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Identifying Conservation Strategies for Group-Spawning Coral Reef Fish in the Indo-Pacific, Using a Case Study of a Protogynous Giant Wrasse

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Abstract

Fish reproducing in group-spawning aggregations face intense fisheries during spawning events due to increased ease of capture. Other traits often associated with group spawning, such as late sexual maturation and sequential hermaphroditism, cause group-spawning species to be especially vulnerable to population declines, either because fishermen target large, reproductively mature specimens or because they target juveniles that would otherwise have reached sexual maturity and contributed to reproduction. In group-spawning species that are protogynous hermaphrodites, including species of grouper, snapper, and the giant wrasse (*Cheilinus undulates*) fishing large specimens skews sex ratios towards females, thereby interfering with reproduction through sperm limitation. Unprecedented sex ratio skew could cause aggregations to disappear from their historical sites, with potential evolutionary implications. In this paper, I review the unique threats afflicting group-spawning species, as well as possible resolutions to these threats. I use the highly endangered humphead wrasse as a case study in the deleterious effects of overfishing on population dynamics, in the effectiveness of trade regulations and conservation strategies already in place, and in potential solutions not yet applied. Using the conclusions of this analysis, I extrapolate trends likely to continue in the Indo-Pacific region, where aggregation spawning is unfamiliar to fisheries scientists but familiar to local fishermen, and where aggregation-forming species are apt to benefit most from the implementation of effective conservation strategies.

Keywords: Giant Wrasse, conservation, marine wildlife, coral reef, Reef Food Fish Trade, group spawning, Indo-Pacific

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Group Spawning: A Reproductive Pattern Worthy of Further Study

Group spawning is a reproductive behavior in which fish of the same species aggregate at a particular site, in numbers or densities far greater than during non-reproductive activities, in order to spawn (Domeier and Colin 1997, Nemeth 2005). Usually, group-spawning aggregations are characterized by the release of gametes by a single female and multiple males (Domeier and Colin 1997), though fish may also spawn in pairs (Colin 2010) or in a variety of other combinations on a spectrum of spawning techniques (Domeier and Colin 1997). Group spawning is a prevalent reproductive system in relatively large coral reef fish that carry platonic eggs (Domeier and Colin 1997). Within this broad group, the Nassau grouper, *Epinephelus striatus*, is perhaps the most famous (Sala et al. 2001, Sluka et al.1997, Colin 1992). This mode of reproduction has also been observed in other groupers (Sadovy and Domeier 2005), snappers (Sala et al. 2001, Grüss et al. 2013, Sadovy and Domeier 2005), *Cheilinus undulatus,* better known as the humphead, Napolean, or Maori wrasse (Sadovy de Mitcheson et al. 2010, Sadovy et al. 2004), and some other wrasses (Domeier and Colin 1997, Sadovy and Domeier 2005). Spawning typically occurs either residentially, with local fish taking no more than a few hours to migrate to the aggregation site, or transiently, with fish traveling beyond their home ranges for days or weeks in order to reach the site (Domeier and Colin 1997). Finally, spawning can be correlated with lunar phases as well as the seasons (Colin 1992, Domeier and Colin 1997); seasonality of spawning is likely a response to optimal water temperatures (Colin 1992).

Group spawning and, more generally, spawning aggregations, are interesting phenomena worthy of scientific inquiry for a variety of reasons. These range from their lucrative fishing prospects for indigenous and commercial fisherman and the problems of sustainability inherent in this market value (Domeier and Colin 1997, Beets and Friedlander 1998, Sadovy and Domeier 2005, Poh and Fanning 2012), to the potential insight gained for implementation and evaluation of different protective strategies for their conservation (Sala et al. 2001, Beets and Friedlander 1998, Drew 2005, Grüss et al. 2013), to the awe-inspiring visual impressions they can make on observers (Domeier and Colin 1997). Although group aggregations have been the subject of many diverse studies (Domeier and Colin 1997, Nemeth 2005, Colin 1992, Sala et al. 2001, Sadovy et al. 2004), the knowledge we have amassed both about aggregations and about most species using this mode of reproduction remains limited (Domeier 1997, Sadovy et al. 2004), primarily because collecting data on aggregations and spawning is difficult. These events are short-lived, tend to occur in relatively inaccessible places, or if accessible,

tend to be already altered by fisheries pressure (Domeier 1997). As a result of these and other factors, many species targeted by aggregation fisheries continue to be depleted without sufficient assurance that populations are not being fished to the point of collapse (Conover and Munch 2002, Sadovy and Domeier 2005). Indeed, in the past two decades, many species exhibiting group spawning behavior—including the Nassau grouper in Belize, the red hind in the US Virgin Islands, and groupers in several Indo-Pacific locations—have faced local extirpations in the face of fisheries pressure (Beets and Friedlander 1998, Johannes 1997, Sala et al. 2001, Nemeth 2005).

Why Are Spawning Aggregations Particularly at Risk?

While overfishing is hardly a unique problem among fish, spawning aggregations face even higher levels of susceptibility to overfishing because aggregation events are predictable based on lunar cycles (Colin 1992, Domeier and Colin 1997) and site retention (Sadovy and Domeier 2005). Based on knowledge of these ecological and biological factors, local fishermen are able to aggressively exploit aggregations, potentially removing large proportions of reproductively mature individuals in discrete fishing events (Sala et al. 2001, Nemeth 2005, Yadovy and Domeier 2005). Furthermore, in protogynous hermaphroditic species—including most groupers (Sala et al. 2001, Domeier and Colin 1997) and some other group spawners (Colin 2010)—wherein the largest individuals are males, fishermen fishing out the largest specimens may unknowingly induce changes in population structure such as sex-ratio (Beets and Friedlander 1998, Nemeth 2005, Grüss et al. 2013, Koenig 1996, Sala et al. 2001, Sadovy et al. 2004), size composition (Longhurst 2002, Sala et al. 2001), and age composition (Longhurst 2002, Sadovy et al. 2004).

Sex-ratio bias is a particularly concerning effect of targeting fish of a certain size and can have reproductive repercussions for the entire population. In protogynous hermaphrodites, removal of the largest individuals in the population could lead to sperm limitation, thereby reducing the overall reproductive success of the spawning aggregation, as has been suggested for the red hind (Beets and Friedlander 1998). If sex-ratio bias driven by fisheries pressure causes severe enough sperm limits so that females are unsuccessful in finding males with whom to spawn, aggregations could cease to form at all (Sala et al. 2001). Additionally, for sequential hermaphrodites, the take of large individuals can eliminate the oldest, most reproductively mature individuals from the gene pool, causing a selection effect in favor of slower growing genotypes; such preferential selection could reduce the population's evolutionary fitness (Conover and Munch 2002). Much of the fishing pressure that group spawners experience results from the Life Reef Fish Trade

(LRFT), in which demand for live reef fish, especially in Southeast Asia, incentivizes the removal of these species even when removal is restricted or prohibited by law (Johannes 1997). In aggregations targeted by the LRFFT, a different size-selection effect emerges: ideal fish are based on market demand for "plate-size" fish, such that the hardest hit age group is juveniles that would otherwise have reached reproductive maturation (Sadovy et al. 2004, Sadovy de Mitcheson et al. 2010). Such preferential selection of juveniles could have far-reaching effects on future recruitment and future reproductive success (Sadovy et al. 2004).

Prevailing Conservation Strategies & Their Effectiveness For Group Spawners

Current conservation strategies for group spawning aggregations can be sorted into three general groups: 1) closures—either permanent, temporary, or seasonal—of aggregation sites to fishing (Nemeth 2005, Grüss et al. 2013, Sala et. al 2001), 2) the institution of marine protected areas (MPAs), in which the fishery for the group-spawning species in question is closed beyond the aggregation site (Nemeth 2005, Grüss et al. 2013, Sala et. al 2001), and 3) a general reduction in fisheries pressure, usually enforced via a quota system (Sala et al. 2001). While participatory management by communities in the Indo-Pacific region has been on the rise, as of 2005, Indo-Pacific marine conservation policy did not incorporate spawning aggregations due to limited knowledge of aggregating species and their spawning sites (Sadovy and Domeier 2005). Nevertheless, examples from locales with parallel ecological, social, and/or economic conditions are indicative of the challenges and opportunities offered by the common conservation strategies mentioned above.

In a study modeling the effects of a permanent no-take reserve applied to the aggregation site of a protogynous grouper in the Seychelles, Grüss et al. found that aggregation reserves—measured in biomass-per-recruit—improved, and the sex-ratio bias was reduced for each of the scenarios they modeled (2013). However, these improvements were marginal and varied with stage of sexual maturity in individuals (Grüss et al. 2013). Furthermore, for each of the scenarios modeled, yields-per-recruit improved a negligible amount or did not improve at all (Grüss et al. 2013). Based on these results, the authors concluded that other conservation strategies involving broader geographical protection, such as seasonal closures of the entire fishery for the grouper (especially where spawning and non-spawning areas overlap), or reduced fishing overall, would likely be more successful (Grüss et al. 2013).

A study of a red hind (*Epinephelus guttatus*) aggregation in St. Thomas examined possible effects of the strategies suggested by Grüss et al. In this observational study, the average size of individuals, average density and biomass of spawners, and maximum spawning density were measured before and after the implementation of a permanent MPA designed to protect an important *E. guttatus* spawning aggregation (Nemeth 2005). After permanent closure of the area to fishing, Nemeth found each of the above indices to increase significantly: the maximum total length of male red hind increased by seven centimeters., the average density and biomass of spawners increased by >60%, and the maximum spawning density more than doubled (Nemeth 2005). The author also suspected that the closure of the MPA contributed to the overall increase in the size of red hind caught in the extant commercial fishery beyond the boundaries of the MPA (Nemeth 2005).

In light of these results, policymakers should conclude that even permanent protection of spawning sites is not sufficient protection for species that group spawn in aggregations; rather, full protection of a geographical range broader than and encompassing the spawning aggregation must be instituted for successful recovery from overfishing (Grüss et al. 2013, Nemeth 2005). Of course, suggesting the implementation of such strict conservation measures is relatively simple for waters in the jurisdiction of wealthy nations such as the United States, where the potential immediate profit of the fishery can be overlooked for the purposes of the inherent value of the species, or for the purposes of serving the long-sighted view that protecting the species now could facilitate a sustainable fishery in the future (Sadovy and Domeier 2005). Some group-spawning species, however, do not have endemic ranges in such bureaucratically smooth-sailing regions, and their plight is representative of the many socioeconomic factors at play in achieving effective conservation (Poh and Fanning 2012). Thus, in order to understand the unique challenges of conservation in one such ecologically vibrant region—the Indo-Pacific—I will now examine an emblematic protogynous group spawner native to that region: the humphead wrasse.

A Case Study: The Humphead Wrasse, Cheilinus undulatus (Pisces: Labridae)

Natural History

The humphead wrasse, also known as the Maori wrasse and as the Napoleon wrasse, is a giant among Labridae, measuring up to over two meters long and weighing up to 190 kg (Sadovy et al. 2004). Its range extends across most of the Indo-Pacific; it naturally occurs in low-densities except when aggregating to spawn, at which time groups of between tens to about 100 humpheads gather (Sadovy et al. 2004). Like most protogynous hermaphrodites, it is long-lived and

late-maturing, living about thirty years and becoming sexually viable at approximately five years old (Sadovy et al. 2004). Humphead wrasses are residential spawners and may spawn as often as every day (Colin 2010). The humphead wrasse is considered an endangered species by the International Union for the Conservation of Nature (IUCN) and is listed under Appendix II by the Convention on International Trade in Endangered Species (CITES) of flora and fauna (Poh and Fanning 2012).

Cultural Importance

The humphead wrasse has long held significance for a variety of cultural groups in the Indo-Pacific, a fact that researchers speculate may account for the proliferation of names that exist to identify the species at different life stages and colorations (Sadovy et al. 2004). In these cultures, consumption of humphead wrasse has typically been reserved for royalty, chiefs, elders, or other community members in positions of power in Palau, the Cook Islands, Fiji, Pohnpei, and the Carteret Islands of Papua New Guinea (Sadovy et al. 2004). In Papua New Guinea, access to the fish is gendered—women are not permitted to consume it—and it has had a role in defining gender roles in Guam, where spearing a humphead wrasse was once a rite of passing into manhood (Sadovy et al. 2004). Today, however, the cultural role of the humphead wrasse has been superseded by its leading role in traditional peoples' scramble to earn a fraction of the profits available in the burgeoning Live Reef Fish Food Trade (LRFFT) (Barber and Pratt 1997, Sadovy et al. 2004, Poh and Fanning 2012).

Commercial Importance and Its Accompanying Threats

Although the humphead wrasse is also targeted in low volumes for the chilled fish trade and for the aquarium trade, it is most severely threatened by its very high relative value in the LRFFT (Sadovy et al. 2004, Barber and Pratt 1997, Poh and Fanning 2012). In 2004, the value of a humphead wrasse weighing 0.5-1.0 kg—a "plate-size" fish—ranged from US$3 to $60 per kg. (Sadovy et al. 2004). Profits from selling humphead wrasse are the primary cause of illegal, unregulated, and unreported (or IUU) trade in the fish in Malaysia, where fisherman engaged in IUU activities can earn a salary between three times and ten times greater than the average non-participating artisanal fisherman (Poh and Fanning 2012). Purveying humphead wrasse for the LRFFT is not only associated with sizeable export profits in Indonesia, Malaysia, and the Philippines (Sadovy et al. 2004), it also underpins ecotourism in many Indo-Pacific nations. Both local and international tourists—primarily from Asia—have come to expect the rare species to be available live for immediate cooking and serving in exchange for competitive prices; "plate-size"

fish can earn up to US$ 300 per plate (Barber and Pratt 1997). In Sabah, Malaysia, for example, the high demand for *C. undulatus* has promoted the development of a smuggling hub from the Philippines, where trade in the species is illegal (Poh and Fanning 2012).

Perhaps one of the most disturbing trends perpetuated by the demand for humphead wrasse in the LRFFT is the use of destructive harvesting techniques such as cyanide poisoning and explosives (Barber and Pratt 1997). Because humphead wrasse are naturally shy fish, they are difficult to catch by traditional methods such as hook and line (Sadovy et al. 2004). As a result, the use of cyanide as a stunning agent has become widespread, driven by the high additional profits to be made by using such technique. Indeed, the use of cyanide and explosives has been found to increase profits for an individual fisherman by up to ten times (Poh and Fanning 2012). Cyanide use represents a potent threat not only to the fish captured—a high proportion of which die in transit—but also to non-target fish, to the coral reef itself, and to the fisherman using the method (Barber and Pratt 1997). When cyanide solutions are sprayed onto coral reefs, it induces bleaching, killing the corals. Furthermore, implementing cyanide techniques with primitive diving apparatuses, as is done by local fishers, is often dangerous and can result in decompression sickness. On a larger scale, bleaching corals represents a significant threat to the long-term economic and food security of artisanal fishermen, who rely on the reefs for their livelihoods (Barber and Pratt 1997).

For protogynous hermaphrodites such as humphead wrasse, a second trend related to commercial importance is worth noting: the explosion of the LRFFT has been accompanied by a sharp increase in demand for "plate-size" fish, weighing in at about 0.5-1.0 kg (Sadovy et al. 2004). In turn, this demand has caused preferential selection of juveniles that fall within this size range or slightly below because they can be grown out in floating cages until they are large enough to sell (Sadovy et al. 2004). Such preferential selection threatens the reproductive stability of the species because juveniles in this size range would otherwise have reached full reproductive maturity, but are instead lost to the LRFFT (Sadovy et al. 2004).

The threats identified here, both at the ecosystem level for coral reefs and for the artisanal fishers exposed to Cyanide, are representative of challenges experienced by the Indo-Pacific region (Sadovy et al. 2004), where regulations are under-enforced due to lack of resources, commercial pressure, and low opportunity cost. Together these factors encourage fishers to continue to harvest from populations they know to be declining, using techniques that are dangerous both to the corals and to themselves (Poh and Fanning 2012). Furthermore, increased profits from LRFFT primarily benefit industry middleman. Although fishers do better economically than they might otherwise, the costs of meeting consumers' demands—including local extirpations of humphead wrasse, loss of coral reef-

based industry, and risk of bodily harm assumed in participating in illegal and dangerous harvesting techniques such as cyanide fishing—makes profits from the LRFFT risky and unsustainable (Poh and Fanning 2012, Barber and Pratt 1997).

While my discussion here has focused on *C. undulatus* and similar group spawning aggregations of fish in the Indo-Pacific, the perils of this particular species offer insight into the ecological complexities of conservation. In the case of fish that use group spawning as a reproductive strategy, for example, people are not the only predators that choose to increase their probability of a catch by honing in on aggregation sites. Whale sharks and manta rays have been observed feeding on eggs and other materials released during spawning; were spawning aggregations to disappear due to overfishing, these megafauna would lose a resource, potentially causing widespread harm to the trophic balance (Sadovy and Domeier 2005). Such disruptions to the food web can also proceed in the opposite direction, resulting in increased populations of lower-trophic-level organisms—such as smaller fish and invertebrates—that would otherwise be consumed as part of group spawners' diets (Sadovy et al. 2004). On a macroscopic scale, the removal of even one species from an ecosystem can reverberate throughout the food web, as has been widely documented in studies on the impact of sea otters on kelp forests' carbon storage capacity (Wilmers et al. 2012) and of the reintroduction of gray wolves to Yellowstone National Park (Ripple and Beschta 2012). Extrapolating outward in this fashion can be useful for prioritizing the issues facing a single species, such as *C. undulatus*, during a policymaking process that must not only address ecological considerations, but must also acknowledge economic, political, cultural, and historical conditions to achieve sustainable, effective outcomes.

Why Worry About Spawning Aggregations & Artisanal Fishers in the Indo-Pacific?

Having established that the problems of *C. undulatus* are symptomatic of problems that could face any group-spawning species in the Indo-Pacific, it is worth asking why the Indo-Pacific merits special consideration. First of all, the Indo-Pacific, often called the "Amazon of the Oceans," is a biodiversity hotspot for marine life (Barber and Pratt 1997). However, preliminary and qualitative data related to the humphead wrasse suggest that the species is in decline (Sadovy et al. 2004)—an ominous indicator for other sensitive species endemic to the region and for future species richness. Additionally, the scientific infrastructure of nations in the Indo-Pacific is poor, and knowledge of spawning aggregations is limited among scientific communities (Sadovy and Domeier 2005) in

comparison to the cache of traditional economic knowledge stored within indigenous communities (Drew 2005, Barber and Pratt 1997, Sadovy et al. 2004, Sala et al. 2001). Furthermore, due to a lack of resources and incentives among officials to resist corruption, regulations that are in place both to curb trade in humphead wrasse and to limit such harmful harvesting techniques as cyanide application are either limited in scope or virtually unenforceable (Poh and Fanning 2012). Finally, because other sources of income seldom exist, traditional fishers often find it economically necessary to systematically exploit known spawning aggregations in the region (Sadovy and Domeier 2005, Poh and Fanning 2012), especially when they are faced with competition from other fisherman using relatively modern—if dangerous and illegal—technologies, such as cyanide poison and SCUBA night fishing (Sadovy et al. 2004)

In short, the Indo-Pacific faces a host of challenges that would make traditional conservation strategies, such as Marine Protected Areas or quota systems, impractical and difficult to enforce. In light of this reality, developing conservation plans that take advantage of intrinsic properties of the Indo-Pacific, such as high biodiversity and extensive traditional ecological knowledge (TEK) (Drew 2005, Sala et al. 2001), must be the goal of conservation biologists and conservationally-minded citizens seeking to protect group-spawning coral reef fish.

Alternative Conservation Strategies for Consideration in the Indo-Pacific

While traditional techniques of conservation are likely to be ineffective in the Indo-Pacific, recently identified alternative strategies have optimistic outlooks for success based on preliminary studies (Drew 2005) and modeling (Sala et al. 2001). The two most applicable of these strategies for the Indo-Pacific are ecotourism and community-based strategies utilizing TEK.

Ecotourism leverages a place's innate ecological characteristics, such as high endemic biodiversity, for economic gain by offering recreational and/or educational experiences that rely on maintaining those ecological characteristics within the landscape, rather than removing them for other uses that generate income. Conservationists prefer ecotourism to resource extraction as a method of generating income from nature because of the local economic benefits that carry minimal disturbance to ecosystem function. This is especially true if organizing parties endeavor to construct a sustainable ecotourism model (Buckley 1994). In an economic modeling study that compared the value of an existing aggregation fishery of Nassau groupers in Belize versus a prospective ecotourism industry reliant upon the aggregation, researchers found that replacing the fishery with ecotourism would be significantly

more profitable and long-lasting (Sala et al. 2001). While ecotourism must be undertaken carefully to ensure that it causes minimal disruption of an aggregation, generating ecotourism in the Indo-Pacific is a logical conservation strategy. Not only would it prevent culturally and commercially important group-spawning fish from local extirpations (Sala et al. 2001), ecotourism would address many of the issues raised by the LRFFT by reducing the need of fishermen to participate in illegal markets and harvesting techniques that put their overarching source of income—the coral reef—at risk.

While ecotourism represents an immediately viable conservation alternative for fish that form spawning aggregations, the incorporation of TEK into community-based conservation strategies is more abstract. In practice it requires researchers to shift their mindset and incorporate knowledge amassed by native peoples into modern conservation (Drew 2005). This process, however, is already underway in the Indo-Pacific, where native people have recently provided scientists with invaluable knowledge of aggregation locations and temporal patterns of spawning, as well as in establishing MPAs encompassing spawning aggregation sites at Gladden Spit in Belize (Drew 2005), Ngerumekaol in Palau (Johannes 1997), the Solomon Islands (Drew 2005), and in Glover's Reef in Belize (Drew 2005, Sala et al. 2001). Beyond engaging in conservation in these capacities, TEK could be further incorporated into future conservation efforts targeting group-spawning species through the development of customary ecological management practices, in which the native peoples of Indo-Pacific nations would have the final say in conservation plans for their region (Drew 2005). Given that spawning aggregations have yet to be thoroughly considered in the limited policy frameworks currently in play in the Indo-Pacific region (Sadovy and Domeier 2005), instituting the first such plans using baselines drawing on regional TEK would be a step in the direction of participatory management that empowers local indigenous communities to steward these species for generations to come.

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