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Short Communication

Assessment of current data for the octopus resource in Rodrigues, western Indian Ocean

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The annual catch of octopus in the Rodrigues Lagoon, located east/north-east of Mauritius, has dropped by almost half since 1994. This has prompted concern over the resource and has initiated an assessment of the current status of the stock. The limited available biological information suggests that the main pulse of recruitment into the lagoon occurs in the first few months of the year, but that exact timing varies between years and additional staggered recruitment may occur throughout the year. Size frequency information suggests that the brooding period may be variable and extended, with a main peak between October and January. Catch-and-effort data were also limited, but a decreasing trend in catch per unit effort in two of the datasets examined allowed some preliminary within-season assessment of population size (using a depletion model) at selected landing sites. The use of a migration bias correction formula suggested a net emigration from the lagoon, which might be indicative of adult movement into deeper waters. Depletion models seem to be useful as a management tool and should be tested further against more substantial monthly catch-and-effort data. In the interim, a precautionary approach of instituting a national seasonal closure for octopus fishing following periods of peak recruitment may have both economic and conservation benefits.

Keywords: growth, management recruitment, *Octopus cyanea*, regulations, reproduction, stock assessment

Introduction

An increasing demand for seafood continues to place a high pressure on global marine resources, resulting in the overexploitation of fish stocks in many countries (FAO 2004). As traditional high-value finfish species decline, fishers search for alternatives, and cephalopods are being increasingly targeted by both artisanal and industrial fisheries (Caddy and Rodhouse 1998, Smith and Griffiths 2002). Although octopus contribute only some 12% to world cephalopod catches, they are highly desirable and can command high prices, competing directly with finfish and supporting a growing demand worldwide (Cortez et al. 1999). While the global market continues to grow, many octopus fisheries may have already reached their peak and begun to decline (FAO 2004, Humber et al. 2006).

Rodrigues is a small volcanic island of approximately 18 km × 8 km, located 560 km east/north-east of Mauritius, with a population of approximately 37 500. The island is semi-autonomous and governed by the Rodrigues Regional Assembly. Agriculture, forestry and fishing provide the principal source of employment (c. 35% of employment opportunities), followed by public administration (c. 20%) and construction (c. 10%) (CSO 2007). There is conflicting information on the number of fishers, but there seems to be about 1 450 registered fishers with a further 2 000 people fishing on a casual basis (Hardman et al. 2007).

The Rodrigues octopus fishery dates back to the arrival of early French settlers in the 18th century, and presently constitutes the major source of income for many inhabitants. Octopus fishers primarily use harpoons (Lynch et al. 2000), with some individuals also using iron rods and spears. Fishers operate on foot and from small boats, fishing throughout the year, predominantly around the low-tide period (2–8 hours per day) and usually on spring tides. *Octopus cyanea* makes up the majority of the catch (>80%) with a small number of *O. vulgaris* also landed. Once captured, the majority of the catch is purchased from fishers by four companies, three of which export the product — mostly to Mauritius.

Octopus catches in Rodrigues have decreased from 774 t in 1994 to 281 t in 2008. The declining octopus exports (from 396 t in 1994 to 244 t in 2005) are having increasingly serious economic and social consequences. The growing concern over declining catch rates prompted an analysis of the current biological and fishery data available for the octopus fishery in Rodrigues.

Material and methods

Fishing area

The fishing grounds at Rodrigues are located in the lagoon and concentrated mainly on the reef region (Figure 1). There are approximately 15 major fishing areas, with the major fishing grounds each supporting between 13 and 94 fishers (Lynch et al. 2000). Boat use is high at the landing stations between Pointe Palmiste and Pointe Monier and between Port Sud Est and Riviere Coco (Figure 1), but <25% of fishers at the other villages have access to boats (Lynch et al. 2000).

Available data

Catch-and-effort data were provided from two sources:

1. A local government agency, Fisheries Research and Training Unit (FRTU), routinely collects catch-and-effort data from landing sites throughout the island. There are three collectors who cover a combined region of 23 landing sites, and sample sites are selected randomly on a weekly basis. Both registered and non-registered fishers provide the following data: personal details of the fisher (name, age and gender), the species landed, total weight per species, and landed price.
2. Additional monthly assessments were carried out by a local non-government organisation (Shoals Rodrigues) over a number of days, coinciding with spring tides, between January 2004 and February 2005 (Period 1) and between August 2008 and October 2009 (Period 2). Two sites were surveyed in Period 1 (Baie du Nord and Grande Baie) and two sites in Period 2 (again Baie du Nord and Pointe Monier). The choice of sampling days was based on the lowest tide of the spring tide weeks each month and only one site was sampled each day. The information recorded for each fisher included arrival and departure times from the fishing site, species composition of the catch, and the weight of each individual octopus. The total length of the octopus was also recorded during Period 1.

Timing of reproduction and recruitment

As the FTRU data did not provide individual octopus weights, the 'Shoals' data were used to determine recruitment patterns. The proportion of individuals weighing <50 g (early recruits) was calculated each month to determine peak recruitment. The time from spawning to juvenile recruitment is normally three months in Rodrigues (JT Genave, University of Mauritius, unpublished data), so peak reproduction was estimated to be three months prior to peak juvenile recruitment.

Growth estimates

Although it is recognised that a modal length progression analysis is not generally suitable for soft-bodied animals (that

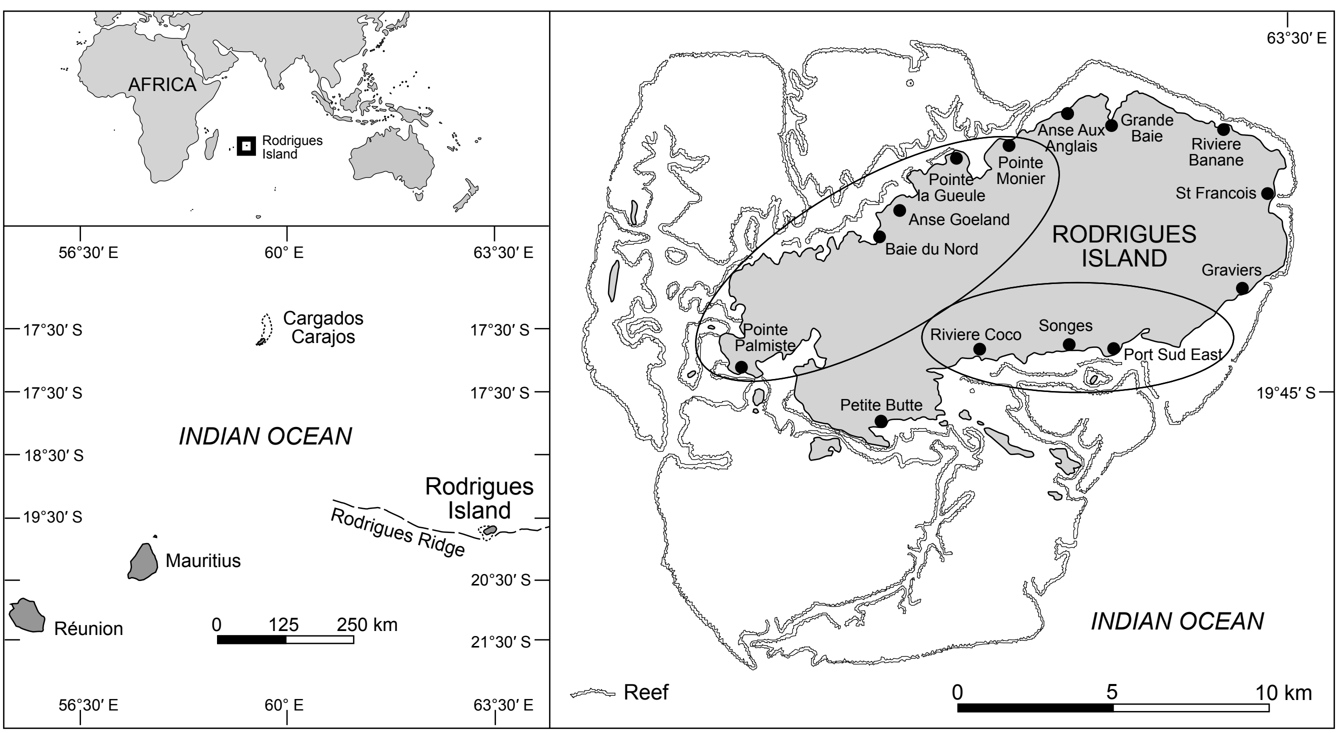

Figure 1: Rodrigues Island, showing the principal fishing villages and landing sites used by vessels (from Lynch et al. 2005)

vary in length depending on the contraction of their muscles) or for animals that have variable growth rates (Semmens et al. 2004), it remains a cost-effective and widely used technique for aging octopus (Guerra 1979, Mangold 1997). All weight information was converted to total length using the length–weight relationship: Mass = $60.722e^{(0.0033\text{Length})}$, which was estimated from the Shoals Period 1 data. The monthly length frequency information was grouped into 100 mm length classes and plotted as a frequency histogram. The Fisat II fisheries stock assessment package was used to estimate the average length-at-age from the modal progression using the ELEFAN method. Based on studies by Guard and Mgaya (2002) in Tanzania, the brooding period was assumed to be 20–30 days, followed by a larval stage of 30 days and a post-settlement phase of 40–55 days. Therefore, the average age of early recruits (<50 mm TL) was estimated to be two months after hatching. A linear regression was fitted to the predicted average length-at-age estimates and an exponential equation was fitted to the predicted average mass-at-age estimates. The linear and exponential equations were used to predict the expected growth beyond seven months of age. This corresponded to the time when the cohorts became less distinguishable.

Stock status and population estimates

A major drawback of the catch per unit effort (CPUE) data from the FRTU was that the number of hours that each person spent fishing and the individual octopus weights were not recorded. These data were, however, collected over 15 years and it was possible to examine long-term trends in catch, effort (in fisher-days rather than hours) and CPUE (kg fisher-day^{-1}).

The Shoals CPUE data included the time that individuals spent fishing each day (expressed as kg fisher-hour^{-1}) and were considered suitable for a depletion model population estimate. The Leslie depletion model with the Ricker modification was considered the most suitable (Ricker 1975):

$$y_t = \text{q}\text{N}_0 - \text{q}K_t \quad (1)$$

where y_t is the response variable, qN_0 the *y*-intercept (a constant), q the slope (a constant) and $K_t = (K_{t-1} + \text{Catch}/2)$, where K_{t-1} is the explanatory variable.

In the absence of any evidence to the contrary, the assumption of constant catchability, the lack of competing gears, and equal vulnerability of all animals, were assumed to be fulfilled during both sampling periods. Population estimates were only considered valid if the reduction in CPUE was 60% or more between the beginning and end of the fishing season.

To satisfy the assumption of a closed population, we used the migration bias correction formula by Guard (2003):

$$I_r = \frac{[1 - \text{CPUE}_1 / \text{CPUE}_2] \times 100}{P} \quad (2)$$

where CPUE_1 is the catch per effort from the last fishing day of the previous spring tidal cycle and CPUE_2 is the catch per unit from the first fishing day on the next spring tidal cycle, *P* is the number of days between the last and first fishing day and I_r is the percentage daily migration of the stock. As explained earlier, in many cases the sampling periods did not correspond with the final fishing day of the previous and first fishing day of the next spring tide. In these cases, the overall rate of migration was used. The rates of immigration were used to correct the population estimate, using the equation:

$$S_c = S_e - \left[\left(\frac{S_e}{100}\right) \times (I_r \times F_d)\right] \quad (3)$$

where S_c is the corrected population estimate, S_e is the uncorrected population estimate from the Ricker-modified Leslie regression, I_r is the rate of daily migration expressed as a percentage, and F_d is the number of fishing days during the spring tide period.

Results

Timing of reproduction and recruitment

Early recruiting (<50 g) individuals were not a dominant component of the octopus catch, probably because of the low catchability of the smaller individuals. Early recruits were most prevalent in January and June during 2004, whereas peak recruitment was in March 2009 (Figure 2). This suggests that recruitment pulses do not always occur at the same time of the year and may also occur more than once during the year. Given that the time from spawning to juvenile recruitment is normally three months in Rodrigues (JT Genave unpublished data), the size frequency information suggests that the main brooding period may be variable and extended. In Period 1, brooding probably occurred predominantly in October and November and again in March, and in Period 2, the main brooding period occurred in December and January, with a small peak in June.

Growth

In Period 1, the length frequency modes progressed rapidly each month between January and May (Figure 3a). After May, there were no clearly discernible cohorts, possibly due to extensive harvesting and the common phenomenon of variable growth of same-aged individual. The length-

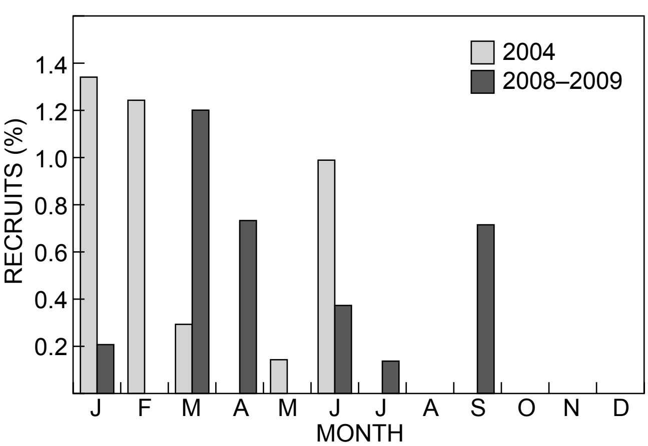

Figure 2: Proportion of recruits (<50 g) in the octopus catch at Rodrigues in 2004 and between 2008 and 2009

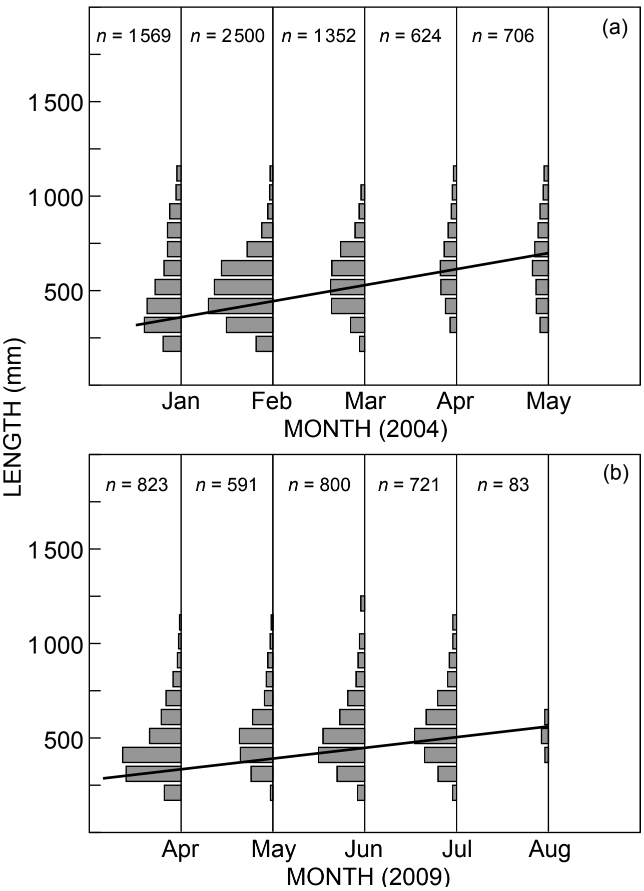

Figure 3: Modal progression analysis for *Octopus cyanea* captured off Rodrigues Island in (a) 2004 and (b) 2009

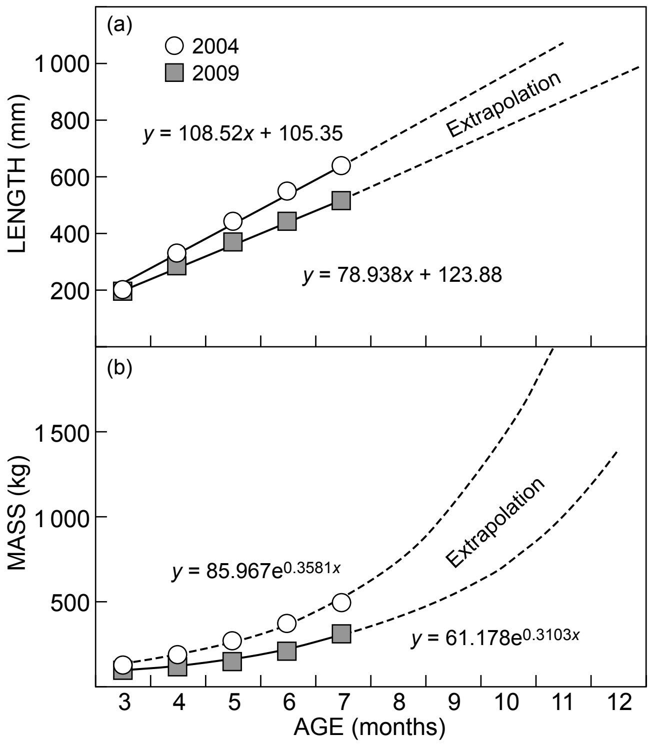

Figure 4: (a) The length-at age described by the linear equation and (b) the mass-at-age described by the exponential equation for *Octopus cyanea* captured off Rodrigues Island in 2004 and 2009

at-age was best described by the linear equation: TL = 108.52 × Age + 105.35, and mass-at-age by the exponential equation: Mass = $85.967e^{(0.3581\,Age)}$ (Figure 4). At 12 months of age, the average length and mass of an octopus was predicted to be 1 408 mm TL and 6.3 kg respectively.

On account of late recruitment in Period 2, the length frequency modes progressed from the smallest individuals in April to the largest clear modal length class in August (Figure 3b). The length-at-age was best described by the linear equation: TL = 78.939 × Age + 123.88 (Figure 4a), and mass-at-age by the exponential equation: Mass = $61.178e^{(0.3103\,Age)}$ (Figure 4b). At 12 months of age, the average length and mass of an octopus was predicted to be 1 083 mm TL and 2.5 kg respectively.

Stock status and population estimates

Figure 5 shows that the total catch of octopus dropped substantially between 1994 and 2008. During this period, however, there was an increase in CPUE, which may have been a result of an increase in the time spent fishing by individuals on a daily basis, as both the total catch and number of fisher-days decreased (Figure 5). The lack of more accurate CPUE information precludes further analysis of these data.

Analysis of the combined Shoals data for periods 1 and 2 shows a substantial drop in CPUE each year. The last two model assumptions were satisfied at both sites in Period 1 and at Pointe Monier in Period 2 as there was a considerable drop in CPUE and a large number of individuals were harvested. In contrast, there was a limited (23%) and inconsistent reduction in CPUE in Baie du Nord during Period 2 and these data were considered unsuitable for further analysis.

Use of the depletion model without correction for migration gave estimated octopus population sizes (at the beginning of Period 1) of 2 730 and 6 255 at Baie du Nord and Grand Baie respectively (Figure 6). During Period 1, there was an average net emigration of 1.3% at Baie du Nord and a net immigration of 0.2% at Grand Baia. When incorporating Equation (2) to remove the bias of migration, the population estimate was slightly higher for Baie du Nord (2 943) and lower for Grand Baie (6 180). The estimated octopus population using the depletion model without correction for migration size was 4 256 at the beginning of the 2009 fishing season at Pointe Monier (Figure 6). Average immigration during the study period was 1.6% and, when incorporating Equation (2) to remove the bias of immigration, the population estimate was slightly higher at 4 665.

Discussion

Although the limitations of the current datasets are recognised, available information suggests that the main pulse of recruitment of octopus into the Rodrigues Lagoon occurs in the first few months of the year, but that the timing varies between years and additional staggered recruitment may

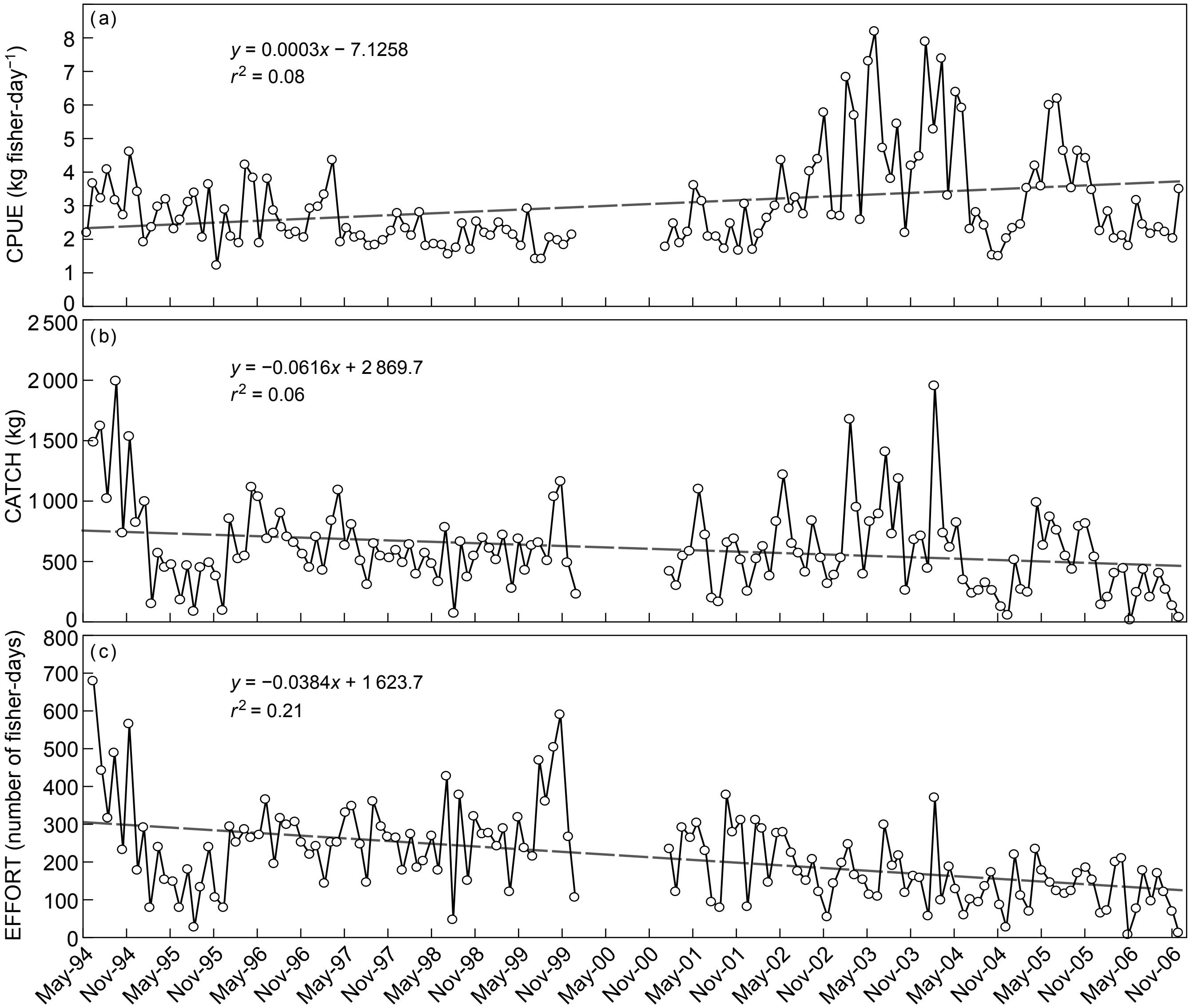

Figure 5: Trends in (a) the catch per unit effort, (b) catch and (c) effort data for the *Octopus cyanea* fishery on the island of Rodrigues between 1994 and 2006 (data supplied by the Fisheries Research and Training Unit)

occur throughout the year. The different times of recruitment may affect the life history of the octopus, because in Period 2 the later recruitment was associated with a slower growth rate relative to that during Period 1. Generally, octopus growth is primarily influenced by food intake and water temperature (Wells and Wells 1970, van Heukelem 1973, Cortez et al. 1999), suggesting that these factors may have been less suitable after the later spawning in 2009.

The size frequency indicates that the main brooding period may also be variable and extended, with a main peak between October and January. This is in agreement with an earlier study of gonad development (JT Genave unpublished data), which concluded that the primary spawning period off Rodrigues is between November and December. The lack of more detailed knowledge of the life cycle and movement patterns of *O. cyanea* limits understanding of the stock dynamics. For example, catchability will be influenced by the movement of both juveniles and adults across the range of habitats available, covering both the lagoon and deeper waters farther offshore. Further investigation of the ecology and movement of this species is warranted, both on a temporal and a spatial scale.

A general lack of biological knowledge of octopus (Boyle 1990, Pierce and Guerra 1994, Lipiński 1998), the interannual variability of recruitment, their very rapid growth, and having an annual life cycle, all make stock assessment a difficult undertaking. Most stock assessment tools are designed for finfish and are not directly applicable to octopus that may only live for one year. In most cases, octopus fishery management measures must be adapted annually to account for population variability. That many models rely on a good understanding of the age structure of the population complicates matters further, and the lack of reliable ageing methods makes the use of analytical

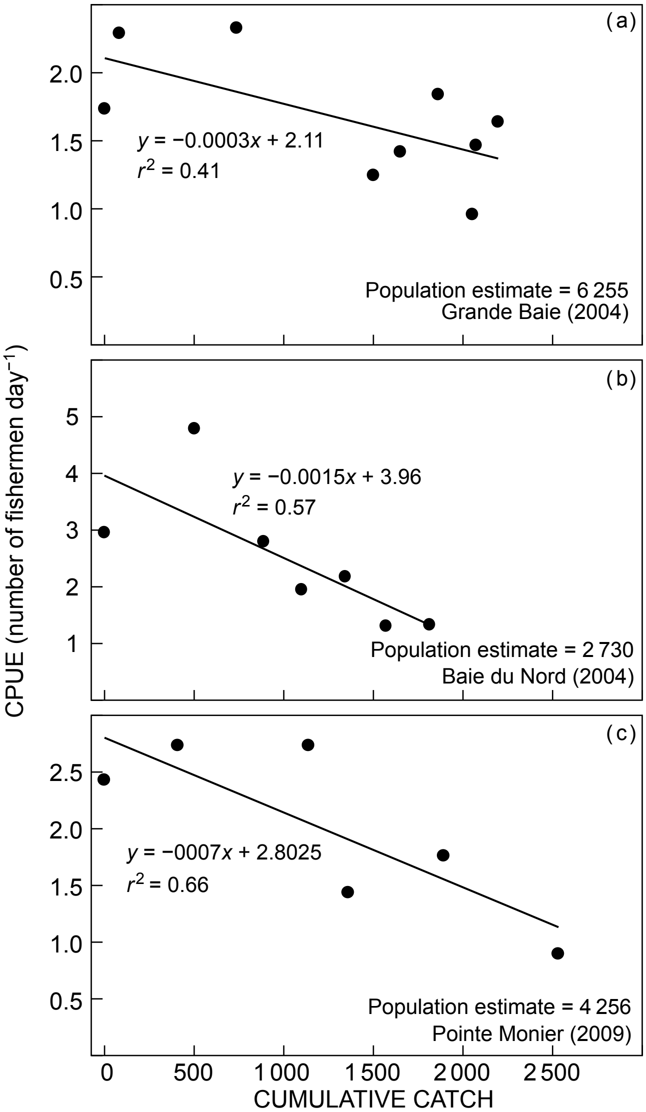

Figure 6: Ricker-modified Leslie depletion model for *Octopus cyanea* at three locations on Rodrigues Island: (a) Grande Baie in 2004, (b) Baie du Nord in 2004 and (c) Ponte Monier in 2009

models more difficult (Semmens et al. 2004). Depletion models can be useful for within-season monitoring and allows adaptation of management measures over the lifetime of the cohort (Young et al. 2004). The long-term datasets examined here provide general trends on the stock size in relation to times of reduced exploitation; in so doing, they provide information for target reference points for the octopus fishery in Rodrigues.

Although the data presented here has limitations and the estimates of population size in the various areas should be viewed with caution, the decreasing CPUE in at least two of the sites monitored by Shoals made it appropriate to explore the use of a depletion model. This method may prove appropriate for future assessments. The difference in population estimates between sites in the same year may be a reflection of variable recruitment, effort, and catchability between different areas. Use of the migration bias correction formula by Guard (2003) provided some evidence of a migration from and to the lagoon. The net emigration might indicate adult movement into deeper waters. These results should, however, be considered as preliminary and future studies that incorporate migration should include catch-and-effort data collected at least on the first and last day of the spring tide. The calculation of a 'within-season' total allowable catch, based on a proportional escapement, is not currently possible using the available data. Nevertheless, a cost/benefit analysis for such an undertaking may prove useful for future management.

In summary, there is limited information to fully assess the Rodrigues octopus fishery and a full revision of the current data collection strategy is required. This should include the collection of relevant catch-and-effort data, biological information, movement studies, and the factors affecting recruitment dynamics, particularly environmental influences. In the interim, the introduction of a national seasonal closure for octopus fishing, for at least three months following periods of peak recruitment — similar to that introduced in Madagascar (Humber et al. 2006) — may have benefits from both an economic and a conservation standpoint.

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