



Secretariat of the Pacific Community

LIVE REEF FISH

The live reef fish export and aquarium trade

Number 14 – October 2005

I N F O R M A T I O N B U L L E T I N



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Special issue on reef fish aggregations

From the Editor

This special issue of the bulletin is devoted to the topic of reef fish aggregations. Spawning aggregations are a fascinating phenomenon, and they are of critical importance when it comes to the challenge of managing reef fish resources effectively. This issue was compiled in recognition of that importance. Its intent is to provide a focus on the topic of reef fish aggregations, especially as they relate to fisheries for live fish, and to highlight recent progress in aggregation research and management.

The following articles document recent efforts to study and manage spawning aggregations in Papua New Guinea, Solomon Islands, Pohnpei and Palau, and they focus on the grouper species that dominate the trade in live reef food fish. The articles pay particular attention to the three groupers that are among the most valuable species in the trade and whose spawning aggregations in the Indo-Pacific tend to share the same sites and times. These three species, which make up Yvonne Sadovy's "trusting trio" in the article that follows, are *Epinephelus fuscoguttatus*, *E. polyphkadion* and *Plectropomus areolatus* (with some region-specific substitutions and additions — see the articles by Sadovy and by Hamilton and coauthors).

Richard Hamilton and coauthors share some of the rich local knowledge of aggregation sites and patterns held by fishing communities in Papua New Guinea and Solomon Islands. The authors' interviews with fishers in four study areas reveal detailed information about the dynamics and status of aggregations at no less than 50 grouper aggregation sites.

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Kevin Rhodes and coauthors summarize the results from four years of underwater surveys of a grouper aggregation site in Pohnpei and discuss how the results can be used to devise more effective conservation measures for aggregating fish populations.

Yvonne Sadovy and coauthors discuss various ways to track the status of aggregations over time, focusing on underwater monitoring methods. They highlight the difficulties — in terms of both survey design and practice — that must be overcome in order to obtain information that is truly valuable for management.

Finally, Terry Donaldson summarizes the ongoing aggregation studies in Micronesia, Melanesia and Asia conducted by the University of Guam Marine Laboratory and its partners.

All these articles deal with the effects of fishing on aggregations and on fish populations that aggregate. A common theme, not surprisingly, is that many aggregating populations are in trouble from fishing, and not just from live food fish fisheries. Hamilton and coauthors find that “What is more startling [than the effects of the live reef food fish trade] is the dramatic impact that recent artisanal night-time spearfishing appears to be having on [grouper aggregation sites] throughout Melanesia.” The assessment of management options provided by Rhodes and coauthors for the case of Pohnpei takes into account a similar finding: “the removal of reproductively active fish for subsistence use may equal or exceed that of commercial catch....”

In 1999, Bob Johannes and coauthors commented that “Researchers and fisheries managers in the western Atlantic have a substantial lead over those elsewhere in their employment of management measures focusing on spawning aggregations.”¹ The articles in this bulletin are evidence that this lead is eroding. Although this small collection does not represent all the recent progress in the Indo-Pacific, it reflects the growing momentum in documenting and monitoring aggregations and the increasing efforts to use the resulting information to effectively manage the region’s reef fish resources (efforts that I’m sure these authors would say are not yet enough).

Tom Graham

1. Johannes R.E., Squire L., Graham T., Sadovy Y. and Renguul H. 1999. Spawning aggregations of groupers (Serranidae) in Palau. Marine Research Series Publication No. 1. The Nature Conservancy.

PIMRIS is a joint project of 5 international organisations concerned with fisheries and marine resource development in the Pacific Islands region. The project is executed by the Secretariat of the Pacific Community (SPC), the South Pacific Forum Fisheries Agency (FFA), the University of the South Pacific (USP), the South Pacific Applied Geoscience Commission (SOPAC), and the South Pacific Regional Environment Programme (SPREP). This bulletin is produced by SPC as part of its commitment to PIMRIS. The aim of PIMRIS is to improve



Pacific Islands Marine Resources Information System

the availability of information on marine resources to users in the region, so as to support their rational development and management. PIMRIS activities include: the active collection, cataloguing and archiving of technical documents, especially ephemera (“grey literature”); evaluation, repackaging and dissemination of information; provision of literature searches, question-and-answer services and bibliographic support; and assistance with the development of in-country reference collections and databases on marine resources.



Troubled times for trysting trio: Three aggregating groupers in the live reef food-fish trade

Yvonne Sadovy¹

The live reef food-fish trade has a long history in Southeast Asia, but expanded particularly rapidly during the 1990s. Today the trade constitutes a multimillion US dollar business that involves countries throughout much of the tropical Indo-Pacific region (Johannes and Riepen 1995; Sadovy et al. 2003). The geographic expansion of the international trade in live fish was due in part to improvements in economic climate and higher consumer demand, and in part to declines in fish stocks in the South China Sea. Improved air links also spurred the expansion, allowing for the more rapid transport necessary for live animals. With the increase in the number of source countries (many located a significant distance from the trade centers of Singapore and in particular Hong Kong, with the latter a gateway to mainland China) came an increase in the number of species in the trade. Most of the species in the trade belong to just a few fish families, above all the groupers (Serranidae).

Groupers make up the bulk of the live reef food-fish trade in terms of both volume and value, comprising hundreds of tonnes each year, and attracting high unit prices at retail (Figs. 1 and 2; Table 1). Groupers tend to be susceptible to high levels of uncontrolled fishing, however, because they are typically long-lived (it is not unusual to find groupers aged 15 or 20 years, or more) and slow to mature; in addition, many species aggregate (form groups) to spawn (reproduce). Their long life and late sexual maturation mean that populations are typically slow to replace themselves, or to recover from overfishing, while their aggregating habit makes them easy to target in large numbers while spawning. In an economically valuable fishery, in which there is much interest in catching as many fish as possible in a short time and shipping them back to demand centres, targeting spawning aggregations is particularly attractive. However, aggregation-fishing can very

rapidly deplete spawning aggregations and, in more extreme cases, lead to serious declines in the fishery (Sadovy and Domeier 2005). All of the species in Table 1 are important live food fish, all aggregate to spawn, and their aggregations are sometimes targeted for the live reef food-fish trade.



Figure 1. Live groupers and a few snappers in a tank outside a restaurant in Hong Kong, awaiting sale to diners. All of the fish have been imported; the sources of live reef food fish found in Hong Kong's markets include Southeast Asia, the eastern Indian Ocean and the western Pacific Ocean. Hong Kong imports an estimated 60% of all fish in the trade (Johannes and Riepen 1995).

In this article I chronicle our growing understanding of the particular vulnerability of and biological interrelationships between three of the most economically valuable species in the live reef food-fish trade: brown-marbled grouper, camouflage grouper and squaretail coral grouper (Fig. 2). I use these three species to demonstrate the vulnerability of aggregating species in the Indo-Pacific to unmanaged fishing (whether for live or dead fish), and explore what we need to know to manage them effectively.

Underwater observations and fisher surveys undertaken over the last three to four years indicate that the camouflage grouper, brown-marbled grouper and squaretail coral grouper form spawn-

1. Society for the Conservation of Reef Fish Aggregations (www.scrfa.org), Department of Ecology & Biodiversity, University of Hong Kong. Email: yjsadovy@hkucc.hku.hk

Table 1. The most valued species in overall volume in the live reef food-fish trade centred in Hong Kong. Note that the mouse grouper, *Cromileptes altivelis*, and the giant grouper, *Epinephelus lanceolatus*, are also high in unit value but are not traded in high volumes. Almost all fish of the four listed species have been sourced from the wild.

Scientific name	FAO (Hong Kong trade name) name	Wholesale (retail) price (USD kg ⁻¹) in Hong Kong and southern China (2001) ^a	Price paid to fisher (USD kg ⁻¹) (1999–2001) ^b
<i>Epinephelus fuscoguttatus</i>	Brown-marbled (tiger) grouper	26 (51)	7–12 (Philippines) 1–2 (Indonesia) 4–5 (Australia)
<i>Epinephelus polyphekadion</i>	Camouflage (flowery) grouper	26 (51)	Same as for <i>E. fuscoguttatus</i> although depends on fish size as well
<i>Plectropomus areolatus</i>	Squaretail coral grouper	Approximately between the prices for <i>E. polyphekadion</i> and <i>P. leopardus</i>	
<i>Plectropomus leopardus</i>	Leopard coral grouper	38.5 (64)	7–28 (Philippines) 6–12 (Indonesia) 10–25 (Malaysia) 10–17 (Vietnam) 12–33 (Australia)

a. International Marinelife Alliance, Hong Kong Office — data from regular market surveys.

b. Sadovy et al. (2003) — the values are for guidance only since they can vary somewhat within country, according to fish size, etc.

ing aggregations together throughout much of their geographic ranges, and do so more frequently than any other known species groups. The co-occurrence of the three species was initially noted in Palau (Johannes et al. 1994), but only after fisher surveys had been conducted much more widely did it become apparent that this particular species association was both quite widespread and apparently consistent (see the fisher survey reports database of the Society for the Conservation of Reef Fish Aggregations (SCRFA) at www.scrfa.org). Associations between at least two of the species (and often all three) have now been reported from Indonesia, Palau, Federated States of Micronesia, Solomon Islands, Papua New Guinea, Seychelles (no squaretail coral grouper), New Caledonia (no squaretail coral grouper), Malaysia, Maldives (no squaretail coral grouper) and Fiji. The natural geographic ranges of the three species partially explain these patterns: while the camouflage and brown-marbled groupers have very similar global distributions, the squaretail overlaps with the other two only in some areas (Heemstra and Randall 1993). In at least one place where the squaretail coral grouper does not occur a different *Plectropomus* species makes up the trio. An example of this is *P. punctatus* in the Seychelles (Robinson 2004). In addition to forming large aggregations at sites shared by the two groupers, *P. areolatus* also spawns in other outer reef areas in small groupings. It thus shows signs of being a resident spawner (i.e. it may not travel far from resident sites to form spawning aggregations), like its congener, *P. leopardus* (Domeier and Colin 1997).

Despite these differences, the three species often spawn in the same general areas in outer reef passes or channels or along the outer reef slopes, often not far from passes. Within such shared sites, however, they typically occupy distinctly different areas or habitats, and may not all aggregate at exactly the same time, with spawning activity possibly separated by approximately a month. Moreover, different species will be dominant (numerically) at individual sites, which may reflect individual site characteristics. In some fisher interviews I have even noted that the more observant spearfishers can describe the distribution of these different species in some detail.

The three groupers are economically valuable and vulnerable to uncontrolled fishing, as noted by specific case studies and documented in fisher interviews. One early indication of their vulnerability came from Palau: several grouper spawning aggregations disappeared in or after the 1970s (Johannes and Riepen 1995), possibly due to over-fishing. One of these aggregations consisted mainly of camouflage grouper and brown-marbled grouper and was lost in the 1990s. Another aggregation, mostly of squaretail coral grouper and brown-marbled grouper, was almost eliminated from Denges Channel in the late 1980s by a live grouper-for-export fishing business.

Fisher interviews conducted by SCRFA in several western Pacific countries during 2003 and 2004 revealed that many of the aggregations of one or more of these species were thought to be declin-

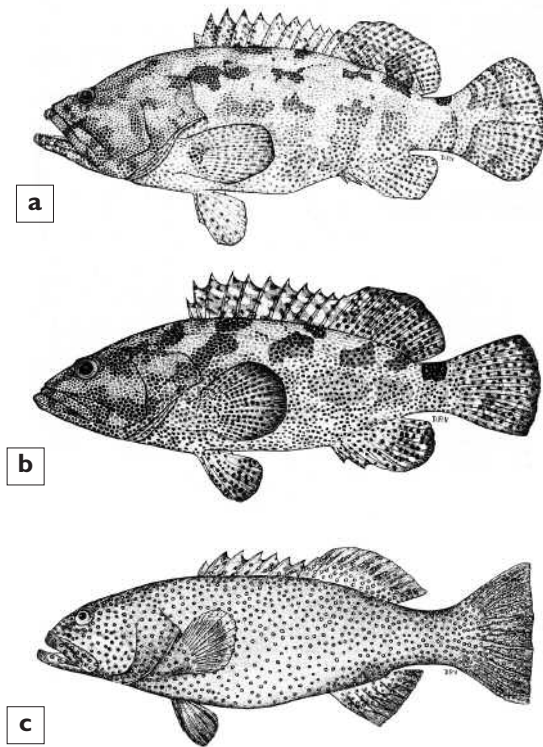


Figure 2. (a) *Epinephelus fuscoguttatus*, brown-marbled grouper; (b) *E. polyphkadion*, camouflage grouper; (c) *Plectropomus areolatus*, squaretail coral grouper. Reproduced with permission from the Food and Agriculture Organization of the United Nations from the publication by Heemstra and Randall (1993).

ing in terms of numbers of fish (Fig. 3). Although these general trends could only be very crudely determined and await validation, different communities often reported very similar patterns for the same aggregation sites and species, suggesting that changes had been consistently perceived by interviewees.

There is a growing realization that spawning aggregations are particularly vulnerable to fishing and that they often need management or protection from excess fishing activity. Aggregations may be targeted for subsistence or commercial purposes, and for live or dead fish. It is the intensity of commercial fishing activities that appears to pose a real threat to spawning aggregations. While the most intense threat in some places may be from the large-scale live reef fish operators (some of whom aim to catch more fish than they need to compensate for mortalities), there is a significant trade in chilled fish that is based on fish caught in aggregations. Moreover, some live fish traders prefer not to take groupers from aggregations because the stress experienced by the animals (especially females full of eggs) during those periods tends to result in high levels of mortality (Patrick Chan, pers. comm. 2003, Chairman, Chamber of Seafood Merchants, Hong Kong). Nonetheless, many fishers and traders continue to view these gatherings as a way to quickly obtain many fish, reduce crew costs, and in the case of traders, to sometimes benefit from the lower prices paid to fishers due to the large numbers of fish that suddenly become available on the market. Aggregations consisting of a trio of grouper species are particularly attractive to fishers and, thus, susceptible to overfishing.

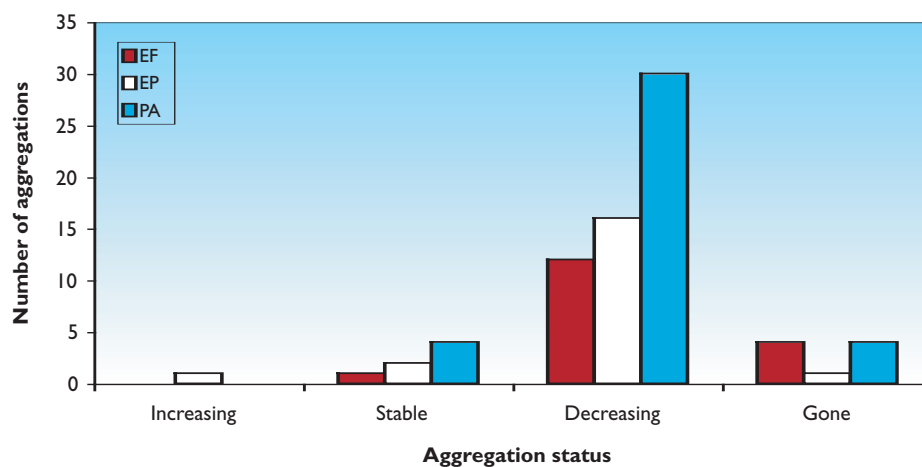


Figure 3. The status (in terms of 4 categories that refer to trends in catches) of 75 aggregations (according to not yet validated fisher surveys) of *Epinephelus fuscoguttatus*, brown-marbled grouper (EF), *E. polyphkadion*, camouflage grouper (EP) and *Plectropomus areolatus*, squaretail coral grouper (PA) from 11 countries in the Indo-Pacific (see database at www.scrfa.org).

To better manage aggregating groupers we need more information on several issues. Some of the most pressing questions are:

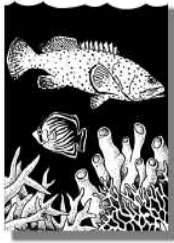
- How far do fish travel from their home reefs to the aggregation site and, consequently, how large an area does a single aggregation site “service”? It is important to know how large an area might be affected if an aggregation disappears due to overfishing, and to determine the management area that needs to be considered.
- What proportion of annual landings come from aggregations, and what proportion from fishing activity that targets the species at other times of the year? This information is important in order to determine when and how management can best be implemented — management may be needed during aggregation periods and also at non-aggregating times, for example.
- How should the aggregation be managed? Seasonal closures and sales bans are widely practiced, but it is also possible to protect the spawning site itself. The best approach will depend on the location of the aggregation, enforcement capacity, etc.
- How should the aggregation be monitored, given local social and economic circumstances, enforcement capacity and fishing pressure? Effective management is possible only with good monitoring (see the article by Sadovy, Colin and Domeier in this issue).
- How large is the aggregation area of all species combined? Each species tends to gather in different areas within a larger site, so the combined areas of all three species should be considered if area management is used.
- What are the spawning seasons for each species? This information is important for seasonal management. For example, although the three groupers share an aggregation area, they often do not overlap completely in terms of the timing (months) when aggregation takes place; even within one country, the aggregation timing can vary widely. Therefore, national-level seasonal regulations may not be appropriate and locally relevant measures would need to be adopted.
- Does the value of the fish vary according to whether or not the species is taken during the spawning season or according to the number of fish on the market? For example, in Fiji, fish caught during the aggregating season are sold for 50% of the price at non-aggregating times. Better economic data could help communities plan to get better value for their fish.

I have focused on the three grouper species because they are valuable, heavily sought after for the live reef food-fish trade, and their aggregations can be very predictable in terms of location and timing (although studies are needed to better understand the patterns). Moreover, their potential economic yield makes them especially appealing to target. Careful management can ensure that the aggregations persist, and, with them, both the fish and their fisheries.

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Applying local knowledge and science to the management of grouper aggregation sites in Melanesia

Richard J. Hamilton¹, Manuai Matawai², Tapas Potuku³, Warren Kama⁴, Philip Lahui⁵, Joseph Warku⁵ and Andrew J. Smith¹

Introduction

In 2003 The Nature Conservancy (TNC) commenced a project titled "Protecting Coral Reefs from Destructive Fishing Practices: Protecting and Managing Reef Fish Spawning Aggregations in the Pacific". The goal of this project is to significantly reduce the degradation of coral reef ecosystems in the Pacific region from destructive fishing practices, with a particular focus on reducing the overexploitation and degradation of reef fish spawning aggregation sites⁶. Papua New Guinea and the Solomon Islands were identified as two of the target countries where this project would focus. The three broad objectives of the Destructive Fishing Project, now in its final year, are to: 1) develop and facilitate the application of cost-effective management controls on the exploitation of reef fish resources; 2) strengthen the capacity to assess, monitor and manage aggregating reef fish resources; and 3) raise the awareness and appreciation among stakeholders of the vulnerability of aggregating reef fish populations and associated ecosystems.

Although the project seeks to address how to best conserve and manage all exploited reef fish aggregations, particular importance is placed on conserving transient spawning aggregation sites (Domeier and Colin 1997) that are used by large commercially important serranids, or groupers, specifically: the squaretail coral grouper (*Plectropomus areolatus*), brown-marbled grouper (*Epinephelus fuscoguttatus*) and camouflage grouper (*Epinephelus polyphekadion*). These three species often form transient spawning aggregations at overlapping sites and times (Johannes et al. 1999) and these aggregations are frequently targeted by subsistence, artisanal and commercial live reef food fish trade (LRFFT) fisheries (Hamilton 2003a;

Sadovy et al. 2003). The predictable aggregating behaviour and life history characteristics of these large serranids make them unable to sustain high levels of fishing pressure (Sadovy and Vincent 2002), and it can take as few as two to three years of intensive fishing on transient spawning aggregations to virtually eliminate breeding populations of fish (Johannes 1997).

At the commencement of the Destructive Fishing Project it was recognised that in both Papua New Guinea and the Solomon Islands there were several basic information gaps that needed to be addressed if TNC was to meet its objectives. First, the locations and biological parameters of spawning aggregation sites in target areas in each country needed to be identified, and second, the destructive fishing pressures on spawning aggregations and the impacts of these practices needed to be understood. In most regions in Melanesia there are no scientific data on spawning aggregations, yet ethnographic surveys that have utilised local fishers' knowledge have often proven to be a cost-effective and successful way to document baseline information on reef fish spawning aggregation sites (e.g. Johannes 1989; Johannes and Kile 2001; Hamilton 2003a). Recognising this, TNC commissioned local knowledge surveys in Manus Province and Kavieng, New Ireland Province, in Papua New Guinea, in 2004. In the same year, local knowledge surveys were also conducted in Roviana Lagoon, Western Province and Choiseul Province⁷, Solomon Islands. A further local knowledge survey was conducted in Kimbe Bay, West New Britain Province, Papua New Guinea, in 2005. The aim of the TNC local knowledge surveys was to quickly amass as much information as possible on reef fish spawning aggregations and any related local management strategies in each region of interest. It was

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3. The Nature Conservancy, Kavieng Field Office, PO Box 522, Kavieng, New Ireland Province, Papua New Guinea

4. Nusabanaga village, C/- Munda Post Office, Munda, Western Province, Solomon Islands

5. The Nature Conservancy, Kimbe Bay Field Office, PO Box 267, Kimbe, WNB, Papua New Guinea

6. The purpose of the project is not to protect all spawning aggregations in the target countries, but to develop the necessary tools and approaches required to protect aggregations by working at selected sites, and then sharing the results and lessons learned with other agencies and organizations working in similar situations.

7. Results from the Choiseul survey are not included in this paper in accordance with local communities' requests that this information remain confidential.

envisaged that documented local knowledge on aggregation parameters (such as specific locations, species composition and aggregation status) could provide a template of information that could be used to tailor future research, conservation and management efforts.

In this paper we explain why local knowledge is increasingly used in spawning aggregation research, describe some of the common problems that need to be taken into account when collecting this type of ethnographic information, and outline the methods we used to collect this local knowledge. We also summarize some of the key biological findings on grouper aggregation sites (GASs)⁸ that were brought to light through the local knowledge field surveys carried out in Manus, Kavieng, Roviana Lagoon and Kimbe Bay. An overview of the main fishing pressures placed on GASs in Melanesia and the effects that these fishing pressures are having on GASs is then provided. In the discussion we detail how local knowledge is being used to assist TNC in its efforts to work with local communities, provincial fisheries agencies and other non-governmental organisations (NGOs) to manage and conserve GASs.

Utilising local knowledge for spawning aggregation research

The logistical difficulties of locating spawning aggregations that form at localised areas for brief periods of time has meant that marine biologists and fisheries managers wanting to research or protect spawning aggregations have often drawn on the local knowledge of fishers in the initial stages of their field work (e.g. Johannes 1981; Beets and Friedlander 1998; Johannes et al. 1999; Sala et al. 2001; Colin et al. 2003). It is noteworthy however that the precision and depth of documented local knowledge on spawning aggregations has varied widely between both regions and researchers (Graham 2002), no doubt reflecting the:

- amount of local knowledge present in each region;
- willingness of local fishers to divulge this information;
- skills of the researcher and appropriateness of the methods used to obtain local knowledge; and
- amount of time spent documenting this cultural information.

Detailed anthropological-based studies that have focused purely on documenting the local knowledge of Pacific Island fishers have revealed that as well as knowing the locations of spawning sites, local fishers can also provide highly precise information on the annual and lunar periodicity of spawning aggregations, species composition at mixed species spawning sites, the spawning behaviour of aggregating fish, and changes in the status of an aggregation over time (e.g. Johannes 1981, 1989; Johannes and Kile 2001; Hamilton 2003a).

It is important to highlight the fact that although local knowledge of marine environments can be of great practical value to scientists and conservationists, there are several cultural and methodological issues that need to be taken into account:

1. Local ecological knowledge is an important component of the intellectual and cultural property of many indigenous societies, and it needs to be documented and utilised in ways that are endorsed by the custodians of this information.
2. Anthropological methods such as interviewing and participant observation are required to accurately document this material.
3. Local knowledge is often stratified by gender, age and geographical location, and specific knowledge pertaining to specific families of fish is often restricted to expert fishers who specialise in targeting those species (Johannes et al. 2000).
4. Most local knowledge of marine ecologies is ultimately directed towards identifying patterns that maximise capture success. Thus, some details of fish biology that are important to marine biologists studying reef fish ecology may well be irrelevant to a local knowledge base, since these biological parameters have no influence on subsistence practices (Hamilton and Walter 1999).
5. While local knowledge on recent changes in the abundance or size structure of local fish stocks will often be very accurate, local explanations for the mechanisms underlying these changes may not be compatible with scientific paradigms (Ruddle et al. 1992:262): "In some places declining yields may be attributed to sorcery or a failure to propitiate the gods."
6. Fishers' knowledge, like that of scientists, is fallible, and this cultural information needs to be gathered systematically and treated with the same critical scrutiny that is applied by scientists to any other data set (Johannes et al. 2000).

8. In the local knowledge reports we documented information on a wide variety of harvested reef fish species that are known to aggregate. But due to the volume of data collected we decided to limit this paper to information collected on GASs. In the original reports there is also information on underwater visual census (UVC) surveys that were conducted at GASs identified in the local knowledge surveys, as well as data on local management practices and customary marine tenure (CMT) systems in the regions visited. This information is beyond the scope of this paper but can be found in the following TNC reports: Hamilton and Kama (2004), Hamilton et al. (2004) and Hamilton et al. (2005).

Documenting local knowledge

The fact that coastal managers and environmental NGOs working in the Indo-Pacific recognise the value of systematically documenting fishers' local knowledge on reef fish spawning aggregations can be attributed to the pioneering work of the late Robert Johannes (e.g. Johannes 1978, 1981, 1989). Recently the local knowledge field survey approach has gained global momentum with the formation of the Society for the Conservation of Reef Fish Aggregations (SCRFA). SCRFA has developed a global spawning aggregation database (available at <http://www.SCRFA.org>) and has conducted local knowledge surveys throughout the western Pacific (Hamilton 2003a; Rhodes 2003a; Daw 2004; Sadovy and Liu 2004). It is noteworthy that the senior author on this paper was commissioned to carry out the 2003 SCRFA local knowledge survey in Papua New Guinea and the Solomon Islands, and the methodologies used in the TNC local knowledge surveys reported on in this paper were virtually identical to the ones used by Hamilton (2003a) and designed by SCRFA.

Community liaison and interviewing procedure

In each region that local knowledge surveys were conducted we attempted to cover as wide a geographical area as possible, focusing our efforts on communities that were known to be heavily dependent on marine resources. The authors' knowledge of a region, word of mouth and any available unpublished or published literature were used to determine where we based the majority of our efforts. In each region visited, the local knowledge surveys lasted between one and two weeks. Upon arriving in a community we would ask to speak to the community leaders, then we would explain who we were working for and what our agenda was. Typically the community leaders would then call a group of available expert fishers together under a tree or by the beach. We would then introduce ourselves and TNC, and give an introductory talk on the life cycle of aggregating fish, covering among other things, aggregating behaviour, spawning, the pelagic larvae stages of fish and sex reversal. We would then point out that although we, as biologists, knew a lot about fish biology, we knew nothing about where or when spawning aggregations occurred on reefs in this region, which is why we wanted to ask local fishers for their help. We ended by clearly stating that the information we

were collecting was part of a preliminary assessment of spawning aggregations that TNC was making in the region, and specific details on locations of sites and other sensitive local knowledge would remain confidential.

These introductory talks frequently generated a great deal of interest and served as a very effective way of initiating conversations on reef fish aggregation sites. Fishers often enthusiastically shared their own observations and asked numerous questions on spawning aggregations. Reef fish guide books and posters showing the main target species of the LRFFT were used as visual aids so that fishers could show us which species aggregated on their reefs (Fig. 1). Importantly, these introductory talks also served as a quick way of assessing the level of local knowledge of spawning aggregations in the area visited. If we drew completely blank stares from all fishers at the completion of a talk and further inquiries confirmed that no such aggregations were known to occur on surrounding reefs, then we moved on to the next location fairly quickly. On the other hand, when we discovered an area that had a wealth of knowledge about reef fish aggregations, we would often ask to stay for a few nights so that we could get to know the fishers and learn as much as possible. In these instances we would also ask local experts to take us to known aggregation sites so that we could observe aggregation habitats and collect global positioning system (GPS) coordinates of the aggregation boundaries.

Individuals or groups of knowledgeable fishers who were willing to be interviewed in detail were asked a wide range of questions on reef fish aggre-



Figure 1. Interviewing fishers in a coastal community in Kimbe Bay, Papua New Guinea.

gations that occurred within their fishing grounds. The questions contained in the SCRFA questionnaire (see <http://www.scrfa.org/server/studying/introduction.htm>) formed the template of the questions covered. Interviews were conducted in Tok Pisin, Solomon Pijin and several other local languages in which the authors are fluent.

Local knowledge of grouper spawning aggregation sites

The four local knowledge surveys conducted in Kavieng, Manus, Kimbe Bay and Roviana Lagoon enabled us to document a great deal of information on 50 single-species and multi-species GASs. Species that had spatially overlapping territories

were deemed to occur at the same aggregation site. A summary of the local knowledge documented in each region is presented in Tables 1 through 4. Each table shows the species known to aggregate at specific sites, the moon phase when these aggregations occur and coded information⁹ on the annual seasonality with which aggregations are reported to form. For the majority of aggregating species, direct and indirect evidence of spawning was noted and oral histories of the fisheries (stock status, exploitation, fishing methods employed and any existing forms of management) were also documented. Much of this information is not presented in this paper, but can be found in the following TNC reports: Hamilton and Kama (2004), Hamilton et al. (2004) and Hamilton et al. (2005).

Table 1. Summary of grouper aggregation data documented from around Kavieng, Papua New Guinea.

Aggregation site no.	Aggregating species	Moon phase	Months of formation
1	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter	Every month of the year
2	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter	Every month of the year
3	<i>Plectropomus areolatus</i>	Third quarter	Unknown
4	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
5	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
6	<i>Epinephelus polyphkadion</i>	Third quarter	Unknown
7	<i>Epinephelus polyphkadion</i>	Third quarter	Unknown
8	<i>Epinephelus polystigma</i>	Third quarter	Every month of the year
9	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter	Every month of the year
10	<i>Plectropomus areolatus</i> , <i>Epinephelus fuscoguttatus</i>	Third quarter	Every month of the year
11	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i>	Third quarter	Every month of the year
12	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i>	Third quarter	Every month of the year
13	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
14	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
15	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
16	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year
17	<i>Epinephelus fuscoguttatus</i>	Third quarter	Every month of the year
18	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Unknown	Unknown

9. Due to the continued threat of commercial LRFF fishing activity in the regions discussed, we have adopted the approach used by Rhodes et al. (this issue) and coded the actual months of the reproductive season. Coded months match those of the calendar year, but are out of phase (e.g. coded month A is not January). It is noteworthy that while this article was being written, we learned that the Manus Provincial Government had approved the establishment of an LRFF company, Golden Bowl Ltd. Golden Bowl Ltd is currently waiting for the Papua New Guinea National Fisheries Authority to issue it a license (Dan Afzal, Wildlife Conservation Society, Kavieng, pers. comm.).

Table 2. Summary of grouper aggregation data documented from around Manus, Papua New Guinea. Aggregations that were documented by Squire (2001) are marked with an ^S. Aggregations that were documented in Hamilton (2003a) are identified with an ^H.

Aggregation site no.	Aggregating species	Moon phase	Months of formation
19 ^{S & H}	<i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i> <i>Epinephelus ongus</i>	Third quarter	A, B & C
20	<i>Epinephelus ongus</i>	Third quarter – New moon	A, B & C
21 ^{S & H}	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year; peak season in months A, B & C
21 ^{S & H}	<i>Epinephelus fuscoguttatus</i>	Third quarter	A, B & C
22 ^H	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year; peak season in months A, B & C
23 ^{S & H}	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year; peak season in months A, B & C
23 ^{S & H}	<i>Epinephelus fuscoguttatus</i>	Third quarter	A, B & C
24	<i>Plectropomus areolatus</i>	Third quarter	Every month of the year; peak season in months A, B & C
25	<i>Plectropomus areolatus</i> <i>Epinephelus polyphkadion</i> <i>Epinephelus lanceolatus</i>	Unknown	Peak season in month A
26	<i>Epinephelus polystigma</i>	New moon	Every month of the year

Table 3. Summary of grouper aggregation data documented from around Roviana Lagoon, Solomon Islands. The parameters of many of these aggregations sites were discussed in Johannes and Lam (1999)

Aggregation site no.	Aggregating species	Moon phase	Months of formation
27	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter – New moon	Unclear, but known to have an extended season, possibly with a peak season in months H, I, J & K
28	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i> <i>Epinephelus ongus</i>	Third quarter – New moon	Unclear, but known to have an extended season, possibly with a peak season in months H, I, J & K
29	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i>	Third quarter – New moon	H, I, J & K
30	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
31	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
32	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter – New moon	H, I, J & K
33	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
34	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
35	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
36	<i>Epinephelus ongus</i>	Third quarter – New moon	H, I, J & K
37	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter – New moon	H, I, J & K
38	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphkadion</i>	Third quarter – New moon	H, I, J & K
39	<i>Epinephelus fuscoguttatus</i>	Third quarter – New moon	H, I, J & K
40	<i>Plectropomus areolatus</i>	Third quarter – New moon	H, I, J & K

Table 4. Summary of grouper aggregation data documented from around Kimbe Bay, Papua New Guinea.

Aggregation site no.	Aggregating species	Moon phase	Months of formation
41	<i>Plectropomus areolatus</i>	New moon	Every month of the year
42	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphekadion</i>	Unknown	Unknown
43	<i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphekadion</i>	Unknown	Unknown
44	<i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphekadion</i>	Unknown	Unknown
44	<i>Plectropomus areolatus</i> <i>Epinephelus fuscoguttatus</i> <i>Epinephelus polyphekadion</i>	Unknown	Unknown
45	<i>Plectropomus areolatus</i>	Unknown	Unknown
46	<i>Plectropomus areolatus</i>	Unknown	Unknown
47	<i>Plectropomus leopardus</i>	Unknown	Unknown

Lunar periodicity

In Manus, Kavieng, Roviana Lagoon and Kimbe Bay existing local knowledge on the lunar periodicity with which grouper aggregations form was virtually identical. *P. areolatus*, *E. fuscoguttatus*, *E. polyphekadion*, *E. ongus*, *E. lanceolatus* and *E. polystigma* were nearly always said to aggregate at GASs during the third quarter, with aggregations often reported to persist early into the new moon phase. In all, local knowledge pertaining to the lunar periodicity with which aggregations of serranids form was available for 39 out of 50 (78%) GASs spread across four geographically separate regions.

The very precise nature of this local knowledge gives overwhelming support to the validity of this information and demonstrates that the lunar timing with which many species of serranids aggregate may vary little in Melanesia.

Annual seasonality

Local knowledge on the annual seasonality with which grouper aggregations form was highly variable between both species and regions. The extent to which annual seasonality was understood and noted in the local knowledge bases also varied markedly between regions. The most detailed information on annual seasonality was documented among fishers of the Titan tribe of Manus. Titan fishers report that *P. areolatus* aggregates to spawn at multi-species aggregation sites in every month of the year, with a peak season in the months of A, B and C, during which time the abundance of *P. areolatus* at aggregation sites is an order of magnitude higher than in other months of the year.

Aggregations of the white-dotted grouper (*E. polystigma*) were also said to form in all months of the year in Manus. The spawning season of *E. fuscoguttatus*, *E. polyphekadion* and *E. ongus* is known to be far more limited, with aggregations forming in the months of A, B and C each year. Frequently these species aggregate at the same sites that are used by *P. areolatus* throughout the year. In Manus one community also informed us that several *E. lanceolatus* aggregated at multi-species aggregation sites in months A and B each year.

Roviana fishers also had detailed local knowledge pertaining to which months of the year aggregations of groupers formed on their reefs, with *P. areolatus*, *E. fuscoguttatus*, *E. polyphekadion* and *E. ongus* widely reported to aggregate during the months of H, I, J and K each year. However, some Roviana fishers were aware that at least for some sites, the spawning season can be longer than this four-month period. In Kavieng, local knowledge of annual seasonality was typically vague, and fishers who answered questions on annual seasonality frequently reported that they believed *P. areolatus*, *E. fuscoguttatus* and *E. polyphekadion* aggregated throughout the year. Some Kavieng fishers also stated that these species have a peak season of several months each year, with this peak season being most pronounced for *E. fuscoguttatus* and *E. polyphekadion*. Local knowledge of when exactly this peak season occurred was limited. An aggregation of *E. polystigma* that local fishers recently discovered in the Kavieng region was reported to occur during every month of the year. In Kimbe Bay there was very little knowledge of annual seasonality, although some fishers did state that they believed aggregations of *P. areolatus* and *P. leopardus* formed in all months of the year.

Fishing pressure placed on grouper spawning aggregations in Melanesia

One of the priorities of the local knowledge surveys was to gain an understanding of the type of fishing pressures being placed on GASs and the effects that various forms of fishing were having on the status of these aggregations. In all of the regions surveyed, subsistence and artisanal fishing at aggregation sites occurs, and in Kavieng and Roviana Lagoon many of the known grouper aggregation sites have been targeted by commercial LRFFT operations. An overview of each of these fisheries and their impacts on GASs is provided below.

Subsistence fishing

All of the GASs identified in the local knowledge surveys are exploited by local fishers for subsistence purposes and many of these sites have been fished for generations. In all regions surveyed, the main forms of subsistence fishing at GASs are hook and line and daytime spearfishing (Fig. 2). Night-time spearfishing is not generally carried out for day-to-day subsistence purposes due to the expense of purchasing batteries for underwater flashlights. The degree to which GASs are targeted for subsistence needs is highly variable within and between regions, and relates to how close an aggregation is located to human settlements, the size of these settlements, the extent to which fishers are aware of the aggregation site and the abundance of other non-aggregating fish in the area.



Figure 2. Kavieng fishers displaying, from left to right, a *P. areolatus*, *E. fuscoguttatus* and *E. polyphekadion* that were speared during the day from a known grouper aggregation site.

Artisanal fishing

In this paper the term artisanal fishing refers to fishing by local fishers specifically for the purpose of harvesting fish for sale. In all regions surveyed the predominant fishing method used by artisanal fishers to target GASs is night-time spearfishing, with fishers typically limiting their activities to lunar days when aggregation numbers are known to peak. Night-time spear fishers use a variety of equipment, the most basic gear consisting of a pair of goggles, an underwater flashlight, and a handheld steel spear which is thrust into sleeping fish. The most advanced technologies involve the use of underwater flashlights, masks, snorkels, fins and rubber-powered steel spears or short homemade spear guns. In all four regions the advent of night-time spearfishing is recent, starting in the mid-1970s in Roviana Lagoon and as late as the mid-1980s in Kavieng. The rapid introduction of this method was related to the increasing availability and affordability of underwater flashlights in the regional centres. Very high catch rates of reef fish can be obtained by night-time spearfishing compared with other fishing methods, and when market outlets are available this makes spearing fish while free diving at night very lucrative (Hamilton 2003b).

The aggregating species most commonly targeted by night-time spear fishers is *P. areolatus*. This species is a prime target because:

- Large numbers of *P. areolatus* aggregate in very shallow water on the reef at GASs, where they are often exposed and clearly visible (Fig. 3).
- *P. areolatus* is typically inactive at night and consequently is easy to spear (this contrasts with *E. polyphekadion* and *E. fuscoguttatus*, which often flee from divers at night).



Figure 3. Two resting *P. areolatus* at a spawning aggregation site. This photo was taken at night. The fish on the left is in the camouflage colour phase that is seen in males and females. The fish on the right is displaying the yellow/green colour phase seen only in females.

- *P. areolatus* is a moderate size fish that is easy for spear fishers to catch and handle (many spear fishers stated that they did not spear *E. fuscoguttatus* when they came across them, as these fish bent their spears and occasionally escaped with the spears lodged in them).
- *P. areolatus* is generally more abundant than *E. fuscoguttatus* and *E. polyphkadion* at aggregation sites, especially in shallow waters that are accessible to free divers.

Catch rates of *P. areolatus* from GASs can be very high. Kavieng and Manus fishers report that during a peak aggregation period, two or three night divers can remove more than 100 *P. areolatus* from an aggregation site in several hours. In Roviana Lagoon a catch per unit of effort (CPUE) survey of 41 night-time spearfishing trips that were carried out over a four-month peak aggregation period in 2001 shows that spear fishers who specifically targeted a multi-species GAS prior to a new moon had maximum catch rates of 16.8 kg *P. areolatus* per hour per fisher (authors' unpublished data 2001).

Commercial fishing – the LRFFT

LRFFT operations have operated on and off in Kavieng since June 1994, and operated intensively in Roviana Lagoon in 1996 and 1997. In Roviana Lagoon, LRFFT operations were pulse fishing events that targeted seasonal spawning aggregations of groupers, with local fishers capturing target species with hand lines. In Kavieng, hand lines and traps have been the most commonly used gear for capturing serranids, although trap fishing is currently banned (NFA 2002). In Kavieng, LRFFT operators also consistently sought out and targeted spawning aggregation sites, with untrained local divers using hookah gear supplied by LRFFT operators to place lines of traps along known migration routes and at aggregation sites (Fig. 4).



Figure 4. Tapas Potuku holding a functional fish trap that had been left behind from previous LRFFT operations at a spawning aggregation site.

Effects of subsistence, artisanal and commercial fishing at aggregation sites

Older fishers from Manus, Kavieng and Roviana Lagoon whom we interviewed frequently stated that when GASs had been exploited for subsistence purposes only, catch rates tended to remain stable. There were, however, several exceptions to this generality. Where declines were noted at sites that had only ever experienced subsistence fishing pressure, these declines were frequently attributed to human population growth or increasing pressure placed on these aggregations as other reef fish resources became scarcer (Hamilton and Kama 2004; Hamilton et al. 2004).

Market driven night-time spearfishing and commercial LRFFT operations are both relatively recent fishing pressures at GASs in Melanesia. Artisanal night-time spearfishing occurs in all the regions reported on in this paper, and in all regions this highly effective practice is reported to have resulted in rapid and dramatic declines in catch rates from GASs. At one GAS in Roviana Lagoon, night spearfishing pressure alone is reported to have been sufficient to overfish an aggregation of *P. areolatus*, *E. fuscoguttatus* and *E. polyphkadion* to the point of economic extinction. Spear fishers reported that until the early 1980s they were able to catch large numbers of all three species in very shallow water at night. A fisher who had exploited this site for more than three decades reported that in the 1970s and early 1980s approximately 500 to 1000 *P. areolatus* and several hundred *E. fuscoguttatus* and *E. polyphkadion* aggregated at the GAS during peak seasons. Fishers reported that when artisanal night-time spear fishing at the site commenced in the late 1970s, a party of two or three spear fishers could catch approximately 100 *P. areolatus*, 50 *E. polyphkadion* and 50 *E. fuscoguttatus* in a single night. Catch rates declined steadily through the late 1980s and early 1990s, and since the mid-1990s aggregations have not formed in significant numbers. The same fisher who had exploited this aggregation site since the 1970s said that since the mid 1990s, the maximum number of *E. fuscoguttatus* and *E. polyphkadion* he had seen at this site was less than 10, and the maximum number of *P. areolatus* was less than 20. He also stated that aggregating groupers were all very small fish (Hamilton and Kama 2004). In the Kavieng region artisanal night spearfishing was also blamed for dramatic declines in catches from GAS, and in this region many sites have been simultaneously targeted by artisanal night-time spear fishers and LRFFT operations (Hamilton et al. 2004).

In Roviana Lagoon and Kavieng, LRFFT operations markedly increased fishing pressure on

known GASs. A two-year seasonal LRFFT operation in Roviana Lagoon that targeted a seasonal GAS was intensive enough to fish this aggregation to the point of extinction. Historically this aggregation supported large numbers of *P. areolatus* and *E. fuscoguttatus* and had been exploited for subsistence purposes for generations. In the 1996–1997 spawning season, approximately three to four tonnes of serranids were removed from this site for a LRFFT operation (Hamilton and Kama 2004). This aggregation site is located in a sheltered passage near a large village, and at the time that the LRFFT was operating the spawning aggregation was targeted on a 24-hour basis, with women, children and men hook-and-line fishing (Hamilton 1999). Fishing was intensive enough that fishers noticed a major decline in catch rates after only one year of targeting the aggregation site for commercial purposes. In 2001, when LRFFT operators returned and told local fishers that they were interested in recommencing their trade, local fishers informed them that it was no longer worth targeting this site, as the aggregations had not reformed since 1997.

In Kavieng, LRFFT operations are reported to have seriously affected many aggregation sites. One site where *P. areolatus* aggregates is reported to have been completely fished out in 2000 by a combination of LRFFT operations and night-time spearfishing. In Roviana Lagoon and Kavieng LRFFT operations have also resulted in local fishers targeting GASs that were previously unknown or relatively unexploited. This was demonstrated when the location of a little known GAS in Kavieng was widely publicized to local fishers once LRFFT operations commenced. Prior to this, the aggregation had rarely been fished and only one fisher knew its location. Furthermore, the large number of people hook-and-line fishing for LRFFT operations around this “new” site resulted in fishers discovering another previously unknown GAS that was located nearby. In Roviana Lagoon several GASs were also reportedly discovered in the mid-1990s when local fishers were doing exploratory fishing to locate GASs to exploit for the LRFFT (Hamilton and Kama 2004).

On a more positive note, even heavily overfished aggregations in the regions surveyed appear to have the ability to re-establish at this stage. Spear fishers from Kavieng reported that the aggregation of *P. areolatus* that was completely fished out by LRFFT operations had started to reform following the cessation of LRFFT operations in the area, with very small numbers *P. areolatus* (fewer than 10) seen aggregating at the site on a regular basis since late 2003. Aggregations of *E. fuscoguttatus* at another site in Kavieng were also reported to have

recovered over a five-year period of no commercial fishing. Finally, in many lightly populated regions in Melanesia there may still be GASs that are undiscovered. A good example is Kavieng, where five of the GASs identified in our local knowledge survey were discovered within the last five years.

Discussion

The local knowledge surveys proved to be a rapid and cost-effective means of identifying GASs in all of the regions surveyed. We documented detailed information on a total of 50 GASs. Foale (1998) states that Melanesian fishers are often secretive about their local knowledge and disinclined to pass this ecological knowledge to people other than their children or their siblings’ progeny. Although we acknowledge that some Melanesian communities are secretive about their local knowledge, this was certainly not our experience for the regions reported on in this paper. We found that a low-key setting, small to medium sized focus groups of fishing experts, and introductory talks on the biology of reef fish spawning aggregations served as a very good way of breaking down any existing barriers and stimulating talks on aggregations.

As one would expect, local knowledge on GASs varied between individuals, communities and the regions visited. For sites that have been fished for generations, older fishers provided an invaluable historical perspective of the technological and ecological changes that had occurred at aggregation sites in their lifetimes. In all regions very detailed information was also gained by interviewing spear fishers. Although spear fishers were often unaware of the reasons that groupers aggregated, they would frequently describe in detail indirect spawning signs (e.g. colour change, fighting, quivering, and multiple gravid females) that they had observed while free diving at GASs. Such observations provided us with a clear indication that the aggregations being described had formed for the purpose of spawning. Spear fishers also provided us with information on: the lunar and seasonal periodicity of aggregations, aggregation habitat, depth ranges of the various species at aggregation sites, migrations between daytime resting areas and night-time spawning sites, intra-day fluctuations in the core aggregation densities, the response of aggregating fish to human disturbances, and the predominant currents at aggregation sites.

The richest bodies of local knowledge were held by the Titan communities in southern Manus. The depth and precision of indigenous ecological knowledge in this region are far more detailed

than in any other region in Melanesia that the senior author has ever visited, reflecting both the heavy dependence of these Titan communities on the sea and their customs regarding various clans' rights to harvest specific species (Hamilton 2003a; Hamilton et al. 2004). In Kavieng and Roviana Lagoon, where fishing is also a very important way of life, many fishers had detailed ecological knowledge on GASs. In contrast to these regions was Kimbe Bay. Most people in Kimbe Bay are not heavily dependent on marine resources (Cinner et al. 2002; Green and Lokani 2004), and as was expected, local knowledge on GASs was more limited than in other areas. The low levels of dependence that most Kimbe inhabitants have on marine resources relates to several factors: First, many of the Kimbe Bay inhabitants are recent migrants from the Highland provinces who do not have a strong cultural relationship with the sea, and second, virtually all Kimbe Bay inhabitants spend a significant amount of their time engaging in cash crop agriculture, such as oil palm cultivation and logging activities. Indeed, in Kimbe Bay the communities that held the most detailed bodies of knowledge on GASs resided on small islands within the bay, and these small island communities are much more dependent on marine resources than are other coastal communities on the West New Britain mainland.

As well as enabling us to build detailed information on 50 GASs, the local knowledge surveys also highlighted some interesting biological relationships among grouper aggregations in Melanesia. At some sites, up to four species of grouper (*P. areolatus*, *E. fuscoguttatus*, *E. polyphekadion* and *E. onus*) aggregate during the same lunar periods, with aggregations typically peaking just prior to the new moon. *P. areolatus*, *E. fuscoguttatus* and *E. polyphekadion* are known to aggregate at overlapping sites and times in many regions in the Pacific, but it is not widely recognised that *E. onus* may also aggregate in large numbers at the same sites and times as the three previously mentioned groupers (Hamilton 2003a; Hamilton and Kama 2004). In Melanesia, *P. areolatus* form many small to medium sized aggregations (50–1000 fish) and often *P. areolatus* aggregations occur in close proximity to each other. Out of the 32 *P. areolatus* aggregations documented in the four local knowledge surveys, 59% (19 out of 32) formed at sites where other grouper species were known to aggregate, and 41% (13 out of 32) formed single-species aggregations. Underwater visual census (UVC) surveys at some of these single-species aggregation sites revealed that *P. areolatus* often aggregates on reef habitats of low relief that appear unsuitable for supporting aggregations of either *E. fuscoguttatus* or *E. polyphekadion* (Hamilton et al. 2004).

The local knowledge surveys also revealed that the seasonality of aggregations varies markedly between regions (e.g. Roviana Lagoon compared with Manus); however, seasonality was poorly defined in the local knowledge bases in Kavieng and Kimbe Bay. Interestingly, in many regions local fishers reported that *P. areolatus* aggregations form throughout the year. These assertions are supported by the limited data so far obtained from UVC monitoring programmes that were established at GASs in Manus, Kavieng and Roviana Lagoon in 2004. Results to date show that *P. areolatus* does form aggregations of variable sizes throughout much of the year (authors' unpublished data). At GASs in Melanesia *P. areolatus* is typically the most abundant and most sought after species. Consequently, if *P. areolatus* is aggregating in all or most months of the year in many locations then it is not surprising that annual seasonality is poorly defined in many local knowledge bases.

The local knowledge surveys also allowed us to develop a regional picture of the fishing pressures placed on GASs in Melanesia and their overall status. In Melanesia LRFFT operations have had negative impacts on many GASs. As the Roviana case study shows, even very short-lived LRFFT operations can make GASs that were fished at a sustainable level for generations, economically extinct. Our findings on the impacts of the LRFFT are hardly surprising; based on its experience in nearly every island nation in which it has operated, the trade has a dismal track record in terms of its effects on fish stocks (Sadovy and Vincent 2002; Sadovy et al. 2003). What is more startling is the dramatic impact that recent artisanal night-time spearfishing appears to be having on GASs throughout Melanesia. Dramatic declines in fish abundances and catch rates were observed shortly after the commencement of night-time spearfishing at GASs in Manus, Kavieng and Roviana Lagoon. Clearly, market driven night-time spearfishing at GASs is a widely used and highly destructive fishing practice in Melanesia; the extent and impact of this destructive fishing method may be underestimated by many coastal managers.

In all cases, the TNC local knowledge surveys were carried out as a first step towards achieving conservation goals, and the local knowledge collected has been utilised in this manner. For example, in Manus and Kavieng the local knowledge surveys enabled us to identify numerous GASs of high conservation priority (i.e. multi-species aggregation sites that were threatened by destructive fishing practices). Our next step was to conduct UVC surveys at these high priority sites to independently verify that they were definitely GASs. During the verification UVC surveys observations of multiple

indirect spawning signs (i.e. colour change, multiple gravid females, chasing, quivering and bite marks) were used to verify that these grouper aggregations had formed for the purpose of spawning. We then used ethnographic data (not reported on in this paper¹⁰) to identify high priority spawning aggregation sites that were located within social and political boundaries that allowed these aggregations to be managed at a community level. Community awareness meetings and ongoing liaisons between TNC field staff and target communities were then held. As an outcome of this, TNC is now assisting two communities in Kavieng and four communities in Manus in their efforts to manage their GASs. Community based management measures have included banning destructive fishing practices such as spearfishing at aggregation sites, harvesting restrictions, and temporary site closures. A full discussion of these community based management measures will be provided elsewhere.

In Kavieng and Manus, TNC is also assisting local communities with monitoring key spawning aggregation sites. Monitoring efforts have focused on *P. areolatus*, *E. fuscoguttatus* and *E. polyphekadion*. Monitoring at these sites is being conducted with the use of scuba and involves carrying out monthly UVC surveys along permanent belt transects just prior to the new moon. The monitoring methodology being employed is outlined in Pet et al. (2005) and was introduced through basic monitoring workshops run by TNC in Kavieng in 2003 (Rhodes 2003b). The purpose of monitoring in Kavieng and Manus is to collect the biological information necessary to make informed management decisions on the best ways to manage spawning aggregations sites. The two specific objectives are to 1) quantitatively determine the seasonality with which aggregations of *P. areolatus*, *E. fuscoguttatus* and *E. polyphekadion* form in each region, and 2) collect baseline data on the relative abundance of each of these three species at the sites that are being monitored. Quantitatively determining the peak spawning seasons of each species is essential for developing future management measures such as closed seasons. It is envisaged that in the future the data from the monitoring programs will provide communities and provincial fisheries departments with the information required to implement closed seasons. Province-wide seasonal bans¹¹ that prohibit the sale of groupers during peak spawning periods would be highly suitable for areas such as Kavieng. This region has centralised market outlets

and for a variety of political and social reasons many communities do not have the capacity to effectively manage their aggregations at a site level (Hamilton et al. 2004). For aggregations that are being managed at a community level, the site-specific baseline data that are being collected will allow a comprehensive assessment of the status of these aggregations, and will in turn enable future evaluations of the biological effectiveness of community based management strategies that are currently in place at these sites.

In March 2004, TNC also assisted and supported the Roviana Spawning Aggregations Monitoring Team (RSAMT) in its efforts to establish monthly monitoring programs at several GASs in Roviana Lagoon¹². RSAMT is made up of traditional reef owners from the Roviana region that are qualified scuba divers who have been trained in the basic methods of monitoring GAS (Hamilton and Kama 2004; Rhodes 2004). To date the RSAMT has carried out monthly monitoring at two GASs over the past 16 months. It is envisaged that the data obtained from monitoring these sites will be used to further develop conservation programmes that the Roviana and Vonavona Lagoons Resource Management Program has already established in this area (Aswani and Hamilton 2004a, 2004b). Finally, the most recent local knowledge survey was conducted in Kimbe Bay. This area is the main focus for TNC's Papua New Guinea Marine Conservation Program, and TNC is currently working with various partners and stakeholders to establish a resilient and functional network of marine protected areas (MPA) in Kimbe Bay by 2008 (Green and Lokani 2004). The GASs identified in the Kimbe Bay local knowledge survey will be incorporated directly into the MPA network design.

Acknowledgements

We are grateful to all of the individuals in the communities visited throughout Kavieng, Manus, Roviana Lagoon and Kimbe Bay for sharing with us their local knowledge about reef fish aggregations. The information summarized in this paper is based on their knowledge and could not have been documented without their interest and support. We also thank Kevin Rhodes and Yvonne Sadovy for their helpful comments on this manuscript.

This work has been generously supported by the Oak Foundation and The David and Lucile Packard Foundation.

10. Information on customary marine tenure estates and communities' attitudes towards conserving aggregations.

11. See Rhodes et al. in this bulletin for a full discussion on the benefits of closed seasons.

12. In 2004, RSAMT also received some support from the Roviana and Vonavona Lagoons Resource Management Program (RVL-RMP). While TNC continues to provide technical assistance to RSAMT, the RVL-RMP took over funding all of RSAMT's monitoring costs in 2005.

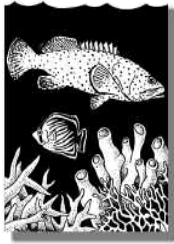
This work was also made possible through support provided by the Office of Procurement, US Agency for International Development, under the terms of Award No. LAG-A-00-99-00045-00 to The Nature Conservancy. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the US Agency for International Development.

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Reef fish spawning aggregation monitoring in Pohnpei, Federated States of Micronesia, in response to local management needs

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Introduction

The global disappearance of tropical reef fish spawning aggregations (FSAs) and the associated decline in fish populations from aggregation overfishing is now widely recognized (Sadovy 1995; Coleman et al. 2000; Domeier et al. 2002). Along with this recognition is an acknowledgement that FSAs need immediate management attention, even in lieu of baseline data (Johannes 1997, 1998). To manage FSAs, several traditional (Western) and customary (e.g. customary marine tenure) management options are available that alone or in combination can be used to prevent FSA overfishing. Among these options are size restrictions, catch quotas, bag limits, marine protected areas (MPAs) and species-specific catch bans, each operating on a permanent or temporary (spawning season-specific) basis. However, in many locales, the number of options is actually few owing to the limited understanding of species' life histories and FSA dynamics, and a basic lack of resources for monitoring and enforcement activities over long coastlines. In addition, those few remaining options may require unconventional approaches to implementation based on local — not regional — circumstances, perhaps even on an FSA-by-FSA basis.

Within the Indo-Pacific, management measures specific to FSAs have been enacted in several island nations, including the Federated States of Micronesia (FSM) (Pohnpei, one of the FSM's four states), Palau, Indonesia (Komodo), Solomon Islands (Munda), and Papua New Guinea (Manus) (Johannes et al. 1999; Rhodes and Sadovy 2002a; Pet et al. in press; R. Hamilton pers. comm. 15 April 2005). None, however, has yet provided complete and permanent protection for all FSAs within their respective jurisdic-

tions, such that FSA management actions may be considered as incomplete or temporary.⁴ In Manus and New Ireland Provinces (Papua New Guinea), six local communities that exploit FSA located within their uncontested customary fishing grounds have imposed a combination of gear restrictions, harvesting restrictions and temporary closures at five FSAs, but with a view to stock recovery and future sustainable harvest. In Komodo National Park, FSA protection is provided through gear restrictions and the incorporation of known spawning sites in no-take zones, although full implementation of the provisions has yet to take place (for more information, see www.komodonationalpark.org). In FSM and Palau, partial area and seasonal FSA protection is provided through MPAs (as permanent no-take zones) around some, but not all, known spawning sites. Market-based sales bans are in place during portions of the target species' reproductive seasons in both locales. Palau has also enacted an export ban.

In Pohnpei, FSM, while MPAs appear to have reduced aggregation fishing at one spawning site (some poaching still occurs), migratory pathways are left open to fishing and there is now preliminary evidence to suggest that fishing along these pathways may offset other area-based management measures (Rhodes et al. unpublished data). In addition, substantial numbers of reproductively active individuals appear in markets outside the sales ban period.⁵ Finally, subsistence fishing is left unregulated in local FSA legislation, except in MPAs. However, the removal of reproductively active fish for subsistence use may equal or exceed that of commercial catch, including during the sales ban period. Therefore, the need for management improvements for FSA-forming species is clear, as is an investigation of the effects of subsistence fishing on FSAs.

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4. Complete and permanent protection refers to the protection from fishing of all reproductively active fish within or en route to an FSA site, including along migratory pathways and at "staging" areas used by individuals between or prior to moving to FSA sites. Permanent protection refers to protection during a species' entire spawning season. Complete and permanent protection is globally accepted among scientists, managers and conservationists as the best method to protect FSA from loss and one of the key protective measures for maintaining fish populations. This form of management is viewed as necessary because partial protections have consistently been shown to fail, and all but the lightest levels of fishing are known to result in the loss or decline of FSAs. The inability of resource managers to devise measures that would allow certain levels of fishing is limited by an incomplete understanding of: 1) aggregation dynamics, 2) the widely varying responses of individual species and FSAs to fishing, and 3) our lack of understanding of which and how many local FSAs are needed to maintain populations.

5. The sales ban was instituted in 1992 as part of the Pohnpei State Marine Protection Act of 1992.

In Pohnpei, a scientific investigation of an FSA-forming species was conducted at a locally recognized (and fished) FSA between 1998 and 1999 (Rhodes and Sadovy 2002a, 2002b; Rhodes et al. 2003). Study findings and subsequent discussions generated greater awareness of FSA vulnerability and created an interest among local organizations to improve FSA management. In recognition of this interest and in light of the need to improve FSA protection, The Nature Conservancy (TNC) trained key stakeholder organizations (Conservation Society of Pohnpei (CSP), Pohnpei Division of Marine Resource Development (DMRD), Pohnpei Environmental Protection Agency, College of Micronesia and Pohnpei Agricultural and Trade School (PATS)) in FSA monitoring techniques in 2001 to facilitate monitoring of key FSA sites and species.

Here we present monitoring results on abundance and reproductive season for three FSA-forming species over four years (2001–2004), describe the results in relation to FSA dynamics and highlight the usefulness of the data for improved management in Pohnpei.

Methods

Beginning in 2001 (Month E, see below), CSP and DMRD initiated monitoring at a locally protected FSA site to determine the reproductive seasons and potential inter-annual changes in lengths and abundance of spawning fish of three locally important species. Monitoring was conducted monthly during both full and new moon periods for the first 12 months and during full moon periods only thereafter. Monitoring activities during 2003 through 2004 focused only on full moon periods between Months C and G, inclusive, which were determined to mark the beginning and end of the spawning seasons for these species at that site. Various attributes of the FSA were observed and measured to inform future management decisions and to gain insight into the response of the three species to the newly formed FSA-based MPA⁶ and the commercial sales ban. Specifically, the determination of the species-specific spawning seasons was necessary to make needed changes to the current commercial management (sales ban) currently in place.

Monitoring was conducted by a three-member team, each with a specific task (e.g. abundance counts, length-frequency estimation, and observation of behaviour). Following initial training during the 2001 monitoring workshop, skills re-training was conducted annually prior to each monitoring season and monthly within seasons for length estimation. Monitoring was conducted monthly over a three-day period just prior to a full or new

moon, and was consistent in relation to the lunar day and time of day. Monitoring was conducted along four non-overlapping transects 100 m in length and 15 to 20 m in width, at a depth of either 13 or 30 m (depending on the species, area and depth of the aggregation), as specified in a sub-sampling protocol instituted during the 2001 training workshop. Aggregations were adjacent to each other within the site, with clearly defined boundaries. Final estimates of abundance were calculated by extrapolating transect counts to total counts based on the size of the transect areas relative to the total FSA area.

In discussing findings, we refer to the three species as "Species A", "B" and "C" rather than using the actual species name because of the continued threat of commercial fishing activity in Pohnpei and the broader region. Similarly, we have coded the actual months of the reproductive season and use relative abundance (using an arbitrary 100-point scale) instead of actual abundance. Coded months are in the same order as the calendar year but are shifted (i.e. Month A is not January). Results from the length frequency and behavioural components of the monitoring are not presented here.

Results

Monitoring results from the 2001–2004 period provide a clear picture of the spawning season for the target species at the monitoring site for management decision-making (Fig. 1). Figure 1 depicts both the general seasonal consistency in which FSAs form and the inherent variability in inter-annual FSA formation and monthly abundance.

Species A was found to aggregate during four lunar months of the year, with highest abundance within a three-month period that initiated in Month D or E. The month of peak abundance varied among years. Similarly, Species B formed annual aggregations either in Months E and F or in Months D and E, with peak abundance typically during the initial spawning month. Species C demonstrated a four-month spawning period beginning in either Month C or D. Minor aggregations occasionally formed one month earlier (e.g. 2003, 2004), such that the duration of the spawning season could be considered five months. Preliminary evidence from a 2005 tagging study suggests the aggregation may be composed primarily or exclusively of males during the initial month of the season (i.e. Month C in 2004) (Rhodes et al. unpublished data). As with Species A and B, the initial month of FSA formation and month of peak abundance for Species C varied among calendar years.

6. The FSA-based MPA initiated in 1995 was expanded in 1999 to incorporate three aggregation sites, compared with only one that fell within the MPA boundaries when it was initially established.

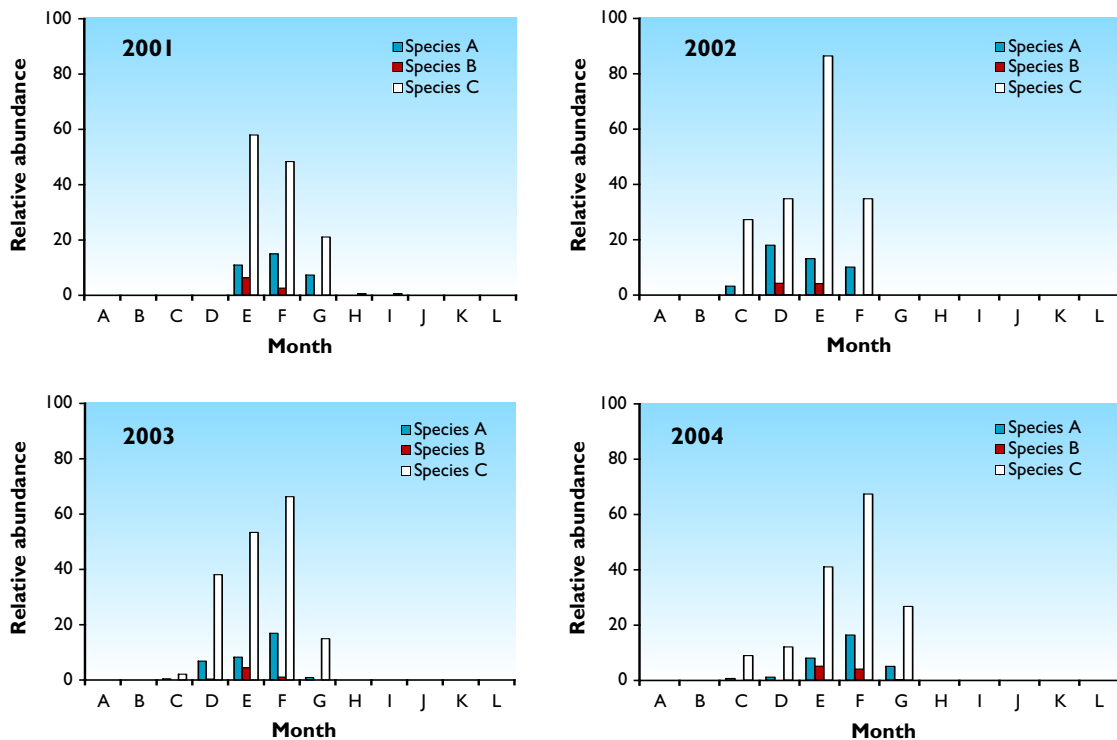


Figure 1. Monitoring results (relative abundance) of Species A, B and C (2001–2004). Monitoring was conducted for 27 consecutive months beginning in Month E, 2001. Monitoring in 2004 was conducted only between Months C and G, inclusive.

Discussion

General background

Pohnpei, Federated States of Micronesia, consists of 607 islands within four major island groups (one of which is the main island group of Pohnpei, Ant Atoll and Pakin Atoll) and 6117 km of coastline. Within these areas, marine resource monitoring and enforcement is administered through the Pohnpei Division of Marine Conservation (DMC) under the Department of Lands and Natural Resources, and by the Pohnpei Division of Marine Resource Development (DMRD) under the Department of Economic Affairs. These two divisions have a combined total of 18 employees, including nine conservation officers, and an annual operating budget of less than 140,000 United States dollars, including salaries. The DMRD/DMC is based within the main island group and located in the population and transportation centre, Kolonia, which contains the central market facility for the sale of coastal marine resources to about 35,000 inhabitants. In addition to the central market facilities, several additional seafood markets are dispersed around the island of Pohnpei, the most distant one about 35 km from the town centre. All exports and sales of FSA-derived products occur in Kolonia.

Current management and impacts to FSA

Currently, Pohnpei has two management measures specific to protecting spawning fish: 1) a two-month sales and possession ban for all fish markets, restaurants, and other points of sale, and 2) an MPA protecting the largest locally recognized FSA site for three locally important species. The sales and possession ban was originally enacted to protect an entire family of fish during what was perceived to be the main spawning period, even though many members of the family do not aggregate to spawn or spawn partially or exclusively outside the ban periods. At the time the ban was enacted, no detailed information on spawning season was available for any species within the family. Even now, the reproduction seasons and spawning patterns for several species covered by the ban are unknown. Therefore, the blanket sales and possession ban may not protect certain species within the family, since it does not cover their respective spawning times.

Substantial numbers of reproductively active fish appear in markets during months not currently covered by the sales ban. There is also some evidence of illegal sales of FSA-forming species during the sales ban period. The allowance of subsistence fishing during the sales

ban period also provides the potential for overfishing since any number of fish can be taken by any number of fishers throughout the spawning season. Other known FSAs for these species are also actively fished throughout the spawning season, although the actual volume and impact of this fishing are unknown.

While the MPA provides nearly complete protection for spawners at the FSA site (some poaching occurs), key migratory pathways are left open to fishing. There is now growing evidence that both Species B and C utilize specific pathways to reach FSA sites and may concentrate in “staging” areas between spawning months (Colin et al. 2003; Rhodes et al., unpublished data; M.H. Tupper, Palau International Coral Reef Center, pers. comm. 15 June 2005). In Pohnpei at least, fish from the MPA-protected FSA are being actively and sometimes heavily fished along migratory pathways and at other unprotected FSA sites. Therefore, some form of management that protects reproductively active fish throughout the spawning season, including at all migratory pathways and FSA sites, is necessary.

Potential for changes in FSA management in Pohnpei

Area-based options

Although area-based management options (i.e. MPAs), when properly placed around staging and spawning areas, have great potential to permanently protect FSAs (but, see Hviding 1998; Foale and Manele 2004), their potential as a catch-all management tool in Pohnpei appears limited. This limitation owes to the wide geographic range of FSAs in the state (even in the main island group), the scarcity of surveillance resources needed to enforce them and the large areas required to adequately protect all FSAs and migratory pathways, even those around the main island group. For example, the currently monitored FSAs, if protected by an area ban enclosing both catchment and spawning areas, would encompass about 20 km², or one sixth of Pohnpei’s barrier reef (Rhodes et al. unpublished data). Since there is more than one FSA within the main island group, the use of MPAs to protect the fish utilizing them would place a considerable amount of reef off-limits to fishing — a difficult proposition for politicians in terms of garnering support from the local community and fellow legislators. Moreover, the funding necessary to enforce these areas is greater than what is available (see *General background* section), particularly when other DMRD and DMC activities are factored in. Therefore, while it may be feasible to protect one or two of the larger, more abundant or biodiverse FSAs, the wide-scale use of

MPAs in Pohnpei as a management tool is currently impractical from an economic perspective.

Market-based options

Based on the 2001–2004 monitoring findings, Pohnpei now has sufficient details on spawning seasonality to make changes to the current commercial sales ban. Based on the seasonal data presented above, Pohnpei can opt to enact: 1) species-specific commercial bans during each species’ respective spawning season; 2) a blanket commercial ban that includes all three species and encompasses the longest of the three species’ spawning seasons (and considers the inherent variability in spawning seasons); or 3) a commercial ban that focuses on common peak months in either a species-specific manner or as a blanket type ban. In the latter instance, a commercial ban could be in place during Months D to G, inclusive.

Here, we use the term “commercial ban” to mean combined sales, catch, export and possession bans, since sales bans alone have proven insufficient to fully protect reproductively active fish during the spawning season in Pohnpei; this is demonstrated by the substantial number of gravid fish available in markets during periods when the sales ban is not in effect, the capture of individuals from other FSA sites, and heavy fishing often observed to occur in staging areas for commercial and subsistence use during and outside sales ban periods. If properly enacted and enforced, the proposed measures have the potential, based on local circumstances, to effectively stop all or most FSA fishing within Pohnpei (including nearby atolls) for these three species, since catch and possession, along with sales, would be prohibited. For subsistence purposes, a bag limit could be established (e.g. five fish per person, 10 fish per boat), although the ability to effectively enforce such a limit would be constrained by some of the same conditions listed above, especially resource limitations for surveillance. A more meaningful and effective method to eliminate all FSA fishing or catch of reproductively active fish within reproductive periods would be to also ban subsistence fishing for these species.

Species-specific, market-based management provides an alternative to resource-intensive, area-based management schemes that, for Pohnpei, have been only partially successful in eliminating fishing pressure on FSAs to date. Such bans could be broadened to include other species once their spawning seasons are identified. Additionally, area protection can be effective in Pohnpei, but only when combined with commercial bans. Area protection could be used more effectively by targeting only key FSA sites (i.e. sites of high abundance and/or biodiversity), which would also reduce

funding requirements for the state and improve the potential for effective monitoring and enforcement.

While we acknowledge that these proposed measures may not work in all regions of the Indo-Pacific, a number of countries have circumstances similar to Pohnpei (e.g. large management areas, limited management resources and centralized markets). These countries may consider a similar approach that relies on a mix of management tools tailored to local political and economic reality; that is, combined area and temporal sales, catch, export and possession bans. Similar management measures are in place in Palau, which has included at least three FSAs under area protection in combination with a sales and export ban during much of the spawning season. Adjustments to that program to match sales bans to spawning times could also improve management there.

Acknowledgements

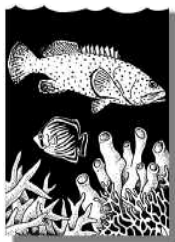
Funding support for monitoring by CSP and DMRD was provided by the Marine Resources Pacific Consortium (MAREPAC), US Department of the Interior and the David and Lucile Packard Foundation. Funding for author KR was provided by the National Oceanographic and Atmospheric Administration (NOAA) and the PADI Aware Foundation.⁷ The authors wish to thank Dakio and Juanita Paul, Kirino and Anson Olpet, and the numerous Peace Corps volunteers who have participated in the project. Monitoring training was provided by Jos Pet and Andreas Muljadi. Comments to improve the manuscript were provided by Jos Pet, Bill Raynor, Peter Mous, Kim Warren-Rhodes and Rick Hamilton. This article is dedicated to the memory of Benster Paul.

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7. Funding from the PADI Aware Foundation was provided to author Kevin Rhodes through the Pacific Islands Conservation Research Association, 4845 SE 3rd, Corvallis, OR 97333, USA.



Monitoring and managing spawning aggregations: Methods and challenges

Yvonne Sadovy¹, Pat Colin¹ and Michael Domeier¹

Introduction

The increased use of reef fish spawning aggregations as sources of food fish, and their susceptibility to overfishing make it increasingly important that such aggregations be managed and monitored. While we recognize that various options for managing spawning aggregations exist, whether through spatial or seasonal protection, effectively assessing the status of aggregations over time remains a challenge. Such assessment is essential for management but surprisingly difficult to achieve, largely because fishery-dependent data may not always indicate the true status of the fishery, and fishery-independent data can be misleading due to rapid changes in fish numbers during a single aggregation. In large aggregations, simply counting the fish moving about on the bottom can be a challenge. This article discusses some of the more obvious problems and needs, and is extracted from two articles that should be consulted for more information (Colin et al. 2003; Sadovy and Domeier 2005).

Unfortunately, there is no “one size fits all” approach to monitoring or managing commercially exploited, aggregating reef fish. Some species are naturally more vulnerable or more likely to be exposed to heavy fishing pressure throughout the year than others and may need to be assessed and managed during both aggregation and non-aggregation periods. One example would be species that form just a few large and highly concentrated aggregations. In contrast, a species such as the coral grouper, *Plectropomus leopardus*, which forms relatively small aggregations (often several on one reef, in close proximity to one another) may not be so severely affected by the loss of a few small aggregations. Species of either type may be heavily targeted throughout the year, even when not spawning. Some species can be more suitably protected through seasonal measures, others by site-

based protection, and all should be monitored in some way to determine whether the management option selected is effective or needs to be modified.

Management

Currently, the most commonly applied fisheries management measures for species that aggregate to spawn are seasonal bans on catches or sales and temporary aggregation site closures (Fig. 1). Marine protected areas have not typically incorporated spawning aggregations in their design, although this seems likely to change in the future. Sales bans can be a practical approach under certain conditions, such as when surveillance of spawning sites is not possible, if many sites are not yet known (indeed, in many areas the best protection that aggregation sites may have is to remain unknown), or if landings are concentrated in a few public markets. Protection of spawning aggregation sites during the spawning season, or their incorporation into marine protected areas, would not protect species also vulnerable while migrating en route to aggregations, or that are heavily fished at other times of the year. Consequently, the protective measure(s) selected need to take such considerations into account.

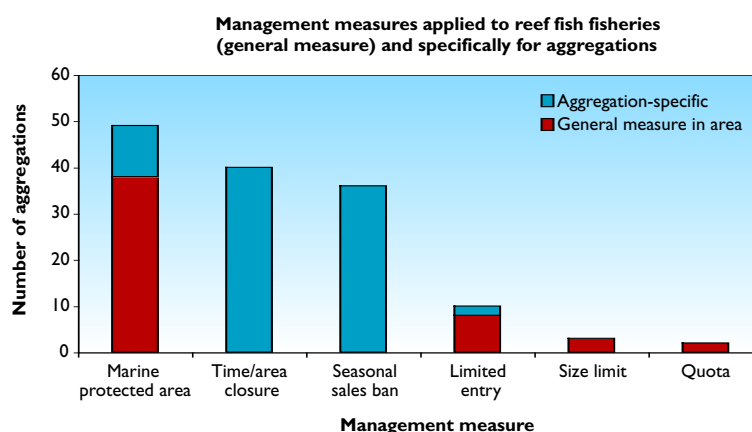


Figure 1. Available data on management associated with spawning aggregations or reef fish globally showed that management that specifically targeted protection of aggregations tended to involve temporary closures of spawning sites, sometimes associated with seasonal sales bans for the target species. Source: Society for the Conservation of Reef Fish Aggregations Database www.SCRFA.org

Fishery-dependent monitoring

Long-term monitoring is an essential component of successful management, and is a deceptively difficult challenge in the case of aggregation-spawners. Without monitoring, the effectiveness of management intervention cannot be assessed, and adaptive management cannot progress. Monitoring involves assessment of abundance over time, which can help to determine the seasonality of aggregations, and assess changes in numbers over time due to fishing, management or other factors. Because absolute numbers of fish are hard to determine, abundance in fisheries is usually determined by a proxy, such as catch per unit of effort (CPUE), which is typically assumed to be directly proportional to abundance. CPUE assessment requires both an estimate of fishing effort and an estimate of fish catch. The way in which fish and fishers are distributed in space and time can impact both catches and the relationship between CPUE and abundance, however. This is particularly important when the behaviour of fish changes in a predictable way, such as in the case of temporary aggregating behaviour.

When large numbers of fish concentrate periodically and predictably, the relationship between CPUE and abundance may not be directly proportional. If an aggregation-based fishery is not over-saturated (i.e. fishers are taking as many fish as they possibly can), CPUE is likely to remain stable even as the actual number of aggregated fish declines. This is a condition known as “hyperstability” and is a major problem for both monitoring and management (Hilborn and Walters 1992). When hyperstability occurs, fishers may resist management in the absence of evidence of dwindling catches; for managers it poses the problem that a monitored stock can decline without any change in aggregation CPUE that would indicate problems until the stock begins to collapse (Fig. 2). Monitoring cannot rely solely on CPUE measures, particularly for spawning aggregations.

Fishery-independent monitoring

While seemingly straightforward, counting aggregating fish in the water and calculating densities and changes in fish numbers over time can be a challenge, both in terms of monitoring design and execution. Nonetheless, the information to be gained can be very valuable for detecting changes in numbers over time, especially if part of a long-term monitoring program, and is critical for understanding the effects of management.

Why is it such a challenge to meaningfully monitor aggregating fish? As we have come to learn more about aggregations of different fish species,

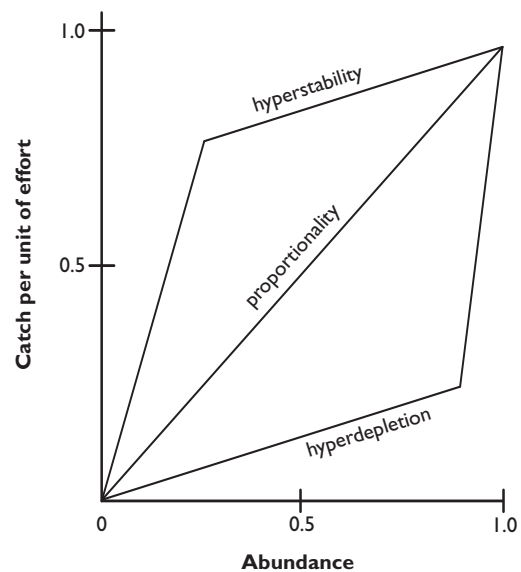


Figure 2. Relationships between catch per unit of effort (CPUE) and abundance under: **hyperstability** (when fish or fisher behaviour results in elevated CPUE even as fish abundance declines until the stock starts to collapse) and **hyperdepletion** (when catches fall disproportionately with effort).

Source: Sadvoy and Domeier 2005, based on Hilborn and Walters 1992.

or the same species over time, we have also come to understand how variable aggregations can be in time and space. For example, fish numbers can vary within a given aggregation site from year to year, and even from day to day, as can the timing of aggregation formation in a given year, or in relation to moon phase. The timing of aggregation formation of the same species can even vary among different aggregations located within just 20 km of each other, and certainly within a country or region. Understanding such variations is obviously very important when seasonal protection is introduced.

The problem of counting fish

The key question is how to count fish with an acceptable degree of precision so that information, over time and across space, is comparable and meaningful. This article discusses the most commonly used method, underwater visual census (UVC), but other methods, such as video recording, might also be possible under some circumstances. If aggregations are small or fish are few, it might be possible to count all the fish. When there are too many fish to count, an estimate can be made of the total number by counting the number of fish in a small and known area of an aggregation and extrapolating from this number

in accordance with an estimate of the total area over which the aggregation extends (see below). There is no easy way to check the accuracy of such estimates, so careful design and execution of surveys and careful analysis of survey results (including consideration of possible errors) are needed to ensure that the information collected is useful. If the methods are applied consistently between years, a valuable index of abundance can be developed, even if the estimates are not absolutely precise.

There are many important decisions that must be made when designing UVC surveys. When, where, how and why the surveys should be done are the key questions to be addressed. It is important, however, that before planning any aggregation survey, a preliminary exploratory dive be conducted at the site to provide basic information on the spatial extent of the aggregation, the depth range involved, and the water conditions, and to assess the order of magnitude of fish present and their responses to divers. Without this important information, it will be very difficult to design and plan a safe and scientifically meaningful survey.

Visual estimates are based on quantitative measures that either include the whole aggregation or can be expanded to include the entire aggregation (i.e. results from sub-areas are used as a basis from which to develop estimates that apply to the whole aggregation area). Most of these approaches fall into the category of "transect methods". The areal extent of the bottom area being surveyed must be known if measures of fish densities are needed, or if only some sub-areas can be sampled; this is why survey areas must often be mapped (see below). If surveys are to be repeatable, it is essential that a method is employed that allows the same area to be surveyed on each occasion. Distinct natural features on the bottom can be used for reference, or permanent floats or markers attached to the bottom. If natural features are used for reference, it is important that these be carefully documented (e.g. by mapping their positions), so that someone else can repeat a survey of the same area at a later date.

The problem of how to estimate fish numbers in an aggregation is tricky, with each species and site presenting its own set of challenges. At present, the best surveys have yielded only an approximation of actual numbers for aggregations numbering more than about 50 to 100 fish. The worst case is where fish are dense, distributed some distance from the bottom up into the water column, are moving constantly (as is the case for some acanthurids and lutjanids), are disturbed by human presence or are often hiding in the reef. In such cases, we would be fortunate to obtain a value that is within half or one-third the true number.

Measuring and mapping an aggregation site

If there is interest in assessing overall aggregation numbers but only sub-areas can be sampled (see above), the areal extent of the aggregation site must be measured. It is often most convenient to mark the edges of the site in advance, or at the time of the aggregation, using a marker that can be found later. This is particularly the case when an aggregation is of limited duration or fish are disturbed by diver activity within the aggregation site. The spatial extent of the aggregation can be measured later, based on the location of the markers, and an underwater survey done with compass and tape. If an accurate chart of the bottom is available, the edges of the aggregation can be plotted relative to known locations indicated on the map. Markers can take several forms: rocks painted different colours to represent different days, small lead fishing weights or short lines with floats. If the area of the aggregation is relatively large and surface floats are used, marker locations can be determined by using a global positioning system (GPS) receiver from a small boat. A rough estimate of the area can then be made, within the limits of GPS accuracy (see more on the application of GPS below). Markers can also be used to indicate the locations of specific fish for later analysis of spacing and density.

How to conduct an underwater survey

The size (i.e. length and width of each transect, with the width determined in part by visibility and general density of fish) and number of sampling units (i.e. total number of transects needed) must be determined. The effective transect width (i.e. the width across which fish numbers are being estimated) should then be determined, either visually (which requires experience) or by using markers previously placed on the substrate (see above). Transect length will be determined by the area or subsection of the aggregation to be surveyed, as well as other factors, such as depth and current. It would obviously be best to survey as large a proportion of an aggregation as possible.

Decisions must also be made regarding placement of transects within an aggregation. There may be few options, due to depth constraints, or as a result of the aggregation following a shelf edge contour or running along the walls of a reef channel or slope. Transects should be placed in areas that appear to be representative, but this may be very difficult to judge; their placement should be systematic. If the density clearly differs around the aggregation, then the best type of design is randomly stratified sampling (refer to Samoily 1997; Samoily and Carlos 2000; Colin et al. 2003). However, in this case, the strata must be identified. For large aggregations,

the appropriate methodology must be used and this may require consulting the literature or obtaining advice from a biologist (Fig. 3).



Figure 3. Counting large numbers of densely packed aggregated fish can be very difficult and needs careful planning. This example is a Caribbean grouper.

Photo printed with the kind permission of Philippe Bush, Cayman Islands.

In general, considerable care is needed at each decision point when designing an aggregation monitoring programme, taking into account the remarkable aggregation density variability that can occur over time and among locations, even within a species. Every attempt must be made to design a method that is repeatable, representative and provides some indication of the precision of the resulting estimates, although total counts may not have measures of precision associated with them. If these requirements are not met, the data obtained may be of little value and the money and time spent getting them may be squandered. Attempts should also be made to evaluate the accuracy of the results by independent means (such as video) whenever possible.

New methods are being developed that will make fish counts and data analysis easier to perform. For example, Pat Colin has developed a method based on GPS technology using a popular line of GPS receivers (Garmin eTrex; see <http://www.garmin.com/products/etrex/>; this model has the necessary features to support the methodological approach used). A GPS receiver works quite well inside a plastic (e.g. PVC) housing that protects it from the elements. This allows the receiver to be used underwater, where it can record positions over time in any sort of marine survey, logging positions at a pre-programmed time interval. If the unit is attached to a float it can be towed by a diver (who must be on the surface) or a snorkeler to record the surveyor's swimming track. Likewise it

can be attached to a current drifter and the track of the drifter can be downloaded from the unit after its recovery. The resolution of GPS-derived position data is about 2 m and the accuracy about 5–6 m. For further information on how to make or purchase a GPS unit housing, see newsletter No. 6 of the Society for the Conservation of Reef Fish Aggregations at www.scrfa.org or contact crff@palaunet.com.

In some situations, such as where currents are strong, or where fish and divers are in close proximity, it may be preferable for the diver to hold a fixed position and do stationary counts (see Colin et al. 2003).

Sources of error in fish counts

There are many possible sources of error when assessing fish numbers underwater, even when a monitoring protocol has been properly and carefully designed. These include substrate complexity, fish behaviour, between-diver differences in fish counts, changes in fish numbers between and within days, and double-counting (i.e. counting the same fish twice). Preliminary work can help to establish what kind of errors may have to be considered (for more detail, see Colin et al. 2003).

When should monitoring be done?

Having decided why, what and how to survey, decisions must also be made regarding when surveys should be conducted. If aggregations typically occur at a new moon, for example, then monitoring activity should be concentrated during that period. The probable timing of an aggregation must first be determined, however, as a species at a particular aggregation site may sometimes shift the timing of its aggregation between moon phases. Monitoring should initially occur at different moon phases and during the typical non-spawning period to ensure that important information on spawning timing is not missed. Whenever the timing of aggregation is not well known, examination of the reproductive status of fish available in markets and discussion with fishers may provide additional information useful for planning monitoring activities (see the country reports available at www.scrfa.org or write to scrfa@hkucc.hku.hk for examples of an interview approach). Decisions must also be made regarding the time of day to monitor an aggregation, given that fish numbers can vary markedly at an aggregation site over the course of the day. If a species is being studied for the first time, the preliminary studies should involve regular and frequent surveys.

Summary

Before starting any monitoring programme, it is important to ask (and answer) the following questions and take into account a number of considerations. This will help in focusing on the appropriate methods and approaches to use.

Why?

What is the purpose of the survey? Must it be repeatable?

When?

When in the year, month and day should the surveys be conducted? Are non-aggregation surveys also needed for reference? Is information needed on aggregation seasonality throughout the region?

Where?

Should surveys be confined to the aggregation site? Should both aggregation and non-aggregation sites be surveyed (i.e. survey the fish during the non-aggregation season)? Should the entire site or only part of the site be surveyed? Which parts of the site should be surveyed — a core area or along randomly placed transects?

How?

A preliminary site survey is needed first, in order to determine the depth and spatial extent of the aggregation, the order of magnitude of fish numbers, the effects of divers on fish and fish hiding behaviour, and so forth. This information is critical for the proper design of subsequent surveys. Other important steps and considerations include:

- Map the aggregation area.
- Qualitatively assess the number of fish and any core groups or dense schools.
- Depending on the density of fish, divide the aggregation site into sections, grids or contiguous transects to cover entire site.
- If the fish are very dense or spread out, sub-sample the site based on strata (e.g. depth and habitat).
- If fish numbers are not too high or fish not overly dense (50–100 fish or up to 50 fish per 1000 m²) then count all the fish unless they are spread over a very large area. This will give a total count.
- If there are distinct schools or core groups, sample these, map their location within the site to note any shifts in their location, and also sample fish densities between the core groups. If the core groups are very dense, sub-sample them.

- Make careful notes of the methodologies and protocols used so that others can later repeat the surveys.

Concluding comments

Carefully designed surveys are critical for detecting changes in the number of fish over time and to enable conservation and management decisions to be made based on that information. Conclusions drawn from the results of surveys must recognize the limits and constraints of the survey and of the sampling protocol. Most importantly, when designing any survey, ask yourself where, when and how the survey should be done and why it is being conducted in the first place.

The reasons for monitoring need to be carefully considered, and will strongly influence how monitoring can be conducted. Other important determinants of the monitoring approach include the species in question and local conditions (such as depth, current, ease of access to spawning aggregation sites, and budget). Where economically feasible, monitoring is important. In most cases, aggregations should be managed in order to ensure that the stock will persist in sufficient numbers to support ongoing fisheries.

Acknowledgements

We are very grateful to Melita Samoilyls who has provided us with valuable feedback on survey techniques over the years.

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Reef fish spawning aggregation studies at the University of Guam Marine Laboratory

Terry J. Donaldson¹

Studies of reef fish spawning aggregations by members of the University of Guam Marine Laboratory, in collaboration with other institutions, continue throughout the western Pacific region. University of Guam Marine Laboratory (UOGML) graduate student, Peter Dixon, is investigating spawning aggregations of *Epinephelus polyphkadion* and *Plectropomus areolatus* in Palau and Federated States of Micronesia (Pohnpei). His work, funded by a US Sea Grant award to Dr Mark Tupper (Palau International Coral Reef Center and UOGML), utilizes acoustic tracking methods to investigate grouper catchment distances, migratory routes, spawning dynamics, and periodicity of aggregations. In 2004, 27 *E. polyphkadion* and three *P. areolatus* were tagged with coded Vemco V16 transmitters at Ulong Channel in Palau. The tagged fish were monitored using an array of nine Vemco VR2 receivers, and were also tracked actively with Vemco hydrophones. In April 2005, an additional 50 *P. areolatus* (25 male, 25 female) were tagged at Ulong Channel. These fish will be monitored over the course of the spawning season and into 2006. In Pohnpei, in a collaborative effort with Dr Kevin Rhodes, 40 *P. areolatus* (20 male, 20 female) were tagged in January and February 2005 at an aggregation site within the Kehpera Marine Sanctuary. These fish will be monitored over the next year. Dixon's thesis work, which is being supervised by Dr Donaldson, should be available by June 2006.

A preliminary assessment of reef fish spawning aggregations and sites at remote locations in Milne Bay Province, Papua New Guinea, was undertaken in March 2005 with funding from the National Geographic Society, UOGML, and the Coral Reef Research Foundation (CRRF, Palau). Dr Terry Donaldson (UOGML) was joined by Dr Patrick Colin (CRRF), Martin Russell (Great Barrier Reef Marine Park Authority, Australia), Dr Michael Domeier (Phleger Institute for Environmental Research – PIER, California USA), and Bonnie Domeier (PIER) for a survey conducted aboard the MV *Chertan*, a live-aboard dive vessel under the

command of Captain Rob van der Loos. The team surveyed a number of remote reefs, both offshore and in the vicinity of the East Cape. Divers employed towed geographical positioning system (GPS) tracking buoys as they mapped habitats and counted fish at aggregation sites. A GPS-linked fathometer was also employed to map benthic structure at these sites. Team members utilized digital cameras and video cameras to record fish behaviour, as well. Work on the offshore reefs, however, was cut short by the threat of Cyclone Ingrid. The team plans to return again in 2006.

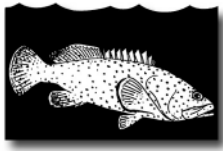
Donaldson continues to collaborate with Colin on related studies in Palau that utilize GPS technology in the quantitative assessment of reef fish spawning aggregations. This collaboration is now in its third year and focuses upon spawning aggregation dynamics, physical and oceanographic characteristics of sites, reproductive behaviour (including lekking — the behaviour associated with a temporary aggregation of sexually-active males for the purpose of reproduction), and egg and larval transport. This work has been funded by CRRF and The Nature Conservancy. Some of the methods employed in this study were the subject of a recent paper, co-authored by Colin, Donaldson and Dr Laura Martin (CRRF), and delivered by Colin at the 7th Indo-Pacific Fish Conference held in Taipei, Taiwan, in May 2005.²

Later this year, Donaldson will also conduct preliminary assessments of spawning aggregation sites in Vietnam and northern Palawan, Philippines, with funding from the US National Oceanographic and Atmospheric Administration.



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2. Colin P.L., Donaldson T.J. and Martin L.E. 2005. A new method for quantitatively assessing reef fish spawning aggregations and other populations of reef fishes. Abstract S9–10, p. 56. 7th Indo-Pacific Fish Conference, May 16–20 2005, Taipei, Taiwan.



Noteworthy publications

live reef fish

Note from the editor: As part of the global database of spawning aggregations being developed by the Society for the Conservation of Reef Fish Aggregations (SCRFA), a series of area-specific reports based primarily on the knowledge of local fishers, called the “Western Pacific Fisher Survey Series”, has been prepared and is available on the SCRFA website. There are reports for Sabah (East Malaysia), Papua New Guinea and Solomon Islands, the Federated States of Micronesia, and Eastern Indonesia, as listed below, and additional studies are in progress. The reports can be downloaded from <http://www.scrfa.org/server/studying/reports.htm>

Daw T. 2004. Reef fish aggregations in Sabah, East Malaysia: A report on stakeholder interviews conducted for the Society for the Conservation of Reef Fish Spawning Aggregations. Western Pacific Fisher Survey Series, Volume 5. Society for the Conservation of Reef Fish Aggregations. 59 p.

Hamilton R. 2003. A report on the current status of exploited reef fish aggregations in the Solomon Islands and Papua New Guinea – Choiseul, Ysabel, Bougainville and Manus Provinces. Western Pacific Fisher Survey Series, Volume 1. Society for the Conservation of Reef Fish Aggregations. 52 p.

Rhodes KL. 2003. Spawning aggregation survey in the Federated States of Micronesia. Western Pacific Fisher Survey Series, Volume 2. Society for the Conservation of Reef Fish Aggregations. 35 p.

Sadovy Y and Liu M. 2004. Report on the current status and exploitation history of reef fish spawning aggregations in Eastern Indonesia. Western Pacific Fisher Survey Series, Volume 6. Society for the Conservation of Reef Fish Aggregations. 41 p.

Note from the editor: At least two practical manuals for studying and monitoring reef fish spawning aggregations are now available, a 2003 publication of the Society for the Conservation of Reef Fish Aggregations (SCRFA) and a 2005 publication of The Nature Conservancy (TNC):

Colin P.L., Sadovy Y.J. and Domeier M.L. 2003. Manual for the study and conservation of reef fish spawning aggregations. Special Publication No. 1. Version 1.0. Society for the Conservation of Reef Fish Aggregations. 98 p. [<http://www.scrfa.org/server/studying/handbook.htm>]

This manual is “intended to serve as a resource to aid in choosing productive and scientifically sound methods for investigating reef fish aggregations and for promoting their conservation....” Its scope is broad, covering scientific study generally as well as management-oriented monitoring.

Pet J.S., Mous P.J., Rhodes K. and Green A. 2005. Introduction to monitoring of spawning aggregations of three grouper species from the Indo-Pacific: A manual for field practitioners. Version 1.2. Sanur, Bali, Indonesia: The Nature Conservancy Southeast Asia Center for Marine Protected Areas. 69 p. [<http://www.tnc-seacmpa.org/>]

This manual offers fairly specific protocols for regular monitoring of aggregations, and it focuses on three particular species of grouper that tend to aggregate at the same sites and times in the Indo-Pacific region. It presents itself as a complement to the SCRFA manual and is an example of one of the “practical guides and protocols” that the SCRFA manual envisions being prepared for specific needs and circumstances.

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Original text: English

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