Aggregation fishing and local management within a marine protected area in Indonesia

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Introduction

The live reef food fish trade (LRFFT) is a widespread commercial fishery that since the 1990s has spread from Southeast Asia to ever-expanding locales within the Indo-Pacific (Sadovy et al. 2003). Historically, the trade has focused on groupers and wrasses, with fish spawning aggregations (FSA) often the primary target. As a direct result of FSA fishing and the heavy fishing pressure otherwise associated with the trade, many targeted species have experienced population-level declines and aggregation loss (Sadovy and Domeier 2005). Some species, such as squaretail coralgrouper (*Plectropomus areolatus*) are now listed as vulnerable (www.iucnredlist.org) and yet are still highly sought after by the trade (e.g. Sadovy 2005). Partly as a reflection of the trade's capacity, annual grouper landings increased from around 30,000 tonnes (t) in the 1980s to more than 140,000 t by 2000 (FAO 2010). To gauge the scale of the impact of the trade, a recent study showed that live reef fish imports into Hong Kong — one of several import countries — equates to the maximum sustainable yield of the entire stock of groupers in Southeast Asia (Warren-Rhodes et al. 2003). China's increasing expansion into the trade as an importer will undoubtedly add significantly to both the volumes of fish harvested and the adverse impacts on fishery resources.

The LRFFT, by its nature, is a boom-and-bust industry, extracting large volumes of fish from an area and then moving on once stocks are depleted (Sadovy et al. 2003). In some locations, such as Indonesia, this cycle has been repeated since the 1980s when the LRFFT expanded from its origin. In most parts of Indonesia, FSA of many species no longer form and few viable aggregations are known. Where they do exist, they appear to comprise no more than a few or a few tens of individuals (e.g. Pet et al. 2005), with little reproductive and recruitment potential. As an example, a recent assessment of spawning aggregations in Misool and Kofiau, Raja Ampat, Indonesia, was unable to verify a single aggregation site among several historically known fishing areas due to the low number of fish remaining. At the inception of the trade in these same locales, fishers reported large aggregations and large volumes of fish exported. Currently, fishers rely on remaining stocks to fuel the trade, yet rarely catch more than a few fish daily. Nonetheless, local LRFFT operations continue to exist, targeting remnant FSA and rapidly depleting newly discovered ones.

In Raja Ampat (Fig. 1), interviews with fishers were initially conducted by Conservation International (CI) at a site that will not be disclosed here (hereafter referred to as Site 1). From these interviews, nine separate FSA of several commercially important species were identified, including among others, groupers (Epinephelidae), snappers (Lutjanidae), trevallies (Carangidae) and wrasses (Labridae). These species are critical to regional and local fisheries and many form the basis of the LRFFT. In addition, anecdotal reports of the spawning season and lunar periodicity were provided during interviews. The information in those reports was confirmed by results from a separate acoustic tagging study of squaretail coralgrouper, *Plectropomus areolatus*, the results of which will not be presented here. Findings confirmed anecdotal reports of a September through January spawning season for the species. Ownership of coral reefs and associated resources within Site 1, including the FSA, is distributed among island groups or clans, with some FSA contested between local villages. Management of, and fisheries for, these FSA is, therefore, complex. Currently, Site 1 is within a marine protected area (MPA) (Fig. 1), with permitted yet managed use of reef resources, including spawning sites. As one example of local management, seasonal or site closures (*sasi*) (McLeod et al. 2009) to fishing are practiced on FSA and there are strict gear restrictions on explosives and cyanide fishing. Damage from previous explosives use is apparent throughout Site 1, similar to the whole of Indonesia.

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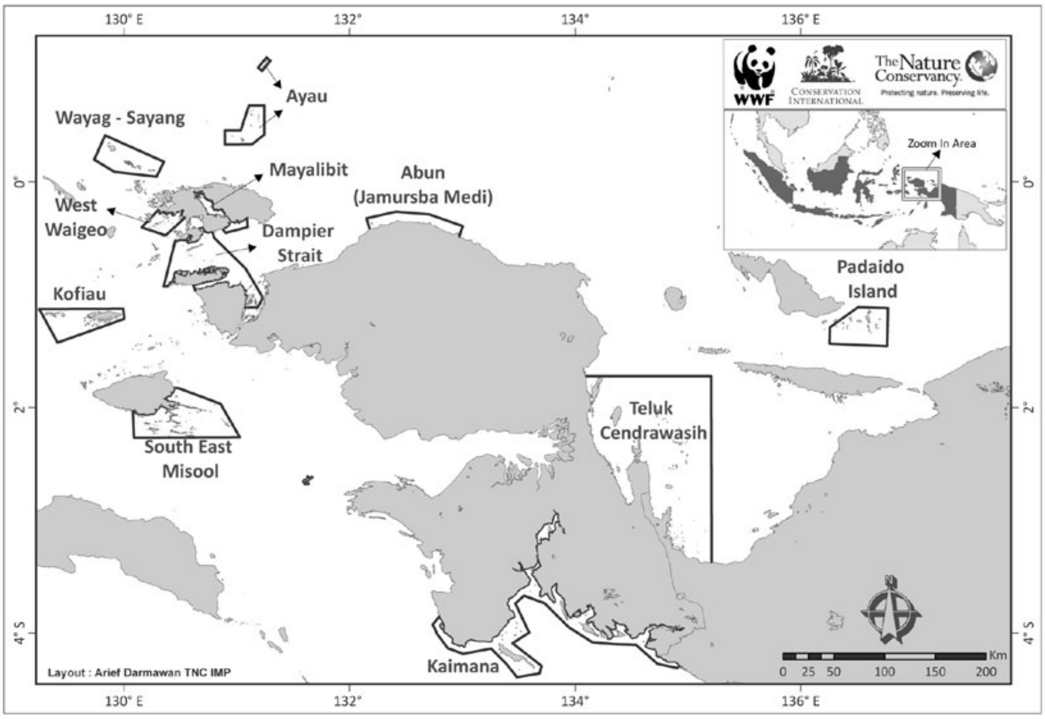

Figure 1. Map of Raja Ampat, Indonesia, where the study was conducted.
Areas bordered by polygons represent marine protected areas.

Site 1 has a long history of FSA fishing that until the 1980s did not appear to be highly commercialised. In the 1980s, Site 1 FSA became subject to commercial fishing for the LRFFT, although the historical sequence of events surrounding the trade has been poorly documented. Anecdotal reports of past levels of fishing pressure (*circa* 1980–1990) and catch and export data from aggregation fishing for the LRFFT indicate a thriving trade, with multiple transport vessels frequenting Site 1 monthly and exporting tens of tonnes annually. More recently, declines in catch at Site 1 have been reported, with only a single transport vessel visiting a few times per year, in comparison to multiple monthly exports in the past. In September 2009, only 3 t of live fish and lobster were shipped from local *karambas* (holding pens), which represented catch from various areas at Site 1 and excluded catch from the study FSA that was at the time closed to fishing (see below).

The main objectives of the study reported on here were to verify and quantify one of several fished and locally managed FSA at Site 1, Raja Ampat, Indonesia. A further objective was to use conventional tag-and-recapture techniques to examine potential (straight-line) distances of movement and vulnerability to fishing of squaretail coralgrouper, *Plectropomus areolatus*, a primary target of the LRFFT. Thirdly, using the existing fishery for the LRFFT at Site 1, we examined catch per unit of effort (CPUE) of *P. areolatus* in order to quantify the impact to the aggregation from a discrete fishing period.

Methods

Monitoring (underwater visual census)

Underwater visual census (UVC) monitoring of the FSA was conducted 8–17 October 2009, using scuba. Since the site had not been investigated previously, initial dives were conducted to locate and define target fish species' aggregation areas and to characterise habitat. Once core aggregation areas were identified, fish counts were made. Fish abundance counts were made by two 2-diver teams swimming along the fore and back reef where FSA were observed to form. Counts were based on all individuals and target species encountered during swims. Monitoring in fore and back reef areas were similar in both depth and distance. Counts included all species suspected of using the site for reproduction.

Conventional tagging

From 10–12 October 2009, *P. areolatus* captured in the existing FSA fishery were tagged with conventional and acoustic tags. All fishing was done by local Site 1 villagers from motorised outrigger-type dugout canoes, each typically fitted with a 5-horsepower inboard 2-cycle gasoline-powered engine (Fig. 2). Fishers targeted their prey from the surface using eye goggles and hook-and-line baited with live soldierfish (*Myripristis* sp.). Fish used for tagging were purchased from fishers at 75,000 rupiah (about USD 8) each. Following purchase, fish were

Figure 2. A fisher and a typical local canoe, Site 1, Raja Ampat, Indonesia (photo by J. Wilson).

brought on board the research boat and placed in an aerated live well.

Floy dart-type (FT-94) tags were used for conventional tagging. Tags were inserted manually between the dorsal pterigiophores using a tagging needle. All conventional tags were uniquely numbered, with the word "Reward" (in Bahasa Indonesia) and contact information printed along the tag shaft. The tag programme was announced verbally and using posted colour posters to alert local stakeholders and fishers (Fig. 3). Prior to tagging, all fish were weighed (nearest 0.1 kg) and measured (nearest cm total length), with sex determined by size and coloration.

Catch per unit of effort and fishing methods

Information on CPUE of *P. areolatus* at the FSA was gathered from 9–17 October, exclusive of 11 October in recognition of local religious custom. Daily counts were taken of the total number of boats and fishers. The data were recorded by a provincial fisheries officer with the aid of local community members. For each fishing boat, surveys were conducted periodically throughout each day to record the type and number of fish captured per fishers, gear use, and total fishing times per individual. Fishing and, thus, CPUE estimates, were limited to daylight hours.

Results

Sites and site characteristics

Dive monitoring at the site during the October 2009 expedition identified three verified and several potential FSA along a finger-like extension (spur) of the reef. The spur was separated from the main fringing reef by a submerged back-reef cove, the depth of which ranged from a few meters to more than 40 m. At its widest point, the spur was separated from the fringing reef by about 100–200 m of sandy bottom, with characteristics that suggested periodic high current flow. The spur had a range of relief, type, cover and complexity. The fore reef was mostly bare of coral, except for a single large promontory that began at about 25–30 m depth and extended to more than 60 m depth. In that area, the substrate was interspersed with areas of scattered, moderate-relief coral (to 1 m of relief). The back reef was rich in coral throughout the length of the spur, with high relief (2–3 m) patch reefs at the shallow end and hard corals of moderate relief and increasing cover along most of the remaining sections. The top reef showed considerable impacts from explosives, with large (100 m^2 and greater) sections of rubble in the area of the FSA. Aggregating fish appeared to have less association with damaged than unaffected areas. Current flow along the spur was generally mild and varied

Figure 3. The poster used to publicise the tag programme.

in direction and strength throughout the monitoring period. Opposing currents, as localised convergences, were noted. Visibility ranged from a few meters to more than 30 m or more, depending on tidal flow and time of day.

Monitoring (underwater visual census)

During initial monitoring, aggregations of barracuda (*Sphyraena* sp., about 50 fish), humpback unicornfish (*Naso brachycentron*, about 100 individuals), longface emperor (*Lethrinus olivaceus*, about 40–60 fish), rudderfish (*Kyphosus* sp., about 100 fish), two-spot red snapper (*Lutjanus bohar*, about 100 fish) and bigeye trevally (*Caranx sexfasciatus*, about 400 fish) were observed, along with large schools of green humphead parrotfish (*Bolbometopon muricatum*, about 20–30 fish). Large adults of both humphead wrasse (*Cheilinus undulatus*) and blacksaddled coralgrouper (*Plectropomus laevis*) were common. During the first days of monitoring, large schools of ringtail surgeonfish (*Acanthurus blochii*) were also present. It is unclear if these aggregations were all reproductive, but direct observation of spawning in bigeye trevally was observed at about 1600 hr, along with associated colour change and courtship throughout the day.

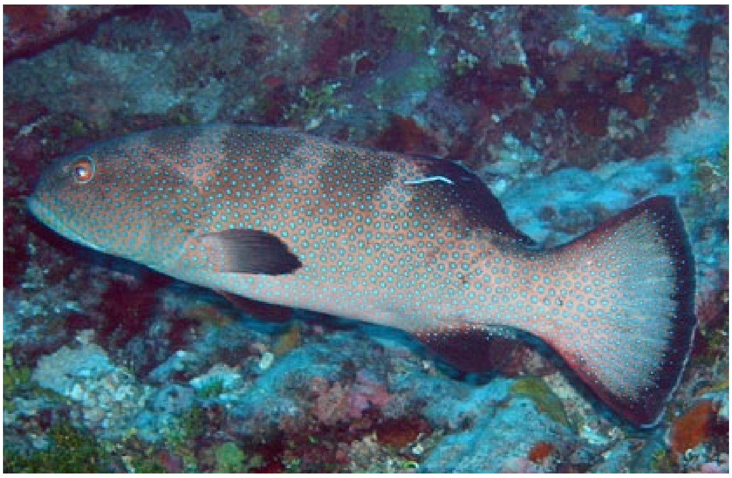

Figure 4. *P. areolatus* tagged with FT-94B dart-type spaghetti tag (photo by E. Joseph).

UVC also identified substantial FSA of *P. areolatus* and brown-marbled grouper (*Epinephelus fuscoguttatus*). On the final day of monitoring, dive teams counted about 300 *P. areolatus* and about 80 *E. fuscoguttatus*, considered to be peak abundances for that lunar month. Brown-marbled grouper were associated with moderate coral reef cover and moderate-to-high relief corals in both the fore and back reefs. *E. fuscoguttatus* were found at 15–30 m depth along the back reef, and from about 10 m to greater than 60 m in the fore reef. *P. areolatus* were primarily associated with hard coral areas along the back and fore reef at depths of 15–20 m. On the final day of monitoring, most individuals of *P. areolatus* were found along a section of the reef crest about 200–300 m in length. Courtship, territoriality, colour change and gravid *P. areolatus* females were commonly observed, while biting, chasing and scars were associated with *E. fuscoguttatus*. Migrating schools of *P. areolatus* females were observed leaving the site two days before new moon, suggesting that some spawning had occurred.

Conventional tag-recapture

Over two days (10–11 October), 40 *P. areolatus* (27 females, 13 males) were conventionally tagged with FT-94B dart-type spaghetti tags (Fig. 4). Tagged fish ranged from 32–53 cm in total length (TL) and 0.4–1.8 kg in weight. Females averaged 40.5±5.0 cm TL and 1.0±0.4 kg, while males averaged 44.0±3.4 cm TL and 1.3±0.3 kg.

In total, fishers recaptured 5 of the 40 tagged *P. areolatus* (12.5% of the total). Three tagged females were recaptured at the FSA over five days of the aggregation period in October. Of these, two fish tagged on 10 October were recaptured once (recaptured 12 October and 14 October, respectively). The third female, tagged on 12 October, was recaptured first on 13 October and again on 15 October). A male tagged on 10 October was recaptured at the FSA site 28 October and a female tagged 12 October was recaptured twice at a location approximately 4 km away from the site, on 30 October and 3 December 2009.

Catch per unit of effort and fishing methods

Information on CPUE was gathered over five of the six days that fishing took place on the *P. areolatus* aggregation. The number of fishers generally increased towards the end of the aggregation period and ranged from 4–28 individuals per day (Fig. 5). During the survey, 564 *P. areolatus* were captured. In combination with the underwater monitoring results, this suggests an aggregation of 860+ individuals at the FSA. On average, CPUE was 0.7 fish hr^{-1} and ranged from less than 0.1 to 4.5 fish hr^{-1} (Fig. 6). Similar to the number of fishers, both CPUE and the number of fish captured increased at the FSA as the new moon approached (Fig. 5 and 6). Captured fish were maintained in a live well on board each vessel or transported to a nearby submerged holding net fitted with a surface float until they were transported to the village *karambas* (holding pens for the LRFFT).

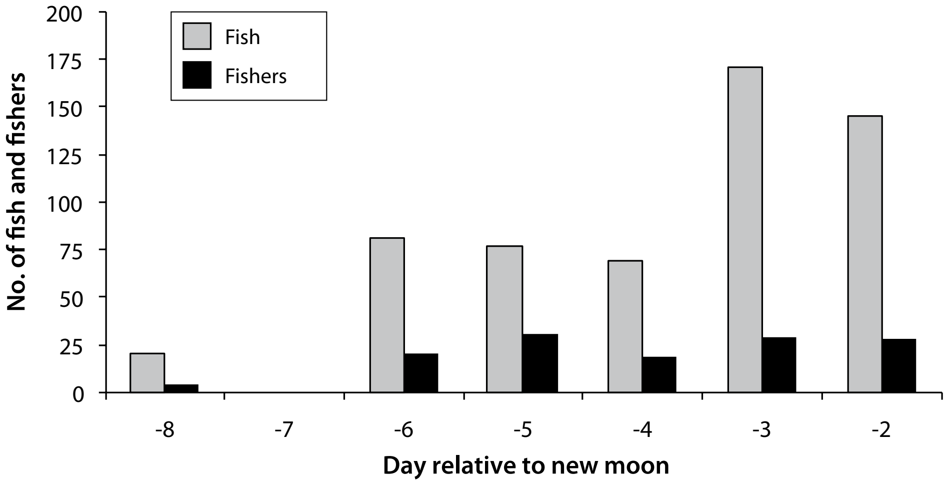

Figure 5. Total number of fish captured (grey) and number of fishers (black) by survey day, at the target *P. areolatus* FSA. No monitoring was conducted on the day seven prior to the new moon (Day -7) in observation of local religious custom.

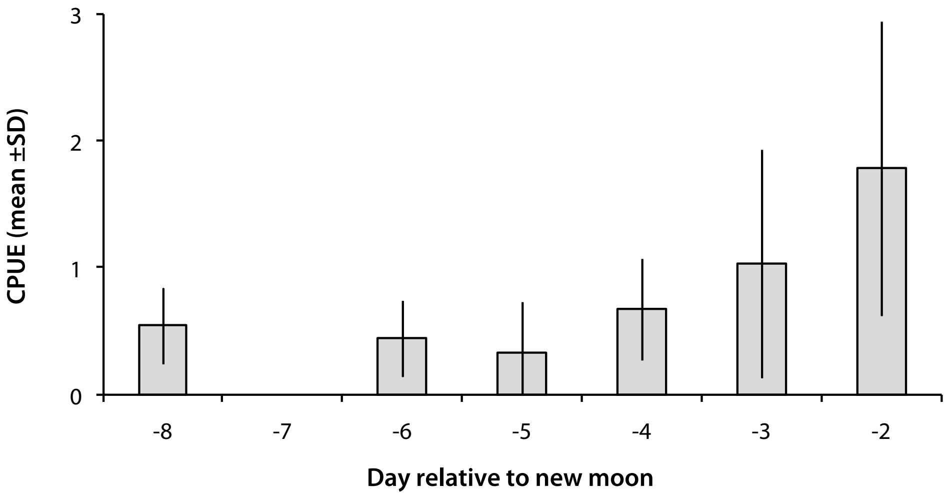

Figure 6. Daily mean (open bars) and standard deviation (SD) (lines) of catch per unit of effort (CPUE) for *P. areolatus*. Means (and SD) are derived by averaging the individual CPUEs for all fishers on the FSA during each day of monitoring. No monitoring was conducted on the day seven prior to the new moon (Day -7) in observation of local religious custom.

Discussion

Informal interviews with local Site 1 fishers by CI provided useful anecdotal information on FSA location, spawning season and species composition that allowed further investigations to be streamlined. In these interviews, *P. areolatus* were reported to form lunar monthly aggregations at Site 1 from September through January each year and to co-aggregate with *Epinephelus fuscoguttatus* at the site. This information was verified using a combination of underwater visual census and both acoustic (not presented here) and conventional tag-recapture surveys. As in previous studies, these results illustrate the utility of anecdotal information in identifying the location and timing of spawning aggregations.

The results highlight the extreme vulnerability to fishing inherent in commercially important aggregation-forming fish species. Specifically, fishing on the FSA over only six days removed what appears to have been more than two-thirds of the size of the *P. areolatus* aggregation.[4] During this same period, CPUE increased along with the number of fishers using the site. The study also provided meaningful insight into spawning aggregation site characteris-

4. Total abundance counts assume no fish left the site prior to the final day of monitoring and that all fish were present within the monitored area.

tics, dynamics, and an aggregation fishery previously unexamined in any detail.

Based on these monitoring results, Site 1 entertains at least one highly biodiverse and reproductively viable multi-species fish spawning aggregation. During monitoring, both *P. areolatus* and *E. fuscoguttatus*, along with one carangid (bigeye trevally, *Caranx sexfasciatus*) showed reproductive activity. The abundance of each of the three species was among the highest recorded in recent years at an FSA site in Indonesia.

The tag-and-recapture component of the study provided information useful for management, highlighting the vulnerability of fish to aggregation fishing. Similar findings have been shown elsewhere, with the highest level of vulnerability shown either at the aggregation or within the reproductive season (e.g. Johannes et al. 1999; Whaylen et al. 2004; Rhodes and Tupper 2008). Specifically, at Site 1, four of 40 tagged fish were recaptured within the FSA during the reproductive season, and one of those four fish was recaptured twice at the FSA. A fifth individual was recaptured twice within the spawning season, but at a locale 4 km northwest of the FSA site. It is likely that this fish was within its non-reproductive home range, assuming home range areas are similar across locales (e.g. Hutchinson and Rhodes 2010). Previous studies of aggregating groupers suggest that individuals migrate to home range areas between aggregation months (e.g. Starr et al. 2007). If true, the recapture of this individual twice in a locale away from the FSA suggests high home range site fidelity in a second regional locale.

The high percentage of recaptures at the FSA underscores the impact of aggregation fishing and provides strong support for protection of reproductive adults. Site 1 is inside an MPA that allows for multiple uses. Zoning and management plans are currently being developed for all MPAs in the Raja Ampat MPA network. Fishing is allowed but is currently controlled under *sasi*. At Site 1, fishing on FSA is only allowed by traditional owners (villagers) using specific gear and during specified periods within the spawning season. It is currently unclear what methods the village uses to determine the allowable period and level of catch. Nonetheless, the level of impact observed during the current survey clearly suggests that greater restrictions are needed, which may include a temporary or permanent no-take zone (NTZ). Using information from recent studies, an NTZ radiating 4–6 km from the "core" could protect reproductively active fish during the spawning period. Previous work on *P. areolatus* has suggested that a NTZ of 100–200 km^2 around and encompassing the aggregation site may be needed to provide full protection of spawning populations of this species, because such an area would likely incorporate migratory corridors and at least some of the home range area and habitat of the reproductive population (e.g. Rhodes and Tupper 2008; Hutchinson and Rhodes 2010). Alternatively, a catch and export ban would provide temporal protection of reproductively active fish, but at Site 1, such a ban is unlikely, given the limited economic alternatives at Site 1 and the historical involvement in the export of live reef food (and ornamental) fish.

At Site 1, commercial aggregation fishing for the LRFFT has been conducted for at least 30 years, presumably at all sites that were recently identified by CI. Whereas persistent, heavy fishing pressure in other locales has often resulted in aggregation extirpation over relatively short periods (e.g. Johannes et al. 1999; Hamilton et al. 2005; Hamilton and Matawai 2006), Site 1 appears to have been sufficiently managed to avoid FSA loss. The questions for Site 1 are: 1) What mechanisms are acting to prevent aggregation loss? and 2) What impacts have occurred to local reproductive fish populations? At Site 1, traditional management is a strong cultural component and is used to control coral reef fisheries, including aggregation fishing. One management technique is a *sasi*, or closure, which provides protection of a particular area during a particular period or periods (McLeod et al. 2009). At the FSA study site, a *sasi* prevented fishing during the 2009 September through January aggregation period, except for a 10-day period in October when fish were known to be aggregating. Similar bans exist elsewhere, such as the *bul* on several aggregations in Palau (e.g. Johannes et al. 1999) and the *tambu* in many parts of Melanesia (Hamilton et al. 2004) and Micronesia. Each of these systems seems to have had some success in controlling fishing. In Melanesia, *tambu* are often used to maintain or grow populations, with fishing only allowed during specified periods when populations appear robust. The Indonesian *sasi* are used similarly, but currently there is insufficient information to determine the rationale or effectiveness of the practice in regard to protecting local spawning aggregations.

Additional studies to investigate the history of both the LRFFT at Site 1 and the use of traditional management of marine resources would inform management options for FSA. Educational levels and per capita income at Site 1 are among the highest in Indonesia as a direct result of the income derived from participation in the LRFFT. Based on average prices paid to local fishers for *P. areolatus* in October (IDR 60,000 kg^{-1}), the October catch from the aggregation was worth USD 3,600. Communities at Site 1 clearly have a strong interest in maintaining aggregation sites and community leaders appear to have an understanding of the need for a balance between resource use and socioeconomic stability. Perhaps due to the strong implementation of the local management system, or *sasi*, Site 1 has been able to exploit FSA for more than 30 years. It is unfortunate that a similar recognition of balance has not been shown elsewhere in Indonesia with regard to the LRFFT. If the LRFFT is to continue in the country, it is clear that strong local governance systems are needed to protect FSA.

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