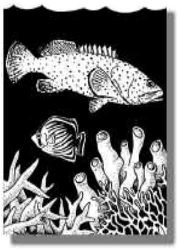

Applying local knowledge and science to the management of grouper aggregation sites in Melanesia

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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 sites[6]. 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 coralgrouper (*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 predicable 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 Province[7], 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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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 information[9] 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	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter	Every month of the year
2	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter	Every month of the year
3	*Plectropomus areolatus*	Third quarter	Unknown
4	*Plectropomus areolatus*	Third quarter	Every month of the year
5	*Plectropomus areolatus*	Third quarter	Every month of the year
6	*Epinephelus polyphekadion*	Third quarter	Unknown
7	*Epinephelus polyphekadion*	Third quarter	Unknown
8	*Epinephelus polystigma*	Third quarter	Every month of the year
9	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter	Every month of the year
10	*Plectropomus areolatus,* *Epinephelus fuscoguttatus*	Third quarter	Every month of the year
11	*Plectropomus areolatus* *Epinephelus fuscoguttatus*	Third quarter	Every month of the year
12	*Plectropomus areolatus* *Epinephelus fuscoguttatus*	Third quarter	Every month of the year
13	*Plectropomus areolatus*	Third quarter	Every month of the year
14	*Plectropomus areolatus*	Third quarter	Every month of the year
15	*Plectropomus areolatus*	Third quarter	Every month of the year
16	*Plectropomus areolatus*	Third quarter	Every month of the year
17	*Epinephelus fuscoguttatus*	Third quarter	Every month of the year
18	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Unknown	Unknown

9. Due to the continued threat of commercial LRFFT 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	*Epinephelus fuscoguttatus* *Epinephelus polyphekadion* *Epinephelus ongus*	Third quarter	A, B & C
20	*Epinephelus ongus*	Third quarter – New moon	A, B & C
21 S & H	*Plectropomus areolatus*	Third quarter	Every month of the year; peak season in months A, B & C
21 S & H	*Epinephelus fuscoguttatus*	Third quarter	A, B & C
22 H	*Plectropomus areolatus*	Third quarter	Every month of the year; peak season in months A, B & C
23 S & H	*Plectropomus areolatus*	Third quarter	Every month of the year; peak season in months A, B & C
23 S & H	*Epinephelus fuscoguttatus*	Third quarter	A, B & C
24	*Plectropomus areolatus*	Third quarter	Every month of the year; peak season in months A, B & C
25	*Plectropomus areolatus* *Epinephelus polyphekadion* *Epinephelus lanceolatus*	Unknown	Peak season in month A
26	*Epinephelus polystigma*	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	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter – New moon	Unclear, but known to have an extended season, possibly with a peak season in months H, I, J & K
28	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion* *Epinephelus ongus*	Third quarter – New moon	Unclear, but known to have an extended season, possibly with a peak season in months H, I, J & K
29	*Plectropomus areolatus* *Epinephelus fuscoguttatus*	Third quarter – New moon	H, I, J & K
30	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
31	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
32	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter – New moon	H, I, J & K
33	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
34	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
35	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
36	*Epinephelus ongus*	Third quarter – New moon	H, I, J & K
37	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter – New moon	H, I, J & K
38	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Third quarter – New moon	H, I, J & K
39	*Epinephelus fuscoguttatus*	Third quarter – New moon	H, I, J & K
40	*Plectropomus areolatus*	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	*Plectropomus areolatus*	New moon	Every month of the year
42	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Unknown	Unknown
43	*Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Unknown	Unknown
44	*Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Unknown	Unknown
44	*Plectropomus areolatus* *Epinephelus fuscoguttatus* *Epinephelus polyphekadion*	Unknown	Unknown
45	*Plectropomus areolatus*	Unknown	Unknown
46	*Plectropomus areolatus*	Unknown	Unknown
47	*Plectropomus leopardus*	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 hand-held 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).

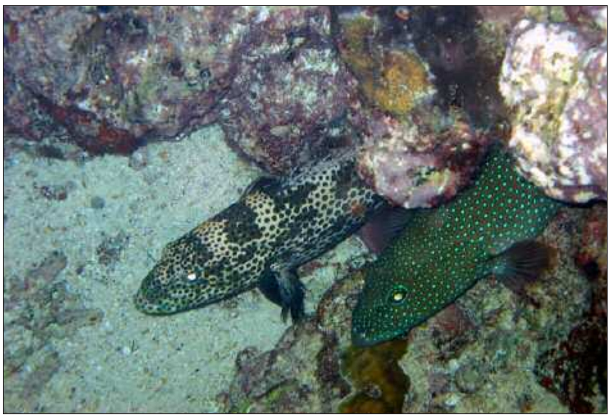

Figure 3. **Two resting *P. areolatus* at a spawning aggregation site. This photo was taken at night. The fish on the left is in the camouflage colour phase that is seen in males and females. The fish on the right is displaying the yellow/green colour phase seen only in females.**

- *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. polyphekadion* 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. polyphekadion* 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. polyphekadion* 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. polyphekadion* 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. polyphekadion* 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 LRRFT 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. ongus*) 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. ongus* 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 LRRFT 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 paper[10]) 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 bans[11] 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 Lagoon[12]. 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.

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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 (RVLRMP). While TNC continues to provide technical assistance to RSAMT, the RVLRMP took over funding all of RSAMT's monitoring costs in 2005.

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