Biology and fisheries status of octopus in the Western Indian Ocean and the Suitability for marine stewardship council certification
By Martin Guard
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This project was commissioned by the United Nations Environment Programme (UNEP) to the Institute for Security Studies (ISS)

ISS has commissioned this paper to Martin Guard
About this report
In 2008 the United Nations Environment Programme (UNEP) began the implementation of a project on ‘Promoting Sustainable Trade, Consumption and Production Patterns in the Fisheries Sector’, funded by Norway. As part of this work, UNEP commissioned the South African based Institute for Security Studies to undertake a short research project on eco-labeling in the Southern African region. This involved a two-day stakeholder conference on certification held in Cape Town in October 2008, and the publication of a research report in 2009.

Technical country reports on South Africa, Namibia and Tanzania are the other key components of the project. The final report of the project is entitled “The growth in certification of marine fisheries in Southern Africa”. It discusses the potential benefits and challenges of certification and is available on the following website: http://www.unep.ch/etb/areas/fisherySub.php

The following report was commissioned by the ISS as background technical report to be presented at the conference and incorporated in their final publication. The paper, authored by Martin Guard aims to provide a comprehensive analysis on the potential certification of the Tanzanian octopus fishery. This fishery is currently undergoing a confidential pre-assessment for MSC certification. It is important because it represents one of a few small-scale fisheries that may achieve MSC certification.

The responsibility for the report fully lies with its author. The report does not necessarily represent the views of the United Nations Environment Programme or of its members. For further information on the UNEP’ work in this field, please contact Anja von Moltke from UNEP’s Economics and Trade Branch [anja.moltke@unep.ch]
October fisheries in the Western Indian Ocean: Suitable for Marine Stewardship Certification?

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1. BACKGROUND

This report was commissioned by the Institute for Security Studies (ISS), Cape Town Office to provide information on the biology, catch status and management for octopus fisheries in Tanzania and their potential suitability for Marine Stewardship Council Certification (MSC).

The terms of reference for this consultancy were:

- Summarily describe the biology of fished octopus species.
- Briefly describe the constraints of octopus stock assessment and management.
- Summarily describe catch dynamics and status of octopus fisheries in Tanzania and the Western Indian Ocean.
- Describe issues relating to by-catch and other fishing effects.
- Describe present and potential management options for the octopus fishery and its suitability for Marine Stewardship Council Certification (MSC).

This report begins with a brief discussion of the general biology of octopus cyanea, the inherent characteristics of octopus and the constraints that these provide to effective fisheries stock assessment and management, what is known of the Artisanal Octopus fisheries in Tanzania and the Western Indian Ocean and finishes with the various options available for management of octopus stocks in the region and concluding points on their suitability or limitation for MSC certification.

2. BIOLOGY OF OCTOPUS CYANEAE

Octopus cyanea is a large ubiquitous octopus associated with coral reefs and widely distributed throughout the tropical Indian and Pacific Oceans to depths of 45m (Norman, 1991).

The biology of O. cyanea has been well studied, yet the majority of work has been conducted in the laboratory (Van Heukelem, 1966, 1973, 1976, 1983, Wells, 1970) and there have been few studies conducted in the field (Yarnall, 1969; Houck, 1982; Forsythe & Hanlon, 1997) and from a fisheries perspective (Guard & Mgaya, 2002, Guard, 2003; Guard et al, in prep a,b, c).

Similar to other cephalopods, Octopus cyanea, the common reef octopus, is a key opportunistic predator with foraging usually taking place around dawn and dusk. A wide range of prey items such as molluscs, crustaceans and fish are consumed while foraging with the octopus only returning to feed at the den with larger prey (e.g. lobster).

Octopuses grow very rapidly and can increase in size by as much as 200g in only 15 days and up to 12kg in weight (Van Heukelem, 1983; Guard, 2003). They seemingly follow the 'live fast and die young' principle and have a total estimated lifespan of between 9-18 months (Van Heukelem, 1983).

Octopuses are generally solitary animals residing in dens in well spaced areas most likely influenced by a feeding area/rate of replenishment relationship but may also help to reduce agnostic encounters between other octopus which may result in the loss of the den, feeding area or injury/predation (e.g. cannabilism) (Yarnall, 1969; Guard, 2003).

If a male meets a female octopus this more often than not leads to a mating whereby the male extends his hectocotylised arm (3rd right arm) into the mantle of the female and passes spermatophores into the females oviducts'. An interesting feature of octopuses is that the received sperm is stored in an oviducal gland and does not immediately fertilise the eggs. Moreover, multiple matings with different males will result in a diversity of sperm being stored that helps the genetic strength/diversity of the egg mass when the eggs are eventually fertilised (Van Heukelem, 1983).
Female octopus only brood once in their lives and when ready to spawn, usually at their largest size or from another trigger such as when food resources become scarce, they barricade themselves into their den. A typical female will lay between 100,000-400,000 eggs and following spawning they attach their eggs to the roof of the den and then spend the next 30 days cleaning, aerating and protecting the eggs from predators during which the female ceases to feed. After 30 days the eggs hatch into paralarvae measuring about 2mm in length and then spend the next 30 or so days in the plankton before becoming benthic and settling on the bottom to live normally as an octopus (Boyle & Rodhouse, 2005). Predation of the paralarvae and newly settled individuals is however high. Subsequent to hatching the female, weakened by a lack of food and a breakdown of somatic proteins in the body (an irreversible process), goes into senescence and eventually dies. Evidence has also shown that males die at around the same age (Van Heuekelem, 1983).

Recruitment to the fished population occurs at around 200g and the success of recruitment will depend on the success of spawning at the source site wherever that may be, see below for details.

3. CONSTRAINTS OF OCTOPUS FISHERIES STOCK ASSESSMENT AND MANAGEMENT

While fishing effects on finfish populations are increasingly well documented, for target invertebrates such as octopus these are less well known (Caddy, 1983, Boyle & Rodhouse, 2005). Results from developing reef fish fisheries indicate fishing can affect target species directly through changes in population abundance and biomass, size and age distribution, spatial distributions and reproductive output and indirectly through effects on non-target species communities and surrounding habitat (e.g intertidal trampling) (Koslow et al., 1988, Dalzell & Pauly, 1990; Watson & Ormond, 1994; Polunin & Roberts, 1993; Jennings & Polunin, 1995a; McClanahan, 1994; Jennings et al., 1996; Thomson & Munro, 1983; McClanahan & Muthiga, 1988; for review-Jennings et al, 2001).

While some of the above fishing effects of finfish populations are likely to be relevant to targeted octopus stocks, differences between the two groups in relation to their biological characteristics and lifecycle may result in different responses;

In contrast to most fish species

- Octopuses are characterised by a short lifespan (9-18months),
- Extremely rapid growth,
- Early and semelparous breeding which usually occurs at their largest size.
- Wide inter-annual fluctuations of recruitment may occur, often influenced by environmental variability (e.g. seasonal changes) aside from any fishing mortality
- Cannot be aged using measurements of body parts

A shorter life span is relevant because it means the time to adjust the fishing strategy to changes in population biology is markedly reduced when compared to fish. Moreover, the trait of a single breeding event after which the female dies, would seem to indicate octopus to be susceptible to recruitment over-fishing, especially if brooding occurs over a defined period through which fishing continues (Boyle & Rodhouse, 2005).

The two points above may however be less important for tropical O. cyanea which are characterised by year round brooding with brooding peaks (Guard & Mgaya, 2002; Guard, 2003) – see below). This should result in a more variable pulsed recruitment into the population and on this basis may buffer the recovery potential for this species. This would however depend on enough females reaching brooding size so as to contribute to the reproductive stock and in heavily fished areas this might not be the case (Guard, 2003). Furthermore, it will depend on the source of recruitment and if this is elsewhere, on the reproductive potential at these sites. For
example, octopus hatchlings are para-larvae that spend about 30 days in the plankton prior to settlement. The question is whether a particular fished reef or area is self-sufficient in the supply of new larval recruits or will its source site for recruitment be elsewhere such as up current of its present location. In addition, adjacent reefs are close enough to enable connectivity between other meta-populations in the area and enable adult immigration/emigration. Both aspects will have obvious implications on how a particular fished area can be managed to ensure sustainability of the stock. In determining the degree to which each site acts as recruitment source, sink or both the use of molecular techniques such as DNA markers would be of great assistance (Boyle & Rodhouse, 2005).

Conversely, extremely high growth rates imply that octopuses, if not recruitment limited, would be capable of rapid recovery from fishing mortality and may therefore be more resilient to intensive fishing pressure. This is reinforced by the fact that O. cyanea of 100g can increase in size by 200g in just 15 days (Van Heukelem, 1983) and it would mean there is potential for large numbers of new recruits to enter the fishery even between fished spring tide periods.

4. ARTISANAL OCTOPUS FISHERIES IN TANZANIA AND THE WESTERN INDIAN OCEAN

In the Western Indian Ocean artisanal fishing for octopus is a highly important economic and subsistence activity for local coastal communities and is extensively practiced in Tanzania, Mozambique and Madagascar (Guard & Mgaya, 2002; Guard, 2003; Humber et al, 2006).

Octopuses are fished from inter-tidal reef flats and sub-tidal inner reefs mainly during spring tides for local and inland consumption and increasingly for export to European and Far Eastern Markets. Octopuses are collected either by walking over the lower reaches of the intertidal reef flat or by snorkelling along the reef edge where they live in small holes (den) and crevices often hidden by small stones, rubble and pieces of shell. Once spotted, a slender stick or metal spear is inserted into the den and jerked up and down, thus causing the octopus to climb the stick. It is then withdrawn and either immediately turned inside out to remove the heart or the spear is pushed through the beak into the brain to kill the animal. Octopus cyanea is the primary species captured in tropical artisanal fisheries and generally comprises over 99% of the catch (Guard et al, 2000; Guard & Mgaya, 2002; Guard, 2003; Humber et al, 2006).

Traditionally, fishing for octopus has been dominated by women and children and is important as one of the few sources of income for this gender group. In recent years, however, men have become increasingly involved with octopus fisheries due to a rise in demand and greater income opportunities (Guard & Mgaya, 2002, Humber et al, 2006). Outside buyers, who process and export octopus, now operate along the coastal regions of Tanzania, Mozambique and Madagascar and often using specially commissioned boats to take fishers to fishing sites also pay premium prices for the catch. While providing much needed income to local communities, fishing intensity has markedly risen in many areas, placing greater pressures on the fishery.

4.1. FAO Catch Statistics for Tanzania and the Western Indian Ocean

During the year 2000 FAO area 51 covering the Western Indian Ocean region provided less than 1% (approx. 1,169 mt) of the total world contribution of octopus (FAO, 2002) but this has markedly increased in recent years. In 2002 over 870 metric tonnes were exported from Tanzania while over 500 tonnes are contributed annually by Mozambique. In Madagascar, where octopus fisheries are considered less developed, a 35% increase in exports of octopus to France was reported between 2002 and 2003 (FAO 2003, 2004, 2005). In 2006, FAO statistics only provided totals of octopus on a world production basis and not for individual countries. To note however is that submitted totals for Tanzania were the same for the last two years (2005,2006) indicating anomalies in this data.

In recent years, octopus exports have markedly increased from Tanzania (personal communication Fisheries director, Tanzania fisheries department) seemingly indicating an...
increase in productivity of octopus fisheries along the coast. However, this may not be the case and the apparent increase is a result of octopus fished from northern Mozambique being brought to Tanzania and sold to processors in Mtwara (Tanpesca Ltd and Sea Products Ltd). Fisheries officers in Mtwara do not admit to this as Tanzania benefits from duty paid from the export of these octopus. Conversely, the government of Mozambique receives no income from the offtake of these octopuses and represents an important loss of a valuable resource (Guard, 2003).

4.2. Catch Assessment And Status Of Octopus Fisheries In Tanzania and the Western Indian Ocean

Notwithstanding the economic importance of the artisanal fisheries for *Octopus cyanea* in Tanzania and the Western Indian Ocean, few specific research or stock assessments have been conducted in the region.

The most extensive study thus far has been conducted in Tanzania (Guard & Mgaya, 2002; Guard 2003). The study examined three geographically separate octopus fisheries namely Kwale, Tanga (north), Jibondo, Mafia Island (Central) and Msangamkuu, Mtwara (south) and provided information on catch dynamics, population and reproductive biology of *O. cyanea* and made recommendations for the sustainable management of octopus fisheries (Figure 1). Guard (2009) has also provided a framework for stock assessment and management of octopus fisheries for Madagascar commissioned by RECOMAP.

In Madagascar, Humber et al (2006) studied the octopus fishery of Andavadoaka and assessed the viability and success of seasonal closures of reef areas as a tool for the sustainable management of the octopus fishery. Results indicated that reef closure can increase the size of catch yields due to an increase in abundance and the mean size of octopus and seems to be a management approach that should be further developed. It was realised, however, that to provide more tangible benefits of increased productivity from reef areas, fishing effort would have to be set at a sustainable level, as otherwise, fishers converge from far and wide and deplete the recovered stock in a short period.


Below is a summary of the main findings from the study of Guard (2003) in Tanzania and those relevant for this report are further elaborated below.

A total of 23,165 individual octopuses were measured from a total of 3,514 catches over 477 sampling days. All findings and tables in this section should be referenced to Guard (2003).

- Local data collector teams can precisely and accurately collect catch data and reproductive material for analysis.
- Higher fishing effort, as expected, led to marked reductions in mean individual size and size range but indicated higher abundance of smaller octopuses at heavily fished sites.
- Fishing during neap tides was detrimental by further reducing the mean average size of octopuses.
- Rotational or ‘pulsed’ fishing regimes maintained a larger size range due to the benefits of increased relaxation days from fishing.
- The De-Lury depletion method proved positive for the estimation of harvestable stock size and should be further developed and tested.
- Length weight relationships varied between sites and sexes and were all negative allometric.
- Brooding generally occurs in deeper water (>3m) with an ontogenetic shift from the intertidal to the subtidal brooding area over the lifecycle.
- Size reductions may be impacting on reproductive output and recruitment.
- Size at first maturity for females was estimated to be between 1500g to 1800g although females as small as 400g were found to be mature.
- Fecundity as expected was shown to increase with size.
Figure 1: Map of the Tanzanian coastline with study sites indicated in expanded sections: a) Kwale, b) Jibondo, c) Msangamkuu.
Breeding activity is likely to be year round but maturity peaks were evident for January and October to November.

4.2.1.1. Differences in fishing regimes
The three reef sites surveyed all had different fishing regimes and levels of fishing effort.

At Kwale fishing was conducted by men who reached the fished sites from motorised dhows. Fishing was conducted repeatedly during both spring and neap tides with few days not fished in a single month. Fishing during neap tides was conducted using mask fins and snorkel. Octopuses were purchased by a local agent for later transportation to a processing factory, Sea Products Ltd.

At Jibondo reefs were fished by men and women on a rotational basis and only during spring tides when buyers arrived at the island with motorised dhows (Tanpesca Ltd) to take fishers to different fishing sites each day. A total of 5 sites were fished.

At Msangamkuu both men and women fished for octopus on a long stretch of intertidal and shallow sub-tidal reef that backs onto the steeply sloping outer reef. Due to the intense wave action in this zone fishing was restricted, except on calm days when fishers could pass the breaking waves, to a narrow strip no more than 150m wide which was fished repeatedly over the spring tide. Collected octopuses were brought back to the landing site and sold to local buyers.

4.2.1.2. Differences in fishing effort
Despite higher number of fishers at Jibondo the differences in fishing regimes and size of fishing area meant that actual fishing effort per km² at Msangamkuu was more than 2.9 times that of Jibondo and over 2 times more than Kwale (summarised in Table 1) and highlights the importance of such analyses to separate actual fishing effort from apparent fishing effort.

4.2.1.3. Catch Landings and description per study site.
Summarised catch descriptions and total landings for study region and study site are provided in Table 2. Despite higher fishing effort at Kwale and Msangamkuu, study site landings were highest at Jibondo and were more than two times higher than Msangamkuu. At region level, landings were again markedly higher at Jibondo. Approximately 33% of the total catch landing at Tanga region derives from the Zanzibar Islands (Pemba and Unguja) with the remaining 66% divided over the entire reef area of the Tanga region.

The total estimated landing for the three regions of 864 mt yr⁻¹ is higher than the total estimated catch of octopus (600 mt yr⁻¹) recorded in FAO fishery statistics (2002) which are provided by the Tanzanian Government Fishery Department. The total estimated landings reported in this study do not, however, include total landings from Zanzibar, and from three further regions along the coast (Coast region, Dar es Salaam and Lindi region). Catch landings from these areas are estimated from government district fishery records at approximately 200 mt yr⁻¹ and means that FAO fishery statistics account for just over 50% of the total octopus catch from Tanzania. Fishery data collection by government fishery departments is regarded as ineffective due to economic, training and incentive limitations.

4.2.1.4 Effects of fishing regimes and actual fishing effort on catch size, mean individual weight and overall size range of octopus.
In correlation with the lower actual fishing effort at Jibondo compared to Kwale and Msangamkuu mean catch size, mean individual weight, and the overall size range of octopus were significantly greater at Jibondo when compared to the other two sites. Mean catch size per fishing trip at Jibondo was double that taken from Msangamkuu and approximately 1.4kg above that at Kwale. The largest octopus sampled during the study period was a male weighing 11.7kg and measuring 158cm total length.
Table 1: Summary description of fishing effort and the fishing regime for *O. cyanea* at study sites and for individual reef sites for Kwale, Jibondo and Msangamkuu.

<table>
<thead>
<tr>
<th>Fishing Effort</th>
<th>Kwale</th>
<th>Jibondo</th>
<th>Msangamkuu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean no. days fished/study site/mth</td>
<td>26.4</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Mean no. days fished/per reef site/mth</td>
<td>13.2</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Effort (mean no. of fishers per day at study site)</td>
<td>75</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Effort (fishers per km²)</td>
<td>4.84=12 days 1.6=14.4 days</td>
<td>9.29</td>
<td>6.02</td>
</tr>
<tr>
<td>Effort (total no. fisher days per km²)</td>
<td>40.56</td>
<td>27.9</td>
<td>72.4</td>
</tr>
<tr>
<td>Effort (mean no. of hours fished)</td>
<td>3.5</td>
<td>3.47</td>
<td>3.85</td>
</tr>
<tr>
<td>Effort (total no. of fisher hrs per month/km²)</td>
<td>141.96</td>
<td>96.7</td>
<td>278.12</td>
</tr>
<tr>
<td>Effort (total no. of fisher hrs per mth/reef site*)</td>
<td>1320.3</td>
<td>780.4</td>
<td>3699</td>
</tr>
<tr>
<td>Effort (total no. of fishers hrs per mth/study site)</td>
<td>2640.5</td>
<td>3121.48</td>
<td>3699</td>
</tr>
</tbody>
</table>

**Fishing Regime**

<table>
<thead>
<tr>
<th>Type of fishing regime</th>
<th>Repeated</th>
<th>Rotational</th>
<th>Repeated</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of relaxation days between spring tides*³</td>
<td>2</td>
<td><strong>10/13</strong></td>
<td>5</td>
</tr>
<tr>
<td>Mean reduction of relaxation days to Jibondo</td>
<td><strong>8-11</strong></td>
<td>-</td>
<td>5-8</td>
</tr>
</tbody>
</table>

*¹ The two levels of fishing effort relate to spring tide and neap tide periods respectively
*² these figures are calculated by either dividing or multiplying the figures directly above by the average area fished per day. Figures in bold indicate highest values among sites
*³ Relaxation days represent days not fished between spring tide periods
Table 2: Overall catch landings and summarised catch data for study region and study sites at Kwale, Jibondo and Msangamkuu. Figure in parentheses represents the proportion of the octopus catch for all of Tanzania

<table>
<thead>
<tr>
<th>Region/Study site</th>
<th>Tanga/Kwale</th>
<th>Mafia/Jibondo</th>
<th>Mtwar/a/Msangamkuu</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated total catch landings for study regions (mt yr⁻¹)</td>
<td>240</td>
<td>495</td>
<td>103</td>
<td>864 (80%)</td>
</tr>
<tr>
<td>Total catch landings for study site (mt yr⁻¹)</td>
<td>37.6</td>
<td>55</td>
<td>22.9</td>
<td>115.5</td>
</tr>
<tr>
<td>Total catch landings for study site per km² (mt yr⁻¹)</td>
<td>2.02</td>
<td>1.70</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>Mean catch (kg/fisher/trip)</td>
<td>5.2</td>
<td>6.6</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>Maximum catch (kg/fisher/trip)</td>
<td>27.7</td>
<td>46.4</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Minimum catch (kg/fisher/trip)</td>
<td>0.18</td>
<td>0.28</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

*For Tanga region the total figure represents catch landings from Zanzibar Islands as well as from Tanga region. For Mafia region the total figure includes catch landings from the Songo-Songo Archipelago to the south and all of Mafia Island and for Msangamkuu/Mtware for the entire Mtware region
Octopuses were significantly larger at Jibondo than for Kwale and Msangamkuu for the entire sampling period. The largest mean monthly weight of 2077g was recorded for Jibondo in June 2000 and was markedly higher compared to Kwale (1185g) and Msangamkuu (774g). Moreover, highest mean individual weights were obtained from the sub-tidal zone indicating a clear zonation of size while a declining mean weight was indicated for all sites over the sampling period.

The size range of *O. cyanea* was far greater at Jibondo (100-11700g) than Tanga (60-4420g) and Mtwara (80-4400g) and overall Jibondo had significantly more octopus of larger size (Kruskall Wallis Test: chi-squared=14.129, p<0.001). Over 36% of octopus at Jibondo weighed above 1.2kg compared to just 12% at Kwale and only 5% at Msangamkuu. Of these 5% were comprised of *O. cyanea* weighing more than 3kg while for Kwale and Msangamkuu combined the proportion accounted for only 0.5%. Smaller sized octopus less than 600g dominated the catch at Kwale and Msangamkuu and individuals less than 200g and as small as 60g accounted for over 11% of the total catch at each site. At Jibondo only 0.7% of octopuses were less than 200g and no octopuses less than a 100g were taken. The high abundance of large octopus and minimum size limit of 500g may discourage fishers from exploitation of smaller Individuals at Jibondo. No differences in weight or length frequency distributions (p>0.05) were obtained between sexes. Compared to Jibondo differences in weight frequency distributions at Msangamkuu and Kwale when considered with the higher levels of fishing intensity at these sites indicate that growth overfishing may be occurring.

**4.2.1.5. Catch per unit effort for both weight and number (indicating abundance).**

Concurring with the above results CPUE<sub>wt</sub> was on average 2 to 3 times higher at Jibondo compared to the other fished sites. The highest CPUE<sub>wt</sub> at Jibondo was 3.4kg per man hour compared to 2.5kg for Kwale and 1.17kg for Msangamkuu. No zero catches were recorded for Jibondo or Kwale during the sampling period with fishers claiming to have caught at least one octopus. At Msangamkuu zero catches were occasionally evident but are not included in the CPUE<sub>wt</sub> calculations for this site. CPUE<sub>wt</sub> for Msangamkuu may therefore have been overestimated and this further highlights the difference between this site and Jibondo.

In contrast, results of CPUE for number of octopus indicate a significantly higher abundance of octopus at the more intensively fished sites than at Jibondo. At Kwale an overall mean of 2.39 octopuses per hour (range 1.67-3.08/hr) were collected during the sampling period compared to 1.81/hr (range 1.43-2.22/hr) at Msangamkuu and 1.61/hr (1.15-1.97) at Jibondo.

**4.2.1.6. Brief discussion of the catch data results for this study.**

The results summarised above indicate the octopus fisheries of Jibondo is more productive and generally healthier when compared to the other two fished sites. Differences in the fishing regimes, the level of fishing effort and the number of relaxation days from fishing pressure at each site are suggested as the main contributing factors for these differences (Guard, 2003). Higher abundance at the more heavily fished sites may be influenced by predator (e.g. cannabilism) and competition release resulting from the reduction of larger octopuses.

The significantly higher number of small individuals in the catches at Kwale and Msangamkuu suggests that fishing pressure has been high enough for a long enough period to remove most large octopuses and combined with short recovery times has continued to maintain the population at a small size. The high number of large octopuses at Jibondo, conversely suggest that low fishing pressure and an increased period of relaxation or rest between fishing periods enables large sizes and therefore higher biomass to be maintained. This assumption is further supported by the larger octopus sampled adjacent to the fishing grounds at Msangamkuu in a den enrichment experiment as part of the larger study (Guard, 2003). The larger size of octopus in the un-fished area was approximately equivalent to the size range of octopus sampled at Jibondo and indicates that productivity might under low fishing pressure be similar between sites. Similarly, fishers at Kwale and Msangamkuu claimed when interviewed that octopuses have reduced in size over time.
Of concern is whether the present level of fishing effort at Tanga and Kwale has resulted in 'growth overfishing' whereby the stock is fished so hard or so young that the obtained yield is below the maximum obtainable (Saville, 1983). This is suggested here from the differences in the size range between sites and if correct will require reductions in fishing effort if recovery of size range and total biomass of the stock is to increase at these sites.

4.2.1.7. Updated catch dynamics at Jibondo, Mafia Island
The following information is based on a telephone conversation and the provision of a report by Haji Machano, Monitoring Coordinator (Fisheries & Ecology) from the WWF SEASCAPE Project.

The rotational fishing regime at Jibondo has now broken down with fishing conducted at each reef site on each day of the spring tide. In addition, some fishing is conducted on particular reefs at neap tides by snorkelling spear fishermen.

The change in the fishing regime has resulted in an increase in total catch landings for the processor (Tanpesca Ltd) but has led to a decline in the mean size of octopus taken from the fishery. The mean average size now taken from the fishery is 1.2kg compared to 2.1kg in the study of Guard (2003). There is a high likelihood that if fishing intensity is continued at the present level that both growth and recruitment overfishing may occur at these sites as shown for the heavily fished sites at Kwale and Msangamkuu in the study of Guard (2003).

4.2.2. Summarised Reproductive Biology Findings From Guard, (2003)
All data quoted from the following sections should be referenced as (Guard, 2003).

A total of 2339 octopuses comprised of 1118 males and 1221 females were used for reproductive analyses.

4.2.2.1. Sexual maturation and onset of maturity
For the three sites combined 57% of collected males were mature but significantly differed between sites with 39% at Msangamkuu, 55% at Kwale and 79% at Jibondo. The smallest mature male was 160g at Msangamkuu compared to 320g at Jibondo.

For females only 2.1% (n=26) of the total number sampled were classified as mature. Of these 80.1% were from Jibondo, 7.7% from Kwale and 11.6% from Msangamkuu. Mature female size ranged from 480g to 8050g.

50% Onset of maturity for males occurs at approximately 500g. For females the estimated mean onset of maturity may be approximately 1200g and is supported by the 79% of mature octopus sampled above 1500g. However, mature females as small as 400g were sampled.

4.2.2.2. Seasonal changes in maturity
Mature females were found throughout the year and indicates year round mating and laying of eggs. However, two periods of peak brooding activity were observed during January and October and November and agree with peaks in mean weight, CPUE and catch landings.

4.2.2.3. Fecundity
Fecundity in O. cyanea was shown to increase with body weight and compare with results reported in Van Heukelem (1973). Fecundity ranged between 27,000 and 375,000 eggs. As females brood only once in their lifetime, these findings suggest larger females through higher fecundity make a greater contribution to reproductive output.
4.2.2.4. Brief discussion on the reproductive biology results for this study

The increased levels of fishing effort at Kwale and Msangamkuu may be having a negative impact on the potential reproductive output at O.cyanea at these sites and is supported by the reduced number of mature males and females at these sites. The likelihood of recruitment overfishing at these sites is expected to be higher than for Jibondo.

It is clear that the recruitment/paralarvae source and supply scenario is not fully understood and requires further study. However, it is expected especially in areas such as Mafia where a high number of reefs are present and fishing controls in the marine park are greater, that paralarvae supply is unlikely to be limiting to the fishery. Rather, it would be more appropriate to conduct effort on effective management actions such as effort control to maintain a healthy size range and ensure the reproductive potential of the stock is sustained.

4.3.1. Other Potential Indirect Effects On Artisanal Octopus Fisheries

This section discusses the potential impacts of bycatch, intertidal trampling, dynamite fishing and climate change.

4.3.1.1. By-catch

Fishermen gleaning for octopus in both intertidal and sub-tidal areas are opportunistic and will target other species such as reef fish, or lobster if possible. However, their primary target species, octopus is, easier to extract once found, is naturally more abundant and easier to sell on once caught. This means it is unlikely that individual fishers will go out of their way for other species with only low numbers being taken for home consumption. Most of these species will be triggerfish in holes or crevices on the intertidal or fish caught in rock pools. Sub-tidal fishers are more likely to remove reef fish although again not in high numbers due to their lower densities in the upper sub-tidal zones. However, if fishing effort is high on a fished site the accumulated impact to associated species may be relevant and should be considered. Ideally, a study on the quantities of by-catch should be initiated and could be part of a stock assessment protocol prior to MSC certification being provided - see below.

Lobster, a highly valuable marine product, tends to reside deeper than most sub-tidal snorkel fishermen can swim to. Therefore, only a small proportion of this stock would be expected to be impacted by octopus fishers. There are however specific fishermen who target lobster with SCUBA, and often this means over-fishing has already occurred on most reef sites.

Sea-cucumbers is one group readily collected by octopus fishers as they are sessile animals of high value and found in both inter-tidal and sub-tidal areas. Studies have shown that over-fishing of sea-cucumbers has occurred throughout the region of which a proportion of this will have occurred from opportunistic reef gleaning.

4.3.1.2. Intertidal trampling

One impact that is often overlooked from intertidal gleaning is the destruction of the reef flat through trampling. At Jibondo over 70 fishers fish a reef site each day and most trample over the main reef flat up to the shallow sub-tidal level beyond the reef crest where large swathes of corals are present. Studies have shown that trampling results in a marked reduction of coral cover and an increase in coral damage especially to branching and plate forms just beyond the reef crest (Rodgers and Cox, 2002). On most fished reef’s, pathways are clearly demarcated due to repeated use by fishers.

4.3.1.3. Dynamite fishing

Dynamite fishing is still practiced along the coast of Tanzania and is apparently only absent in the extreme south at Mtwara (Guard & Msaiganah, 1999, Wells, 2008). Dynamite fishing will be detrimental to octopus populations through direct mortality of individuals and spawned eggs within the blast area but also through the mortality of paralarvae in the plankton. Furthermore,
persistent reef destruction may result in a decline in prey items which could reduce the carrying capacity of an octopus population and may also reduce reef rugosity and potential den structures.

4.3.1.4. Climate change

The only direct impact from climate change may be through increased seawater temperatures resulting in increased coral bleaching of the reef. This may in turn result in a decline in reef productivity which could affect octopus populations. However, due to the catholic diet of *O. cyanea* it is likely that octopuses would simply exploit new prey items that are advantaged by the coral bleaching event (e.g. algae feeders, and coral borers).

5. POTENTIAL MANAGEMENT APPROACHES FOR OCTOPUS FISHERIES IN TANZANIA AND THE WESTERN INDIAN OCEAN AND THE NEED FOR IMPROVED STOCK ASSESSMENT

After review of the above studies a list of potential management actions are summarised and further elaborated in the following sections; All use of the below information should be referenced as Guard, 2003; 2009).

Potential management actions are;

- Initiate a stock assessment programme and continued catch monitoring
- Introduction of rotational or ‘pulsed’ fishing regimes
- Collaborative agreements for restriction of fishing outside of spring tide periods
- Temporary reef closures and reduced fishing effort during brooding periods
- Introduction of size limits
- Collaborative licence scheme for octopus fishermen and the formation of community stewardship groups
- Introduction of recommended maximum sustainable yields and associated effort for each octopus fishery
- Dissemination of results and community awareness raising

5.1.1. Initiate an improved stock assessment programme and continued catch monitoring

In order to provide fishery data of a high enough resolution to determine accurate comparisons of octopus fisheries and provide detailed information for management, a stock assessment programme is required to be conducted for at least two years. Thereafter, a simplified monitoring programme (less data collected) can be continued to monitor the status of octopus fisheries and assess the effectiveness of management actions at fishing sites.

The type of data to be collected should be fishing effort (correctly calculated), individual catch landings, mean individual weights and catch per unit effort for both weight and number.

A point to consider is that for the study in Tanzania three sites were sampled each with differing levels of fishing effort from excessive fishing pressure to low to medium fishing pressure. These differences enabled a clearer picture of the effects of fishing on octopus stocks to be gained by representing a gradient of impact and resulting consequences. If only one of the sites was sampled, recommendations based on the results would not have been representative for sites elsewhere.

A database as designed for the Tanzania study of Guard (2003) should be used to store the data and enable comparison to the data from this study.

5.1.2. Introduction of rotational or ‘pulsed’ fishing regimes

Rotational or ‘pulsed’ fishing regimes were shown in the Tanzanian study to be beneficial for providing extended recovery periods after fishing events and resulted in the maintenance of healthy octopus yields and a wider size range. Due to the high growth rates of *O. cyanea* even
one or two extra relaxation days per spring tide can have a dramatic effect on the health of the octopus stock. In Tanzania, the rotational fishing regime meant that each reef site was fished for only one day per spring tide but on this basis could sustain greater fishing effort for the fished day but still maintain larger catch yields. If a pattern of rotational fishing can be implemented, it is considered one of the most effective tools for maintaining a healthy octopus stock (Guard, 2003).

5.1.3. Collaborative agreements for restriction of fishing to spring tide periods
Fishing for octopus during neap tide periods can dramatically impact the health of the octopus stock due to the reduction of recovery time for the stock to replenish (Guard, 2003). Essentially, continuous fishing rapidly fished down the size of the stock and may result in both growth and recruitment overfishing. Collaborative agreements with local communities to prevent fishing over the neap tide period could be a tool to ensure the minimum relaxation period is assured. This would only be useful however if fishing effort was not increased during spring tides.

5.1.4. Temporary Reef Closures and reduced fishing during brooding periods
Temporary or permanent closure of reef sites can benefit the fishery by enabling the recovery of depleted resources and for potential spill-over effects to other fishing sites in the area. Humber et al (2006) showed that both mean size and abundance of octopus increased on sites closed in SW Madagascar for 7 months and 4.5 months respectively. Significantly, there was a 32% increase in the number of octopus weighing more than 500g which is considered the minimum size limit for octopus accepted by marine product processors. One problem that occurred with the closure of these sites is that when re-opened fishers from outside the area came to fish for the expected increased fish catches. This resulted in markedly increasing fishing effort and the stock being depleted at a more rapid rate thereby reducing the benefits to local fishers. This could be avoided if more closure sites along the coast were operated systematically (e.g. closed and opened) or that some form of ownership or restriction of fishers could be arranged. While temporary closure of sites has clear advantages there is some argument that if fishing effort could be controlled and rotational or ‘pulsed’ fishing introduced healthy catch yields could be maintained yet through continued fishing and the resulting income revenue to fishers overall benefits may be greater (Guard et al, in press a). However, it is often very difficult to control effort effectively due to the monitoring, control and surveillance (MCS) required to enforce it, so the closure of sites may be easier to achieve especially if part of some form of community management.

As for the timing of potential closures it would further benefit to align these with periods of heightened brooding activity. In Tanzania it was shown that brooding of octopus is most likely to occur year round but with brooding peaks indicated during January and October and November (Guard, 2003). In Madagascar, Laroche (cited in Humber et al, 2006) indicated a peak brooding period from November to January and a recruitment pulse a few months after. In order to help protect the spawning stock biomass during brooding periods, and possibly improve future recruitment it may be useful to ensure closure or as a minimum a reduction in fishing effort during the heightened brooding period (Guard, 2003). As research indicates a clear zonation of size with depth and female octopus tend to spawn at their largest size at the end of their life-span a reduction of fishing effort may be more appropriate in the sub-tidal zone and this would still allow the inter-tidal area to continue to be fished (Guard, 2003).

5.1.5. Use of Size limits
The use of size limits would be beneficial to octopus fisheries by helping to prevent the off-take of smaller immature octopus and reduce the possibility of growth over-fishing. A 500g size limit is proposed as this is the minimum size at which male octopus mature (Guard & Mgaya, 2002). Rather than apply size limits to the fishing operation itself, size limits should be imposed on all sea product processors purchasing octopus as it is much easier to prevent purchase of smaller sized octopus by a few processors than to inspect and regulate catches of a large number of fishers. Size limits introductions are reported in Tanzania and Madagascar but should be formalised as a regulatory mechanism so that all processors are obliged to comply.
If awareness information is provided to fishers as to why the taking of octopus is negative to the fishery and if fishers could not sell smaller octopus to local processors they would be less likely to collect them. It should be recognised however that fishers are often unable to know the size of the octopus until it is extracted, after which it is unlikely to be released. Smaller octopuses if not purchased by the processor are used for local consumption.

At those sites where fishing pressure has reduced the size range of octopus, size limits could be phased in over a two year period with 300g being applied for the first six months and 400g for the next year and 500g thereafter. This would then impact less on the yields of fishers and processors who purchase octopus and would allow for the growth responses from reduced fishing pressure to be realised.

Consideration should also be given to the possible introduction of maximum size limits in order to protect the spawning stock as overall females tend to spawn at their largest size. This would however, be difficult to implement as the value of octopus increases with weight.

5.1.6. Collaborative licence scheme for octopus fishers and the formation of community stewardship groups

In order to determine fishing effort with precision, accurate knowledge of the number of fishers at each site is required. The introduction of a collaborative licence scheme and community stewardship for the octopus fisheries would help to provide this information while enabling regulation of the level of fishing effort through limits on the number of licences issued and monitoring of licence possession or correct name and licence no. provided in the field. The idea that a licence scheme is collaborative is that the fishers as much as the government departments which provide the licences would need to recognise the need for such a scheme and its benefit to the fishery. Education of fishers on the concept of maximum sustainable effort (F_{msy}) combined with the encouragement that ownership of the fishery is with the fishers may help in the acceptance of the licensing scheme. Also the benefit of protection of the fishery from outside fishers through the issue of local licences can be explained. Ownership would be further reinforced by the formation of community stewardship groups whose role would be to organise and monitor the licence scheme and its compliance. Ideally, there should be no cost for the licences to fishers as this may prevent them from supporting the scheme and the justification for the government to cover such costs should however, be recognisable by the benefit of gaining precise information relating to the number of fishers in the octopus fishery.

5.1.7. Introduction of a recommended sustainable yield or fishing effort limits for each octopus fishery

A potential aim for management should be to recommend a sustainable yield or fishing effort limit for each octopus fishery. Traditionally, in fisheries stock assessment such guidance has been provided as maximum sustainable yields (MSY) or total allowable catch (TAC) and the associated effort (F_{msy, tac}) to achieve this. Such estimates, if accurate are useful in management planning as they provide a tangible value of yield off-take or sustainable effort that all stakeholders in the fishery can relate to and understand. They can be further improved by a precautionary 10% reduced reference point, referred to as the maximum consistent yield (MCY) to allow for error in the estimation of the MSY and the inherent instability in the model (Punt & Smith 2001).

Owing to the variable average weight of octopus through the year, which will naturally cause yields to vary (larger octopus=greater yields), and natural variability in recruitment, the more important limit for the prevention of over-fishing are the effort target limits and ideally these should not be exceeded at anytime (Guard, 2003).

A sustainable yield or fishing effort target could possibly be ascertained from the use of the Leslie-Delury depletion method in the form of mean harvestable stock size (50% of the total calculated fishable biomass) and/or from a suitable surplus production model as used in Guard (2003) and shown to be suitable for this task.

It should be recognised that once sustainable limits are attained it may in some cases mean a reduction in fishing effort is required at particular fishing sites and will probably result in resistance
from fishers. In order to counter-act such resistance, clear explanations of the needs, objectives and potential benefits should be explained while alternative forms of fishing may be researched and encouraged (e.g. pelagic or under-utilised sea products) or some form of financial assistance provided in the short term. This, however, is not always practical in economic terms and it should be accepted that in order to conserve a fishery by reducing fishing effort such actions may not benefit everyone but may nevertheless have to be implemented.

5.1.8. Dissemination of the results of this study and community awareness raising

In order that local communities better understand the needs for collaborative management and regulation of the octopus fishery, the results of any stock assessment should be disseminated through presentation of the results and visual outputs. A heightened awareness of fishers, will promote better understanding and communication between managers and fishers and management will be more effective if managers and fishers then work together in a collaborative manner.

5.1.9. System of pilot studies

In order to show the positive benefits of sustainable management of the octopus fishery, pilot studies on particular reef sites could be initiated with local fishers implementing the actions proposed in this report. This has essentially been demonstrated with the temporary reef closures in South West Madagascar. Monitoring and feedback of the responses of the fishery to the implemented actions could then be reported to local communities.

6. CONCLUDING POINTS FOR SUITABILITY AND LIMITATIONS OF TANZANIAN ARTISANAL OCTOPUS FISHERIES FOR MARINE STEWARDSHIP COUNCIL CERTIFICATION

1. Octopus fisheries are ‘potentially’ highly resilient when compared to other fin-fish fisheries and can provide a productive resource if properly managed. This has not yet been achieved in Tanzania with the fishery still primarily an open access fishery with no restriction or enforcement of effort controls and no appropriate licence scheme in operation. This is highlighted by the increase in effort and the breakdown of the rotational fishing regime at Mafia so as to provide increased catches to the processor. This however has proved to be a short term strategy with mean size of octopus now markedly reduced at all fishing sites from the time of the original study by Guard, (2003). There is now a need for management intervention from the marine park to control the activities of the processor and fishermen in the region to reduce the level of fishing effort and enable slow recovery of the fishery. This will be a difficult task to undertake but if effort controls or management can be implemented effectively there is no reason why the octopus fishery could not in the future receive MSC certification.

2. There is a need to change the behaviour of the marine product processors from a mentality of maximising productivity at any costs and with no thought as to the fishing effects on the fished stock to a realisation that a sustainable fishery will in the longer term be more productive.

3. The primary aim at any one fishing location should be to provide the most suitable fishing regime with adequate relaxation days and level of fishing effort so as to maintain a healthy size range and biomass of octopus.

4. Rotational or pulsed fishing increases relaxation days and helps to maintain a healthy size range and productivity.
5. Fishing effort controls could only be implemented with agreement from local communities who should be made aware of the benefits that a restriction of fishing effort will bring. These communities can be utilised to help in the monitoring and control of fishing effort.

6. Closure of fishing sites can be implemented as long as fishing effort is controlled when the fishing site is re-opened to maintain productivity and benefits to fishers. Several closed sites would be more effective than one site but this would depend on the extent of potential fishing areas.

7. More research is needed on the larvae source patterns of octopus recruits to fished reef sites. DNA analysis using molecular markers would greatly help to provide that information. Until such information is available a precautionary approach is suggested so as not to cap the size of octopus and maintain adequate breeding success.

8. Mafia octopus fisheries are still the most productive fisheries in Tanzania and if successful management intervention could be implemented and monitored this fishery may be the most suited for MSC due to ongoing marine park management that could result in effective effort controls and monitoring and the lower incidence of dynamite fishing inside the marine park. The processor at Tanga (Sea Products Ltd) is however by far the most receptive and responsible to implement effective management of the octopus fishery. On the negative side dynamite fishing is more prevalent in the area at Tanga. Maybe this processor could conduct a pilot study either in Tanga or at one of the other locations where they purchase octopus. In contrast Tanpesca Ltd, the main processor on Mafia Island seems to have no consideration towards management of any fishery.

9. It should also be recognised that fish processors purchase octopus from all along the coast and it may be difficult to ensure that octopuses are actually from the certified fishery and not other areas along the coast which may not be fished sustainably. This will be a major problem.

10. Prior to a fishery being provided with MSC certification a stock assessment and management and enforcement protocol should be designed and monitored for effectiveness for at least two years. Thereafter, if all aspects to ensure sustainability of the stock are fulfilled then MSC can be provided for that particular fishery.
7. BIBLIOGRAPHY


Octopus fisheries in the Western Indian Ocean: Suitable for Marine Stewardship Certification?


