning season Includes: • catch bans-prevent catch during reproductive seasons • possession ban- cannot possess fish at any period during closure • Export ban- no export of FSA fish during reproductive season • Sales ban- no sale or trade of fish during reproductive season	Prevents exploitation of FSA during their most vulnerable period—migration to, from and during spawning • Maintain/maximize spawning stock biomass and reproductive output • Assist in population recovery or maintenance	• Requires closure only during spawning season • Applicable to LRFFT since can't possess fish in pens, restaurants, or any link in distribution chain during closed period • Fishers can't evade closure by poaching at night • Potentially may require fewer personnel and less costly	• Requires species-specific reproductive data, which can be complex and variable • Markets may be dispersed and difficult to monitor and enforce • May shift pressure to other species during closure period • Opposition from fishers and other user groups from reduced income during closure • Require cooperation from wider user groups	Palau (5 spp. grouper), Pohnpei (3 spp. grouper), USVI (red hind); Puerto Rico (3 FSA sites-red hind, mutton snapper); Bahamas (3 sites permanent + Nassau grouper spawning season)
Customary Marine Tenure	Local community ownership, management and enforcement of FSA	• Provides varying levels of protection to FSA and reproductively active fish(es) for stock maintenance and maximizing reproductive output	• Provides clear incentives and ownership of fisheries resources; avoids tragedy of the commons • Removes pressure from overextended marine resources agencies	• Local communities may not have sufficient authority and resources to undertake responsibilities of marine tenure, especially enforcement • Set stage for local user conflicts May require outside monitoring to ensure population maintenance	Palau, Micronesia, Papua New Guinea, Solomon Islands

Management Option	Description	Scientific justification	Strengths	Weaknesses	Where Adopted?
Quotas (also bag limits)	Sets the total number or volume of fish that can be caught from a population or stock (i.e. reproductive population or FSA)	• Works to maintain or grow population size under specified levels of fishing	• Potentially reduces conflict by allowing certain levels of fishing on FSA When combined with other measures, such as size limits, can help maintain population size with a specified size structure relevant to reproductive output	• Limited/insufficient knowledge of the biology and population or stock size—i.e., the very basis for the quota itself is difficult to obtain accurately • Enforcement and monitoring must occur at all points of catch and sale, which may be numerous and remote • Above issues make quotas especially resource intensive • Poaching renders quotas ineffective • Stock levels vary (e.g., with season) and are difficult to predict; thus there is a high potential for overfishing	US (Nassau; all groupers)-GMFMC 1989 (now replaced by other more restrictive measures); Puerto Rico (yellowtail snapper)
Size limits	Limits size at which fish can be caught	• Ensure individuals reach a minimum size to ensure reproduction for a minimum of 1 one year prior to catch or, alternatively for sex changing species, works to maintain a certain male-to-female sex ratio	• Works to ensure a certain minimum level of reproductive output and population size structure	• Lack of data to determine appropriate size for most species over most locales • Requires enforcement at landing or market • Opposition by recreational or commercial fishing lobbies • Impractical for deep sea fishes (barotrauma-induced mortality)	US (recreational and commercial-e.g. yellowtail snapper); Australia (recreational and commercial): numerous species

Management Option	Description	Scientific justification	Strengths	Weaknesses	Where Adopted?
Gear restrictions	Specifies the type of gear to be used or restricted for capture or one or a number of species	• Maintain sex ratios, size and spawning stock biomass by reducing selectivity and reduces fishing mortality for certain gears	• Reduces overfishing by limiting catchability • Controls selectivity (size, number and sex of fish to be captured) and reduces by-catch • Habitat protection may also be a benefit when fish pots, traps, nets, chemicals or explosives are excluded	• Requires on-site monitoring and enforcement • Biological and other data on historical impacts of the method are necessary	Spear-fishing (on SCUBA)-Mexico, Belize, Pohnpei, Micronesia, Palau, Cayman Islands; all- British Virgin Islands; fish pots (Puerto Rico, Bermuda), chemicals and explosives(Palau, Pohnpei; Puerto Rico, USVI); minimum mesh size (USVI, Puerto Rico for muttons snapper)
Species bans	Bans catch, possession, sale or export of a species	Eliminates fishing mortality for the species of concern, usually for purposes of recovery from overfishing	Provides total protection for a vulnerable or endangered species	Requires fish to be identifiable (not filleted) and monitoring and enforcement at all points of sale, catch or possession	Puerto Rico, USVI, and US (Nassau grouper, Goliath grouper)
Access Permits	Issues fishing permits to fish specified numbers, species or volumes of fish in specified areas by a specified number of vessels or fishers	Limits user access to FSA, which reduces fishing pressure for stock size maintenance	• Reduces potential for user conflict • Provides for some level of self-enforcement against poaching • Establishes rules and method for monitoring and enforcing fisheries regulations • Familiar and established commercial fisheries management tool, which may facilitate its application to FSA	• Still allows fishing on aggregations, with the potential for overfishing • Data intensive, since requires knowledge of stock size and variability (since number of permits based on stock size) • Requires biology data, since this affects population size • Labor intensive, since requires site enforcement	

Table 3: Management Options Implemented for FSA or Aggregating Species in Selected Countries

Dates refer to date of law enactment
*Indicates a national fisheries policy that specifically includes FSA protection and management

	MPA	**Temporal or Seasonal Closure**	**Gear Restriction**	**Quotas**	**Size Limits**	**Species Ban**	**CMT or Local Management**	**Other Fishing ban, licensing, Alternative Livelihoods**
Antilles			Spearfishing, groupers					
Australia*	No specific FSA-related MPAs; some unintentional FSA coverage	Recreational fishing- 3 nine-day periods around new moon in spawning season for several coral reef species; W. Australia- seasonal catch ban, 1 labrid sp.	Destructive fishing practices ban; Ban on explosive spear heads and spearfishing on SCUBA	Recreational bag limits for serranids and tropical snappers in W. Australia	Capture size limits for some grouper species (e.g., coral trout; giant G., potato cod), tropical snappers, carangids, emperors, and labrids	Humphead wrasse, potato cod, humpback G. and giant G.	None	Licensing- required to sell or capture any fish (commercial or recreational); Landing requirements: fillet fish with skin and scales attached for recreational fishers
Bahamas*	One Nassau grouper FSA site	Nassau G. (2003)	Spearfishing on SCUBA; spearguns		Groupers (1986); All groupers and rockfish (1989)			
Belize*	Permanent closure of 11 of 13 known FSA, all country (groupers and snappers, 2002)	Nassau G. (Glover's reef, now permanent, see MPA 2002)				Nassau G.- fishery (2003)		Promotion of young fishermen switch to tourism-related jobs (dive, tour)

	MPA	Temporal or Seasonal Closure	Gear Restriction	Quotas	Size Limits	Species Ban	CMT or Local Management	Other Fishing ban, licensing, Alternative Livelihoods
Bermuda*	29 no-take marine reserves focusing on dive sites, some possible indirect FSA benefits	For 3 red hind FSA (1974, 1990)	Fish pots for groupers (1990); coastal spearfishing ban (≤ 1 mile from shore)	Red hind seasonal quota; black G: 1 per day; 30 silk snapper bag limit; 10 red hind per day	Minimum size: red hind, black, tiger and yellowmouth G. vermillion and silk snapper (1996)	No take, no possession for 6 spp. of grouper: Nassau, gag, red grouper, deer, green and mutton hamlet and tiger rockfish (1996)		
Cayman Islands*	FSA-based marine reserves with buffer zone	Nassau G. - Alternate year fishing strategy for 9 yrs.	No traps Nov. to Mar. within marine reserves or buffer zones; no traps, nets or spears on FSA	Nassau G. – bag limit during fishing years	12 in. minimum for Nassau grouper	goliath G.; Nassau G.- limited to residents and hook and line		Licensing proposed for entering marine reserves
Cuba			Nassau G.- Increase in trap mesh size	Nassau G. (mid 1980s)				
Dominican Republic	FSA protection (north coast)	Nassau-no catch or sale of ripe females in spawning season (mid-1980s)						
Fiji			Ban on use of explosives and cyanide, some limits on mesh size for nets and fences		For 19 spp. of reef fish (includes: 25 cm-grouper; 30 cm snapper, unicornfish)		Can override federal fisheries regulations to allow live reef fish operations	

	MPA	Temporal or Seasonal Closure	Gear Restriction	Quotas	Size Limits	Species Ban	CMT or Local Management	Other Fishing ban, licensing, Alternative Livelihoods
Indonesia*	MPA for groupers and humphead wrasse FSA (2001); zoning for various access to resources	Seasonal no fishing of humphead wrasse, Komodo National Park (2001)	Ban on destructive fishing		Size limits on humphead wrasse			Licensing requirements for LRFFT
Maldives				Export volume limits				
Mexico	None	None	Nassau G.-speargun ban (1993), gillnet or spearfishing on FSA at Mahahual (1995)					
Micronesia*	Permanent marine reserves (2); others proposed	Pohnpei-seasonal sales ban (March-April)	Destructive fishing practices ban; no take on SCUBA					
Palau*	Seasonal and permanent marine reserves	Seasonal sales and catch ban during part of spawning season	Destructive fishing practices ban		25 in. minimum for subsistence catch, possession or sale of humphead wrasse	Export ban for humphead wrasse	CMT of some FSA sites	Licensing for recreational and some local fishing
Papua New Guinea	Temporary marine reserves to increase harvest potential	Seasonal closures for FSA during spawning season	Destructive fishing restrictions	Catch	Size limits; 65 cm min. catch size, humphead wrasse		Traditional management of multi-species FSA	Export restrictions for humphead wrasse; licensing for export

	MPA	**Temporal or Seasonal Closure**	**Gear Restriction**	**Quotas**	**Size Limits**	**Species Ban**	**CMT or Local Management**	**Other Fishing ban, licensing, Alternative Livelihoods**
Philippines	Sumilon Island (1974); Apo Island (~1982, formally 1985); no FSA-specific MPAs		Apo Island, Ban on all destructive fishing methods (small-mesh nets, poisons, explosives; 1986)		Some size limits (can be circumvented in Palawan where juveniles may be captured for grow out)		Apo Island, strong protection and enforcement by local marine-management committee	Apo Island, Ban on fishing by non-residents (1986);
Puerto Rico*		For 3 red hind FSA sites (1995)	Explosives, chemicals, fish pots			Nassau G. (moratorium, 1990); Goliath grouper; *E. guttatus*-fishery (1995)		
Seychelles*	Consultations ongoing on area closures	Consultations ongoing on seasonal catch and sales ban	Ban on destructive fishing practices	Consultations ongoing on effort reduction mechanisms	None	None	None	Export volume controls for the LRFFT
Solomon Islands	Permanent marine reserves	None	Destructive fishing practices ban	None	None	None	Proposed for a number of FSA	License and export controls
US*	Permanent closure at 1 site (Multiple species of snappers (2001)	Snapper (mutton, 1998-2001, then permanent see MPA); recreational closure Gulf of Mexico 1 Nov-31 Dec.		Gulf of Mexico: Red grouper- 1 indiv.) aggregate grouper-3 indiv.; 7,500 lb. trip limit for commercial vessels	Nassau G.-Gulf of Mexico 510 TL (1989)	Nassau G.-fishery (1990, US Atlantic and Caribbean, 1997 Gulf of Mexico); Goliath G.-fishery (1990)	None	None

	MPA	**Temporal or Seasonal Closure**	**Gear Restriction**	**Quotas**	**Size Limits**	**Species Ban**	**CMT or Local Management**	**Other Fishing ban, licensing, Alternative Livelihoods**
USVI*	Hind Bank Marine Conservation District for red hind (permanent)	Red hind (2 seasonal), yellowfin grouper (1 seasonal) and mutton snapper (1 seasonal) on FSAs (1990)	Explosives, chemicals			Goliath and Nassau grouper		

APPENDICES

APPENDIX 1: CASE STUDIES

Case Study 1: US Virgin Islands: The red hind marine reserve of St. Thomas

Similar to many other Caribbean countries, Nassau grouper dominated commercial catch in the US Virgin Islands (USVI) during the latter half of the 20th century, with the common result of aggregation loss. In the USVI, the only known Nassau grouper spawning aggregation site was lost to overfishing in the 1970s and was also a known and fished red hind FSA[22]. Following the loss of two red hind spawning aggregations near St. Thomas and St. Croix and fearful that other FSA would be lost to overfishing, a marine reserve at a site south of St. Thomas was established in 1990. The reserve was established following detailed reports of skewed sex ratios (15 female to 1 male), decreases in mean size (295 mm), declining populations and declining catch (Beets and Friedlander 1992). Following protection from fishing from 1990-1997, an analysis of red hind at the site showed a 100 mm increase in length, a normalized sex ratio of 4 female to 1 male and an increase in overall aggregation abundance (Beets and Friedlander 1998). Currently, a 14 square mile permanent marine area (Hind Bank Marine Conservation District, St. Thomas) and a seasonal 3.5 square mile closure (1 December to 28 February) exist for red hind in the USVI to protect FSA of this species. An additional 2.5 square mile marine reserve exists for mutton snapper in St. Croix between 1 March and 30 June.

Case Study 2: Kehpara Marine Sanctuary, Pohnpei, Micronesia

Following a perceived decline in the number and size of finfish in the waters surrounding his land and apparent poaching by locals, a Pohnpeian landowner approached the Pohnpei State Government about instituting a marine sanctuary (i.e. marine reserve) to protect remaining stocks. A portion of the area requested to be placed under sanctuary status was also a known, historically important spawning aggregation site for three species of epinepheline grouper, although the spatial dimensions and temporal occurrence of these aggregations were unclear. Following the landowner request, in 1998, the Pohnpei State Government began the process of forming a sanctuary (Kehpara Marine Sanctuary, or KMS) in the immediate area of the FSA, later authorized under the State Sanctuary Act of 1999. However, unbeknownst to the state or the landowner, the boundaries of the sanctuary fell short of protecting two of the three species that formed FSA adjacent to the closed area. Instead, the sanctuary seemed to have the unintended effect of promoting overfishing on the FSA since the northern sanctuary boundary also acted as a marker for the unprotected aggregations that fell outside the KMS. As a result, one of the two unprotected aggregations experienced the removal of 20-30 % of the total FSA monthly abundance during a 7-day period (Rhodes 1999). Following a scientific survey in 1998 and 1999, the spatial dimensions of the aggregations were determined and an emergency declaration by the governor provided a redraft of the sanctuary boundaries to include the previously unprotected FSA, including a buffer zone. Recent research has indicated that the sanctuary may not yet provide the necessary protection for reproductively active fishes away from the FSA site (i.e. along migratory pathways and between spawning periods), such that boundaries may again need to be re-drawn.

Case Study 3: Micronesia—Pohnpei Sales, Possession and Catch Ban

In 1995, the Pohnpei State Government instituted a sales, possession and catch ban for grouper (Serranidae) to help prevent overfishing during the spawning season. The sales ban covered the period from 1 March to 31 April that roughly coincides with the spawning season for camouflage grouper, *Epinephelus polyphekadion*). However, although markets were centralized to allow active enforcement, the effectiveness of the ban was compromised by (1) variability in the spawning season of the camouflage grouper[23] and (2) protracted spawning seasons for two other prominent aggregating

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[22] Numerous FSA sites worldwide are multi-species in nature, entertaining up to 20-25 aggregating species within the year.

[23] The spawning season for camouflage grouper varies in Pohnpei from February-March to March-April in some years.

species, the squaretail coralgrouper, *Plectropomus areolatus*, and the brown-marbled grouper, *E. fuscoguttatus*[24]. Although Pohnpei has placed an enforced area closure on the main FSA site for these species (i.e. KMS, Case Study 2), fishing on target species outside the temporal closure period and perhaps at other known, but currently unprotected, FSA sites is ongoing. Since the overlapping spawning seasons for the three species includes the period from approximately 1 January to 30 June, a 6-month spawning season closure would ensure total protection for known grouper FSA in Pohnpei and provide protection for known and unknown-and likely fished—FSA.

Case study 4: US Size Limits on the Nassau grouper, *Epinephelus striatus*

The US is one among many nations that have attempted to use size limits to control the decline in abundance and mean size of an FSA-forming species. Owing to perceived declines in the spawning stock biomass per recruit (SSBR), the US South Atlantic Fisheries Management Council (SAFMC) in 1983 issued a 305 mm (12 inch) size limit, based on yield-per-recruit data from the congeneric red grouper, (*Epinephelus morio*). A similar size limit was implemented for the species in 1985 by the Caribbean Fisheries Management Council (CFMC) and in 1989, the Gulf of Mexico Fisheries Management Council followed suit with a 510 mm (20 in total length, TL) size limit on catch. Current evidence shows that most male and female Nassau grouper mature by about 500 mm TL, far beyond what was initially recommended by the CFMC or SAFMC. Surveys at the time of the initial CFMC recommendation showed a full 31 % of Nassau catch at less than approximately 300 mm TL and almost all less than 600 mm TL. Although the size limits of Nassau were increased annually in the US Caribbean by 1 inch (25.4 mm) per year through the mid-1990s, by 1990, the failure of these and other management policies (e.g. mesh size increases, TAC) toward Nassau grouper catalyzed the US Caribbean territories to issue a complete catch moratorium, in part owing to the commercial extinction of the fish in surrounding waters. These actions were followed by a similar catch moratorium in the US Atlantic in 1991 and the Gulf of Mexico in 1997. In 1996, the species came to be listed as a candidate on the US Endangered Species List and was placed in the IUCN Redlist (Hudson and Mace 1996). The case study clearly shows both the vulnerability of some FSA-forming species to overfishing and the consequences of a slow and improper management response. Currently, Nassau grouper fishing during all life history stages is prohibited in US and US territorial waters (US Virgin Islands and Puerto Rico).

Case Study 5: Fish Pots and the Bermuda Grouper Fishery

In Bermuda, commercial landings of six FSA-forming grouper species declined from 1975 to 1992 between 68 and 95 % (Luckhurst 1996). The greatest impact during this period was shown for Nassau grouper as a direct result of FSA fishing and was considered commercially extinct by 1990. Black grouper (*Mycteroperca bonaci*)-a major target of the fish pot fishery— declined from 40 t per yr in 1975 to less that 2 t per yr in 1991. Similar declines were shown for yellowmouth, tiger and yellowfin grouper (Luckhurst 1996). Following declines in grouper catch in overall landings from approximately 70 % of the total catch in the mid-1950s to 18.7 % by 1989, the Bermuda Government instituted a fish pot ban in 1990 to allow recovery of coral reef fish stocks. However, by 1996, neither landings nor stocks had shown signs of recovery.

Case Study 6: Customary Marine Tenure and marine reserves in Melanesia

In Melanesia, coastal marine resources, including FSA, are managed primarily through customary marine tenure. Under CMT, traditional reef ownership and cultural perspectives on resource use preclude the implementation of permanent no-take marine protected areas (Ruddle *et al*. 1992; Hamilton and Smith 2005). Instead, community landowners are focused on protecting FSA temporarily through *tambu* (temporary closures) to allow resources to improve to levels suitable for harvest, while simultaneously preventing overharvesting. In Manus and New Ireland Province, Papua New Guinea, and Choiseul Province, Solomon Islands, local landowners have apparently sustainably harvested FSA for generations. However, recent economic pressures have increased harvest volumes

[24] The spawning season in Pohnpei for sqauretail coralgrouper is January-May and that of brown-marbled grouper January-April.

to a level that over time appears unsustainable. Moreover, in Manus and New Ireland, FSA have been targeted by the live reef food fish trade, resulting in severe reduction in abundance at several known FSA locales and compromising the potential for sustainable subsistence and low-level commercial fishing. In recognition of these pressures, The Nature Conservancy (TNC) began an awareness campaign with affected clans with undisputed rights to specific FSA to produce a series of measures to provide sustainability to affected FSA. As a result, four communities in Manus imposed harvest and gear restrictions on three separate FSA that allowed only subsistence fishing using hook and line during ten days of the reproductive period for locally important grouper. In Kavieng (New Ireland Province), three FSA were placed under a *tambu* to eliminate all forms of fishing year-round, and in Choiseul Province, permanent marine reserve was placed at a traditional honeycomb grouper (*Epinephelus merra*) spawning site to protect this and other species of local importance. Each of the sites is being monitored with the assistance of TNC to detect improvements to allow harvest.

Case Study 7: Palau-The Live Reef Food Fish Trade, Marine Reserves and Commercial Management

In recent decades, Palau's coastal fisheries have been impacted substantially by both local fisheries and the Asia-Pacific live reef food fish trade (LRFFT). Beginning in the 1970s, local fishing efforts focused on several FSA nationally, with efforts resulting in the depletion of four multi-species FSA, including two FSA apparently fished to extinction (Johannes et. al 1999)[25]. Target species at these sites included camouflage grouper, born-marbled grouper and squaretail coralgrouper. During the 1980s and until 2000, Palau also exported approximately 180 metric tons of live fish through the LRFFT that focused on the aforementioned species, along with the humphead wrasse (Graham 2001). Target sites included the northern reefs, lagoon near Koror and Helen Reef where both FSA were depleted and target species, namely humphead wrasse at Helen Reef, became critically low in abundance. In response to overfishing, several traditional, state and national laws were passed to protect FSA and important FSA-forming species and include both commercial restrictions and area bans. Specifically, Palau banned catch of camouflage, brown-marbled, black saddled grouper and squaretail and leopard coralgrouper between 1 April and 31 July (27 PNCA 1204). Fishing, buying or selling of humphead wrasse less than 25 inches is prohibited, as is its export (27 PNCA 2104). Area prohibitions are in place at Ngerumekaol—a multi-species FSA site—from April 1-31 July (24 PNCA 3001-3004) and is supported by a separate state law (Koror State) (K6-101-99). Ngemelis is also included as a closed area under the same law, although the FSAs that once formed there is no longer active. Ngarechelong State also prohibits fishing year-round at Ebiil Channel—another important and previously LRFFT-fished multi-species FSA— under NSGPL 87, which acts in concert with a traditional *bul* (closure) at the site (1994). In 1994, a traditional *bul* that prohibits fishing between April and July was also placed by Kayangel and Ngarchelong chiefs on eight major channels, including Ebiil and Western Entrance (a known FSA site). Finally, Kayangel State prohibits fishing at Ngeruangel Atoll, which reportedly has channel-associated FSA (KYPL 7-02-96). While these combined management options provide good protection for FSA from fishing, variability in spawning times leaves FSA open to fishing during August and September during some years and highlights the importance of linking temporal bans to actual spawning time. In addition, recent investigations at Ngerumekaol suggest migratory pathways need to be incorporated in marine reserve boundaries to fully protect FSA-forming species from fishing within the reproductive season (Tupper, M., Director, Palau International Coral Reef Center, Koror, Palau).

Case Study 8: The Rise and Fall of the Belize Nassau grouper Fishery

The Nassau grouper fishery has played a dominant role in Belize's fishery during at least the last century and until recently was the second most commonly captured fish in the country (Carter *et al*. 1994). Fishing occurred year-round, with most fishers relying on hook and line fishing using non-mechanized boats and machinery. However, intensive fishing focused on the nine known spawning periods that formed around full moon in the months of December and January. Of those nine sites,

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[25] Recent reports suggest these two 'fished-out' FSA may be re-forming after more than two decades of no fish reported at the site.

perhaps the most heavily fished was the Caye Glory site, located in close proximity to the major population center of Belize City. While the site had been known and fished since at least the 1920s, by mid-century fishers were reportedly removing an estimated 1,200-1,800 Nassau grouper per boat per spawning period (Craig 1969). Anecdotal reports suggest at the peak of the catch, fishers were removing the more valuable roe and tossing fish carcasses to sea in an effort to maximize catch and reduce the effort of cleaning, storing and transport. Following this period, the increase in the number of fishers, the availability of mechanized equipment and ease of storage and transport resulted in a precipitous drop in catch volume, such that by 2001 a total of only 9 fish were captured from site and underwater monitoring showed fewer than 100 individuals aggregating to spawn. In recognition of this decline—also characteristic of other Nassau FSA sites—the Belize government, with the assistance of local participation and non-governmental intervention, decided to increase the protection of the species in Belize. Following years of negotiations between local community representatives and government and non-government organizations (NGOs), in 2003 Belize banned all catch, possession, export and sale of Nassau grouper, as well as fishing on 11 of 13 known FSA sites. In addition, systematic monitoring of the closed sites is being conducted by local NGOs, while enforcement is conducted by the state.

APPENDIX 2: SPECIES COMMON AND SCIENTIFIC NAMES

Grouper (Serranidae)

Yellowfin grouper	*Mycteroperca venenosa*
Nassau grouper	*Epinephelus striatus*
Goliath grouper (formerly jewfish)	*Epinephelus itajara*
Camouflage grouper	*Epinephelus polyphekadion*
Honeycomb grouper	*Epinephelus merra*
Brown-marbled grouper	*Epinephelus fuscoguttatus*
Squaretail coralgrouper	*Plectropomus areolatus*
Warsaw grouper	*Epinephelus nigritus*
Speckled hind	*Epinephelus drummondhayi*
Red hind	*Epinephelus guttatus*
Yellowedge grouper	*Epinephelus flavolimbatus*
Scamp	*Mycteroperca phenax*
Gag grouper	*Mycteroperca microlepis*
Spotted coralgrouper	*Plectropomus maculatus*
Black-saddled coralgrouper	*Plectropomus laevis*
Leopard coralgrouper	*Plectropomus leopardus*

Snapper (Lutjanidae)

Cubera snapper	*Lutjanus cyanopterus*
Mutton snapper	*Lutjanus analis*

Wrasse (Labridae)

Humphead wrasse	*Cheilinus undulatus*
Baldchin groper	*Choerodon rubescens*