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Lessons learnt from experimental temporary octopus fishing closures in south-west Madagascar: benefits of concurrent closures

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This paper presents evidence of the fisheries effect of experimental temporary fishing closures for *Octopus cyanea* in the then-emergent Velondriake Locally Managed Marine Area (LMMA) in south-west Madagascar during 2004–2006. We present an analysis of the *O. cyanea* catch data for the first two years of temporary closures based on landings data collected from village-based octopus collectors. We found a significant closure effect in terms of total weight and number of octopus caught on opening days, but observed that these benefits dissipated quickly, returning to pre-closure levels within days. Mean octopus size increased by 41% on average when compared to data from selected control sites. However, extremely high levels of fishing effort on opening days meant that these biological effects did not translate into increased weight of octopus caught per successful fisher over the opening tide. Upon opening of concurrent closures during the second round of closures we found significant increases in the weight of octopus caught per successful fisher. We conclude that the pilot closures had a significant closure effect, but caution against isolated openings leading to concentrated fishing effort on opening days.

Keywords: fishery management, locally managed marine area (LMMA), *Octopus cyanea*

Introduction

The fishery for reef octopus *Octopus cyanea* is one of the three economically most important activities for coastal communities in the south-west region of Madagascar (Barnes-Mauthe et al. 2013), an arid region where there are few economic alternatives to marine resource extraction. Since the early 2000s, fisheries collection companies have purchased catches from coastal villages throughout the region. This commercial exploitation of octopus has increased the local value of the fishery, and transformed a formerly traditional and subsistence fishery into an export-driven collection fishery, dramatically increasing rates of exploitation and raising concerns over sustainability (Langley 2006; L'Haridon 2006; Nadon et al. 2007). There is evidence of overfishing of a number of marine resources in the south-west (Laroche et al. 1997; Woods-Ballard et al. 2003; Iida 2005; McVean et al. 2005), and these documented declines highlight the need for initiatives to manage the octopus fishery in the region.

Perry et al. (1999) identified three possible management approaches suitable for invertebrate fisheries: size/sex limits, catch regulation and controls on the rate of exploitation. Management regimes for octopus fisheries elsewhere focus predominantly on gear management and minimum catch sizes (Oosthuizen 2003; Fernández-Rueda and García-Flórez 2007; Kim et al. 2008). However, traditional and artisanal fisheries are generally difficult to manage, since methods and restrictions commonly used to promote sustainability of larger commercial fisheries are often not applicable, and data on which to base management interventions are commonly unavailable (Freire and Garcia-Allut 2000; Otero et al. 2005). Size limits for Madagascar's *O. cyanea* fishery were introduced in 2005 as Malagasy national law (Arrêté no. 16 376/2005; MAEP 2005) but have proven difficult to implement because the methods employed by fishers are non-selective. Octopus are injured and often killed during forced removal from their dens, and there is therefore little point in discarding them if fishers subsequently realise they may be below the national minimum size limit of 350 g. Catch regulations, such as quotas, are also difficult to impose as there is little capacity within coastal communities of the region for enforcement of legislation (Harris 2011).

Marine closures such as reserves or protected areas have been widely used to control the rate of fisheries exploitation around the world, and have been shown to increase density and biomass of stocks (Pipitone et al. 2000; Roberts et al. 2001; Halpern and Warner 2002; Halpern 2003; Roberts et al. 2005; Navarte et al. 2006). However, permanent closures of important fishing sites are often hard to establish and enforce owing to the economic cost of lost catches and revenues by fishing communities with near total dependence on marine resource extraction for their livelihood (McClanahan 1999; Freire and Garcia-Allut 2000). Thus permanent closures are often ineffective as a result of community resistance (Hockley et al. 2005).

Targeted management of artisanal octopus fisheries has been reported at only a few sites globally (e.g. Diaz-de-Leon and Seijo 1992; Guard and Mgaya 2002; Jouffre and Caverivière 2005; Navarte et al. 2006; Fernández-Rueda and García-Flórez 2007; Leite et al. 2009). The life history, reproductive cycle and growth dynamics of *O. cyanea* indicate that there are likely to be key periods in the octopus life cycle during which short-term protection would be most effective, namely when females are brooding and nesting and when juveniles are undergoing periods of rapid growth (Van Heukelem 1973; Caveriviere 2006). Temporary closures during sensitive periods of the target species' life cycle may be a more realistic compromise to boost fishery yields while meeting community economic needs.

In 2004, pilot short-term octopus fishery closures were trialled within the recently established Velondriake Locally Managed Marine Area (LMMA). Closure sites and durations were selected by fishing communities, and aimed to boost fisheries yields to local communities. The Velondriake LMMA encompasses over 1 000 km^2 of marine and coastal environment in south-west Madagascar (Harris 2007, 2011), and closures were piloted in close collaboration with local villages.

In this paper we analyse fisheries landings data from the first two years of closures in order to determine the nature of the closures' effect. The data were recorded at octopus collection points in villages within Velondriake. We calculated the weight and number of octopus caught per successful fisher per day, and compared data from the first year of closures, when only one site was closed, with data from the second year, when three closures were held. We present a comparison both with pre-closure data from the closure sites and with data from preselected control sites to test the significance of the biological fisheries effect. Finally we assess lessons learned for management as a result of these preliminary fishery closures.

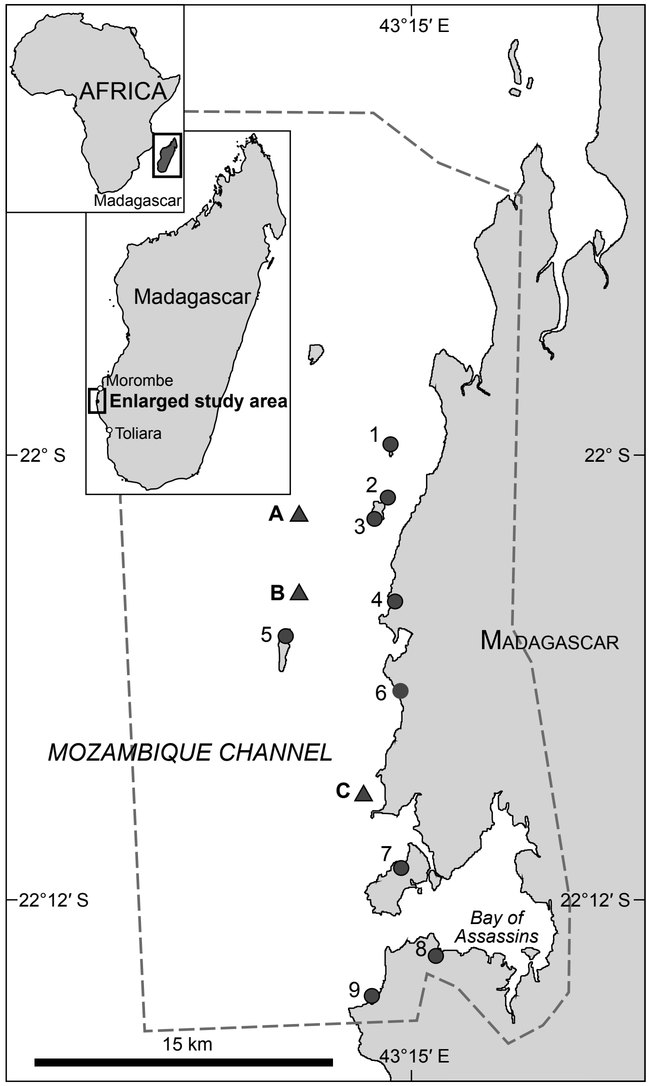

Figure 1: Map showing study area. Solid circles represent villages (1 – Nosy Mitata, 2 – Nosy Andambatihy, 3 – Nosy Ve, 4 – Andavadoaka, 5 – Nosy Hao, 6 – Ampasilava, 7 – Lamboara, 8 – Tampolove, 9 – Ankitambana); solid triangles represent octopus fishing sites (A – Nosy Masay, B – Ankereo, C – Ampisorogna); dashed, grey line represents the boundary of the Velondriake LMMA

Material and methods

Study site

The study is based in the village of Andavadoaka in south-west Madagascar, in the geographical centre of the Velondriake LMMA, approximately 190 km north of Toliara, the regional capital, and 50 km south of the town of Morombe (Figure 1). The marine ecosystem around Andavadoaka is characterised by a nearshore fringing reef and an offshore barrier reef, together forming the northern margin of Madagascar's emergent 458 km south-west reef system (Gabrié et al. 2000). Important octopus fishing sites are found on reef-flat areas throughout the region and octopus are harvested by the local Vezo fishing communities (Iida 2005; Langley 2006). The fishing methods used are extremely low-cost, requiring only a wooden stick or spear. Women and children glean by walking on the exposed reef flats using the spears to probe *O. cyanea* dens. Reef flat areas are generally accessible by foot for 7–9 days around low tides, although fishing may occur throughout the month and fishing effort is relatively constant throughout the year as it is not dependent on sailing to suitable sites. Men may also glean, but predominantly favour freediving with spears over the reef edge to look for subtidal octopus within dens at depths of up to 5 m. No other technique of octopus fishing is practised in the region.

Management regime in place

In 2003, Blue Ventures, a British marine conservation NGO working with communities, introduced the concept of potential fisheries benefits derived from a relatively short-term closure, based on available life-history data of the octopus. The site selected for the first trial octopus fishery closure was Ankereo, a 137 ha reef flat around Nosy Fasy, a sand cay located within the barrier reef system 5 km west of Andavadoaka (Figure 1). Ankereo was selected because of its proximity to the village and ease of delimitation as a closed fishing site. A guard was hired by the village to prevent poaching by patrolling the site in daylight hours in a local pirogue (dug-out canoe). The cost of hiring guards was shared between Blue Ventures and the village.

Ankereo was closed for a pilot 7-month period from 1 November 2004 until 6 June 2005 (218 days) and for a second, shorter period the following year (135 days from 15 December 2005 to 28 April 2006). During the second year, communities concurrently implemented closures at two additional sites, Nosy Masay and Ampisorogna, adjacent to neighbouring villages (Figure 1). Nosy Masay is a submerged patch reef site, 150 ha in size, lying directly west of the islands of Nosy Mitata, Nosy Ve and Nosy Andambatihy, and 8 km north-west of Andavadoaka. Ampisorogna is a fringing reef flat of 90 ha, 9 km south of Andavadoaka. The timing and duration were chosen by agreement among all the local fishing communities.

As a result of the success of the first regional closure at Ankereo (reported below), the state enacted a south-west, region-wide octopus fishery closure from 15 December 2005 until 31 January 2006 (48 days). Thus the three 2005–2006 site closures effectively served as site-specific extensions of the regional fisheries closure.

For the first closure a *Dina*, or traditional local law, was created by village elders to prohibit octopus fishing at Ankereo during the closure period, although fishing for other species could continue (Andriamalala and Gardner 2010). A second *Dina* was developed prior to the second round of closures, prohibiting fishing of any kind at all the closed sites throughout the closure periods. The state's 48-day regional closure was enforced by closing commercial collection during this period.

Data collection and quality control

Octopus catch data were sampled continuously for two years from September 2004 to September 2006 from all octopus fishing sites in the region. Collection companies operating in this region employ local collectors known as 'sous-collectors' in each coastal village, who act as the middlemen, buying the octopus directly from fishers on behalf of export companies. In our study, in nine villages across the region, sous-collectors were trained and employed to record data on octopus purchased from fishers through non-systematic sampling on a daily basis (Figure 1). Blue Ventures staff visited collectors regularly to conduct spot checks to ensure a high degree of reporting accuracy across the study region. Following the first closure as many octopus as possible were recorded by the sous-collectors. In 2006 a second data collector was hired in each village and was trained prior to the reopening of the closure sites, to increase sample sizes. The following information was recorded for each octopus sampled:

- Individual wet weight (g)
- Fishing site
- Fishing method
- Number of fishers in the fishing group
- Fisher name, sex and age

Data from all collectors were collated, double-entered, cross-checked and quality controlled. A confirmed list of fishing site names was gathered through participative village meetings where both fishers and village elders were used to develop maps of fishing site boundaries to consolidate data collected (Blue Ventures unpublished data).

In addition to these monthly monitoring data, additional summary data were collected on opening-day events. Three individual observers recorded visual head counts of all fishers present on the reef flat during the opening event. The values from the three observers were then averaged to produce an estimate of total fishing effort on the opening day. Commercial collectors present at the opening-day events provided estimates of the total weight of all octopus landed on opening days, and the estimates were subsequently confirmed with weigh-ins at the processing plants.

Analytical techniques

Catch data were grouped by spring tide period across the whole survey period, and data from three specific tides (the spring tide immediately before the closure, the tide at opening, and the spring tide following the opening) associated with each closure period at each closure site were analysed using R (R Development Core Team 2009) to allow us to control for site-specific effects among the data. In addition, we compared results from the closure sites with data from 14 preselected control sites collected during the same time periods before and after closures. Control sites were selected based on categorical fishing site size class and distance to villages, in relation to closure sites, to allow for a non-biased comparison and availability of data to ensure sufficient data existed to generate robust results.

Change in octopus body size as a result of the closure periods at all three closure sites was studied using weight frequency distributions and was compared with both 'before' and 'after' data at the other closure sites to control for site-specific effects, and also with a pooled distribution of the 14 control sites using a Kolmogorov–Smirnov (KS) test. Percentage changes in the mean weights before and after closure were also calculated and tested using Welch's two sample *t*-test on log-transformed means.

To calculate catch per unit effort (CPUE), the effort unit was standardised as one day of fishing per successful fisher. Data were not recorded for unsuccessful fishers with zero catch. Average weight of octopus per successful fisher day (CPUE) and mean individual octopus weights were calculated. The significance of any changes in CPUE before and after closure was tested using Welch's two sample *t*-test on log-transformed means.

Results

Over the 25-month study period, we recorded data from 519 sample days and from 100 591 individual octopus. Unsurprisingly, we observed a clear linear relationship between number of fishers and total weight landed per month across the study period ($r^2 = 0.96$, $p < 0.001$).

Total landings

When compared to matched control sites, we observed a significant increase in the number of octopus caught from Ankereo during the opening tide in 2005 (KS test, $D = 0.47$, $p < 0.01$), and in 2006 there was also an increase although this was not significantly different from the control sites. In 2005 a total of 1 200 kg of octopus was purchased by collectors on the opening day from Ankereo. In 2006, 547 kg of octopus were purchased from Ankereo, 368 kg from Ampisorogna and 812 kg from Nosy Masay.

Octopus size

The largest octopus caught on the Ankereo opening day was 6 000 g in 2005 and 3 700 g in 2006. At Ankereo, mean octopus weight increased from 719 g (SD 700) pre-closure to 1 120 g (SD 848; 64% increase) during the opening tide in 2005, although this increase was not significant (*t*-test on log-transformed data, $t = -1.13$, df = 52.85, $p = 0.2$). There was a significant increase in mean octopus weight landed from Ankereo, from 436 g (SD 736) pre-closure to 1 136 g (SD 621; 160% increase) during the opening tide in 2006 (*t*-test on log-transformed data, $t = -9.27$, df = 47, $p < 0.001$). Following the closure in both years, there was a shift in the mean weight back to pre-closure levels within one spring tide of the opening.

For the other sites closed in 2006 the largest octopus caught during the opening days was 3.5 kg at Ampisorogna and 4 kg at Nosy Masay. However, mean octopus sizes showed little change and were 987.9 g (SD 607) and 889 g (SD 740) at Ampisorogna and Nosy Masay respectively on the opening day compared to an average for six weeks pre-closure of 996.6 g (SD 512) and 892.6 g (SD 520).

We observed a 113% increase in the number of large octopus (>1 kg) landed from Ankereo on the opening tide in 2005. Octopus weighing more than 2 kg represented just 8% of all landed octopus in the tide before the closure (n = 3 of 39), while, during the opening period, these octopus represented 20% (n = 155 of 662).

Comparison with preselected control sites

Mean weight of octopus caught at Ankereo during the opening tide in 2006 was 53% higher than at the 14 control sites (1 165 g [SD 621] compared to 737 g [SD 552]) (t = 6.2, df = 246, $p < 0.001$). There was an increase of 21% at Nosy Masay to 889 g (SD 740) and 34% at Ampisorogna to 988 g (SD 607) compared to the control sites. This was significant at Ampisorogna (t = 6.01, df = 915, $p < 0.001$) but not at Nosy Masay, on account of the higher variability in the weight distribution of octopus from Nosy Masay (t = 0.02, df = 652, $p = 0.98$).

Fishing effort

There was a noticeable spike in fishing effort following both rounds of closures, with the number of fisher-days peaking at over 1 300 on the first opening day at Ankereo in 2005. However, after the second round of closures, effort seemed to have dispersed across the three sites – the number of fishers was 547 at Ankereo, 812 at Nosy Masay and 368 at Ampisorogna.

CPUE

We found no significant difference between the catch per unit effort (CPUE: kg octopus landed fisher-day^{-1}) at Ankereo before and during the opening event in 2005 ($t = -1.2$, df = 218, $p = 0.20$; Figure 2). We also found no significant differences when we compared data from Ankereo to data from the control sites following the 2005 opening.

However, following the 2006 opening we observed significant increases in CPUE across all closure sites (Figure 3). Mean CPUE increased significantly from the tide pre-closure to the opening tide by 146% from 1.3 to 3.2 kg fisher-day^{-1} at both Ankereo ($t = -7.8$, df = 12, $p < 0.001$) and Nosy Masay ($t = -3.4$, df = 10, $p < 0.01$), and by 88% from 1.6 kg to 3 kg fisher-day^{-1} at Ampisorogna ($t = -7.8$, df = 14, $p < 0.001$). The slight increase observed at the control sites in 2006 (from 2.4 to 2.8 kg fisher-day^{-1}) was not found to be significant.

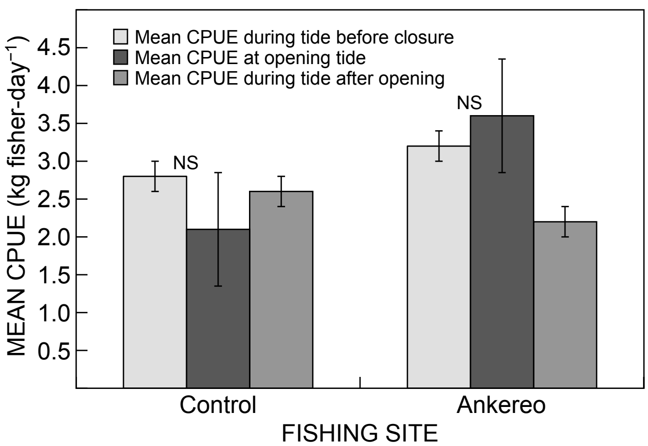

Figure 2: Octopus landings data from Ankereo fishing site and grouped data from 14 selected control sites one tide before the first closure between 2004 and 2005, at the opening tide and one tide after the opening. NS indicates *t*-test was not significant. Error bars represent standard error

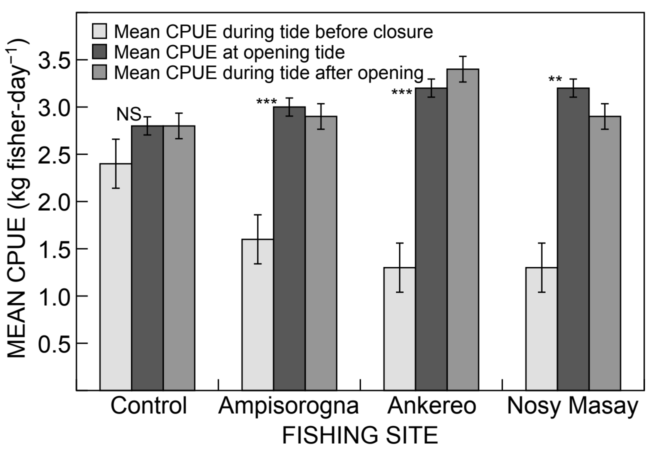

Figure 3: Octopus landings data from the three closures sites and grouped data from 14 selected control sites one tide before the 2nd closure between 2005 and 2006, at the opening tide and one tide after the opening. Error bars represent standard error. At each site, landings before the closure were compared with landings on the opening day using a *t*-test; *** $p < 0.001$, ** $p < 0.01$, NS not significant

Discussion

Management objectives for the first (pilot) closure included economic and fishery-based goals; namely, to increase the number and size of octopus caught and thus to increase fisher revenue from the fishery. Our findings show that these objectives were achieved, given the significant increase in fisheries output.

However, management success following the first closure was only partial, since the increase in fisheries output did not translate into significant increases in yield per fisher, due to the large number of fishers converging on the newly reopened site on the opening day. Fishers travelled from all around the Velondriake region and further afield for the opening day, dramatically increasing fishing effort, free-riding on the restraint of local villagers who refrained from fishing in closed sites, and diminishing both per capita fishing yields and perceived management benefits. While a large number of fishers catching octopus at a site after a period of closure produces broad benefit in terms of maximised total yield, the purpose of this first closure was to maximise the yield specifically to fishers from the village which sponsored the closures. The large increase in fisher numbers on the opening day was due primarily to large numbers of fishers from outside of the sponsor village, which indicates that benefit-sharing around temporary closures needs to be managed effectively to ensure that the goals of the closure are achieved. The second round of closures was more successful in terms of yield per fisher, probably a result of a less intense site-specific spike in fishing effort on the opening day. This reduction is attributed to both the additional adjacent closure sites (which reopened on the same day) and enhanced management measures taken to reduce free-riding, including awareness-raising meetings in villages surrounding the closure sites. Increased numbers of concurrent closure sites dispersed fishing effort among the three sites instead of focusing effort on one area of reef. It seems this problem is not unique to Velondriake; an annual six-month closure in the Yucatan Peninsula of the fishery for *Octopus maya* showed mixed results because of dramatic increases in effort during the open season (Diaz-de-Leon and Seijo 1992).

The fisheries benefits of permanent marine reserves are widely recognised (Roberts 2001; Gell and Roberts 2003; Francini-Filho and Moura 2008). Many life-history traits are similar across the Octopodidae, and management experiences elsewhere provide useful insight into responses of octopus fisheries to closures. Permanent closures for *Octopus tehuelchus* in Brazil showed increases in octopus abundance and recruitment but no change in mean octopus size, possibly as a result of migration of adult individuals into areas surrounding the reserve, motivated by habitat availability (Navarte et al. 2006). Permanent closures have also been recommended to protect juvenile *Octopus insularis* recruitment in Brazil (Leite et al. 2009). The impacts of temporary closures are generally less well documented, but examples do exist related to a number of single-species fisheries, including some for octopus (Wallace 1999; Freire et al. 2002; Guard and Mgaya 2002; Jouffre and Caverivière 2005; Fernández-Rueda and García-Flórez 2007; Bartlett et al. 2009). Given the rapid growth rate and short life span of octopus species (Van Heukelem 1973; Caverivière 2006), we propose that short-term, temporary closures can be used effectively to boost fishery outputs. We note that closures are much better suited than minimum size limits to the Velondriake fishery, due to its non-selective nature.

Local fishers perceived the first closure of seven months to be a very high investment in fisheries management. While fishers were still able to fish other reef areas during the closure, fishers felt a ban of over half a year on a popular reef-flat area was a major sacrifice and many considered it unacceptably long. Encouragingly, despite the considerably shorter duration, results from the second closure produced similar fisheries effects. While this may have been a result of three coordinated openings occurring simultaneously, and the resulting dispersal of fishing effort, we suggest that closures of less than four months would produce desired fisheries results. A recent study in the same region also found that increased temporary closure duration did not correlate to greater profitability (Oliver et al. 2013).

This observation is supported by results from other octopus fisheries. A three-month closed season for *Octopus vulgaris* in north-west Spain, implemented alongside a minimum landing weight of 1 000 g, was considered sufficient to permit sustainable exploitation (Fernández-Rueda and García-Flórez 2007). Similarly, modelling of short-term closures combined with a minimum catch size in Senegal suggested that a two-month closure could produce fisheries benefits (Jouffre and Caverivière 2005). A rotational closure system of *O. cyanea* fisheries in Tanzania, involving closure periods of just 10–13 days, was also shown to enhance the productivity of reef-flat areas, with notable increases in octopus size and CPUE (Guard and Mgaya 2002).

Fishery production benefits are not the only positive outcome from short-term closures, and further potential external benefits may also occur. *Octopus cyanea* is found across all reef types and has been observed at depths of up to 50 m (Norman 1991). The Madagascar octopus fishery mainly targets octopus found in depths of less than 5 m, and there is substantial benthic habitat suitable for *O. cyanea* to depths in excess of 50 m throughout this region. A concurrent study within the Velondriake area reported very low proportions (<1%) of fully mature or post-laying females in catches from the reef flat (Raberinary and Benbow 2012), suggesting that the targeted reef-flat fishery may not be exploiting vulnerable brooding females which are known to select deeper zones preferentially (Whitaker et al. 1991; Oosthuizen and Smale 2003). The presence of a large, unexploited habitat (>5 m depth) for the species may act as an important ‘depth refuge’ for mature females, providing a source of recruitment for exploited areas, and may account in part for the rapid recovery response of the fishery to management. This is supported by research from Tanzania which recommends targeting reductions in fishing effort in important subtidal zones where mature female octopus are likely to be found (Guard 2003). The reproductive biology of *O. cyanea* is poorly understood, but estimates of maturity in south-west Madagascar indicate that males mature at approximately 550 g and females at 2 200 g (Raberinary and Benbow 2012). Thus, the significant increase in mean octopus weight following closures in our study could lead to increased reproductive output of the fishery if mature females can be observed sheltering at depth in future studies.

Community support for the closures remains strong in the Velondriake region and several management lessons have been learned that can be incorporated into future closures. Above all, there needs to be an effective enforcement mechanism to control fishing effort on opening days. Culturally and legally, opening days of the temporary closures within the Velondriake LMMA are open access, and measures are required to disperse fishing effort on the opening tides over a wider area. This will create longer-lasting biological and fisheries benefits, and engender greater community support by enhancing per capita benefits.

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