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Lunar Cycles, Catchability of Penaeid Shrimps and Implications for the Management of the Shrimp Fishery on Sofala Bank in Mozambique

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Abstract—This study investigates the relationship between lunar cycles and catch rates of penaeid prawns on the Sofala Bank, where the fishery occurs for 6.5 to 9 months a year (starting in February or March), and assesses the potential for effort reduction and economic benefits from short-term closures during periods of the lunar cycle with predictably low catch-per-unit-effort (CPUE). A comparative analysis of the day and night CPUE for the daylight-active "banana" shrimps, *Fenneropenaeus (Penaeus) indicus* and *Metapenaeus monoceros* and the night CPUE for the nocturnally active *Melicertus latisulcatus* and *Marsupenaeus japonicus* was undertaken for each lunar phase and month using two-way ANOVA. Significant monthly variations in CPUE were found in both day and night samples of banana shrimps, for which the CPUE declined throughout the fishing season regardless of time of the day. *M. latisulcatus* manifested significant variations in night-time CPUE during the lunar cycle, with full moons yielding the lowest catches. This is thought to be caused by the burrowing behaviour of this nocturnal shrimp which decreases its catchability. The benefits of fishery closure during full moons and from June to the end of the fishing season were tested assuming two fishery scenarios of differing duration: a 6.5-month fishery (15 March - 30 August) and a 9- month fishery (15 March – 15 December). These closures resulted in an effort reduction of 5% and 8%, respectively, with corresponding catch reductions of 4% and 6%. However, profitability of the fishing companies would improve by 3% and 7%, respectively, as a result of more efficient trawling.

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INTRODUCTION

Lunar cycles have been found to be particularly important in the reproduction patterns, catchability (Garcia, 1988) and abundance of shallow water penaeid shrimps (Slack-Smith, 1969), especially in strongly nocturnal species such as *Melicertus latisulcatus* (Penn, 1976).

In a Western Australian stock of this species, it was observed that, during full moon, catch rates fell to minimum levels (Penn, 1976). This information led to the introduction of short-term closures during full moon in a number of Western Australian *Melicertus latisulcatus* fisheries, to provide a cost-effective effort reduction that would improve biomass levels during the remaining fishing periods (Sporer & Kangas, 2005).

The Sofala Bank, located off central Mozambique (Fig. 1), supports a multi-species shrimp trawl fishery, including a number of species common with the Western Australian fisheries. The fishery is fully exploited by a fleet of about 70 industrial vessels, 30 m in average length, which operate for about 20 fishing hours/day/boat, during a 6.5 to 9-month fishing season beginning in February or March each year (Dr L. Palha de Sousa, IIP, unpublished data). The remaining months are currently subject to a complete fishery closure, to protect the recruitment of juvenile shrimps from estuarine waters (Palha de Sousa *et al*., 2006). The fleet targets six penaeid shrimp species: *Fenneropenaeus (Penaeus) indicus*, *Metapenaeus monoceros*, *Penaeus monodon*, *P. semisulcatus*, *Marsupenaeus japonicus* and *Melicertus latisulcatus*, in depths varying from 5-70 m. Most of the catch is taken during daylight hours in depths between 5-24 m. The latter three species are mainly caught while night fishing, a practice which developed when the summer closed-season was first introduced in 1991. These nocturnal species now represent about 10-20 % of the total shrimp landings of about 8 600 t p.a. and contribute significantly to the profitability of the industry in the second half of the season (Palha de Sousa *et al*., 2006; Dr. L. Palha de Sousa, IIP, unpublished data). They are mainly taken in depths greater than 25 m (Palha de Sousa *et al*., 2006). The expansion of the fishery to fishing at night, together with increased day fishing on the major target species (*F. indicus* and *M. monoceros*) in the late 1990's, has raised the potential for growth and, ultimately, recruitment overfishing (Palha de Sousa *et al*., 2006). This has led to recommendations for a reduction of 30% in fishing effort to achieve bio-economic sustainability of the fishery.

The purpose of this study was to investigate the relationship between lunar cycle and catch rates (CPUE) for all species, but particularly the nocturnal species, *Melicertus latisulcatus* and *Marsupenaeus japonicus*, which are the focus of

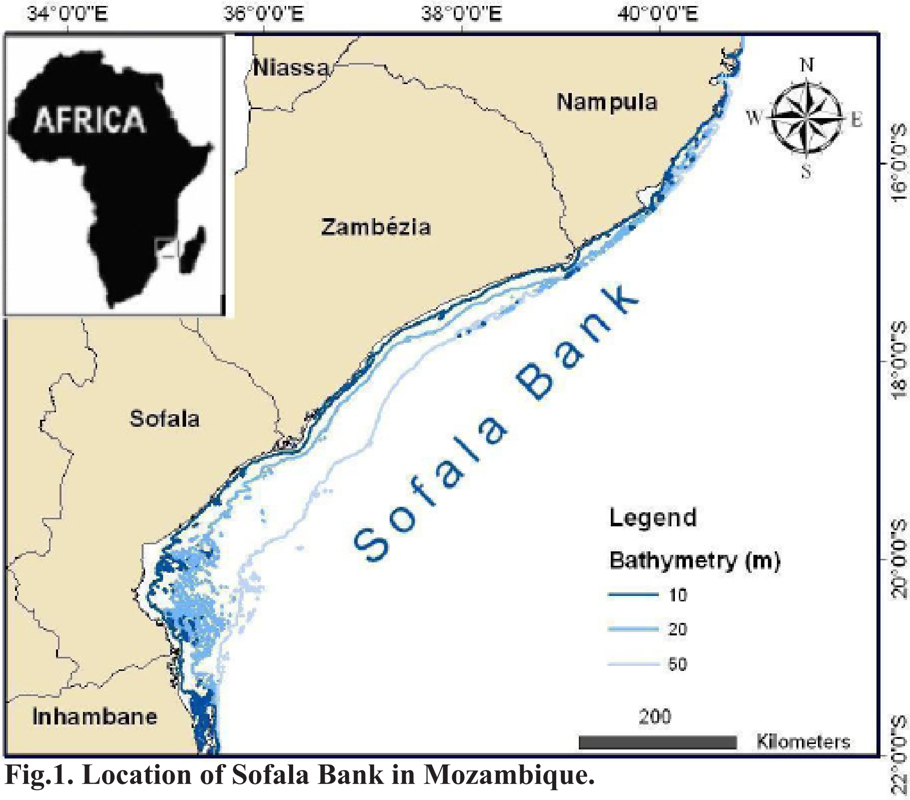

Fig.1. Location of Sofala Bank in Mozambique.

night fishing in the Sofala Bank fishery. The second objective of the study was to assess the potential for economic benefits from short-term spatial closures during the periods of the lunar cycle with predictably low CPUE.

DATA AND METHODS

Data source and processing

Shrimp catch and effort data are obtained annually from log-book records completed by all industrial vessels operating in the Sofala Bank fishery, stored in a database at the Instituto de Investigação Pesqueira (Fisheries Research Institute) in Maputo, Mozambique. A more detailed data-set was selected from these records, for one of the major companies for the 2001 fishing season (March 15th to December 15th), this being a representative year for the study. The 'experimental fleet' consisted of 14 industrial trawlers, of similar power and employing similar fishing methods, with a gross tonnage of 186-272t (Palha de Sousa *et al*., 2006). This fleet comprehensively covered the Sofala Bank fishing grounds during the 2001 season.

Information on the species composition of the catch, the period of the day fished, the geographic coordinates, and the depth of the fishing location were recorded for each trawl. The predominantly daylight-active species, *Fenneropenaeus indicus* and *Metapenaeus monoceros*, were processed onboard as a single category (banana shrimp) for marketing reasons, and they therefore could not be distinguished from one another in the catch records.

For the lunar phase analysis, the catch and effort of trawls at night (6 pm–6 am) were grouped in two depth intervals, 5-24 m and 25-70 m, while daytime trawls (6 am–6 pm) between 5-24 m were combined with the insignificant catches >24 m to provide average day/night catch rates at all depths. Trawls coinciding with each of the four different lunar phases were separated by month, using astronomical tables (Inahina, 2001). To maximize contrast in the data, only the data for the day before, after and of each phase of the moon were used. After this data sorting, 3 229 and 603 night trawls and 3 739 day-time trawls were available respectively for each of the above depth and diurnal intervals for analysis (Table 1).

The relationship between CPUE, lunar phase, and month were examined using two-way ANOVA for both the day-active and nocturnal species. One-way ANOVA was undertaken to assess the relationship between effort and lunar phase (Zar, 1999).

Economic analysis

A profitability analysis of the fishing fleet was undertaken by comparing estimated revenue from the catch and operating costs per hour of trawling. The average landed price per kilogram of catch at the time of the study was US$8.7 based on price information supplied to the Mozambique Ministry of Fisheries by the fishing industry. The average operational cost per vessel-hour during the same period was estimated at US$164.1, which was derived from the Fishing Company's monthly average cost of operation for each vessel and included all fixed and variable costs.

The net profit of the experimental fleet during each lunar phase was obtained by subtracting the total cost of operation from the total revenue of the fleet.

Table 1.Summary of trawl data analysed in the Sofala Bank shrimp fishery, Mozambique

	Period		
	Day-time	Night-time	
Depth intervals (m)	5 – 24	5 - 24	25 - 70
Main active Species	*Fenneropenaeus indicus* *Metapenaeus monoceros* *Penaeus monodon*	*Fenneropenaeus indicus* *Metapenaeus monoceros* *Penaeus monodon*	*Melicercus latisulcatus* *Marsupenaeus japonicus*
Number of trawls	3739	3229	603

Due to the fact that the catch and effort data used were gathered (2001) when the fishery operated for a 9-month fishing season, the economic analyses were re-run assuming a 6.5-month fishing season (15th March to 30th August) to take into account the current fishing scenario (2008-2009) on the Sofala Bank.

RESULTS

CPUE by moon phase

Results of ANOVA analysis of the CPUE (kg/h) for the diurnally active banana shrimps showed that there was no significant relationship between lunar phase and CPUE during either day ($p = 0.3832$) or night ($p = 0.5569$; Table 2) trawling. There were, however, significant variations in CPUE according to month ($p < 0.0001$) for both day and night trawling, and the highest CPUE at the start of the 2001 season was associated with the first quarter of the new moon (Fig. 2a and 2b).

In contrast, the nocturnal species *Melicertus latisulcatus* manifested considerable variation in the mean night-time CPUE during each of the four lunar phases (Fig. 3). This relationship between CPUE (night) and lunar phase was significant ($p = 0.0055$; Table 2), with catches during the new moon and last quarter generally being higher; the relationship between CPUE and month was very close to significance ($p = 0.0548$), with catch rates peaking in June (Fig. 3). Note that the analysis for this species was only undertaken for night catches at depths between 25 - 70 m where this species occurs in fishable quantities.

The ANOVA assessment of monthly variations in the CPUE of *Marsupenaeus japonicus* (Fig. 4) indicated that there were no significant differences in CPUE between the lunar phases of a particular month ($p = 0.4469$), nor between months for a particular lunar phase ($p = 0.8434$); catch rates of this species were lower

Table 2. Results of two-way ANOVA of variability in shrimp catch rates during different lunar phases and months in the Sofala Bank fishery, Mozambique.

ANOVA	Species							
	'Banana' daylight		'Banana' night		*Marsupenaeus japonicus*		*Melicertus latisulcatus*	
Source of Variation	Lunar phases	Months	Lunar phases	Months	Lunar phases	Months	Lunar phases	Months
Df	3	9	3	9	3	9	3	9
SS	197	7323	57	3806	25	43	606	762
MS	66	814	19	423	8	5	202	85
F	1.05	13.10	0.71	15.59	0.91	0.53	5.25	2.00
P-value	0.3832	<0.0001	0.5569	<0.0001	0.4469	0.8434	0.0055	0.0548

than those of the other shrimps.

The catches of *Penaeus semisulcatus* were negligible and therefore not analyzed in this study.

Fishing effort distribution by depth and lunar phase

An analysis of the distribution of day and night fishing effort at various depths and lunar phases over the fishing season is presented in Figure 5 (a, b, c). These data indicated a small shift in night-time effort from shallower waters (5-24 m) in the first three months of the fishing season (Fig. 5b) to deeper waters (25-70 m) in the latter part of the fishing season (Fig. 5c), revealing the increasing importance of nocturnal species in the second part of the season (see slope in trend lines in both). The total daytime effort for the four lunar phases increased slightly over the season (Fig 5a). ANOVA did not reveal any significant relationship between lunar phase and effort in the shallower

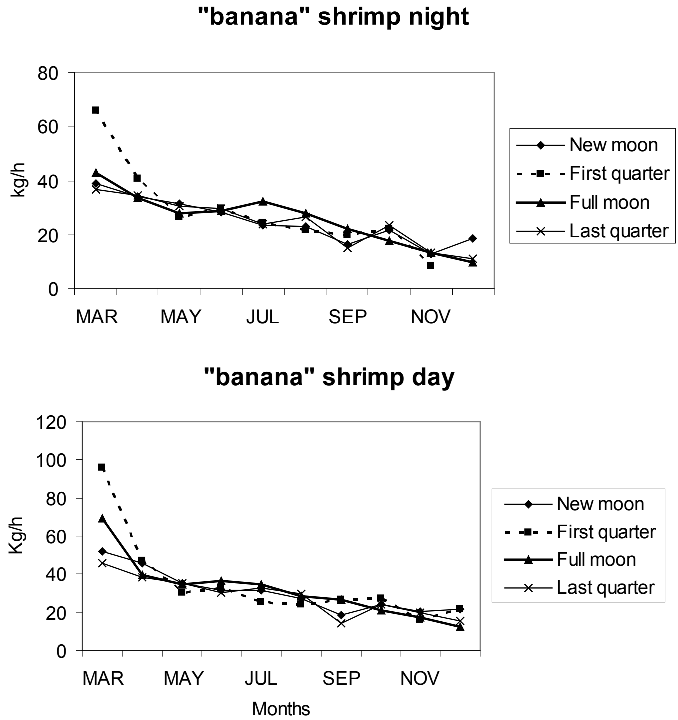

Fig. 2. Lunar variation in CPUE of ‘banana’ shrimp (*Fenneropenaeus indicus* + *Metapenaeus monoceros*) in a) daytime catches and b) at night in 5-24 m on Sofala Bank, Mozambique.

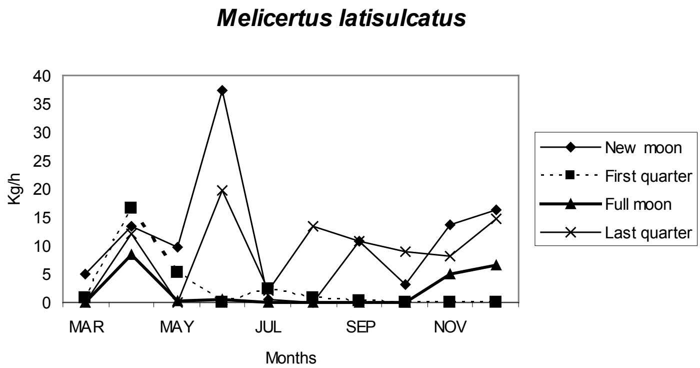

Fig. 3. Lunar variation in CPUE of *Melicertus latisulcatus* harvested at night in 25-70 m on Sofala Bank, Mozambique.

fishing zone (5-24 m) in which banana shrimp were predominant, at either day (F3,35 = 1.0156; p = 0.3974) or night (F3,35 = 0.7752; p = 0.5157).

In contrast to the absence of a relationship between effort and lunar phase in the shallower, banana shrimp zone, fishing effort in night trawls differed significantly according to lunar phase at 25-70 m on the Sofala Bank (F3,33 = 4.6525; p = 0.0080; Fig. 5).

Profitability

Vessel profitability was assessed in terms of the monthly mean CPUE at different lunar phases. The minimum CPUE required to attain profitability was estimated to be 18.9 kg/h, which was obtained by dividing the US$164.1 operational cost per hour by the value of 1 kg of shrimp, averaged at US$8.7.

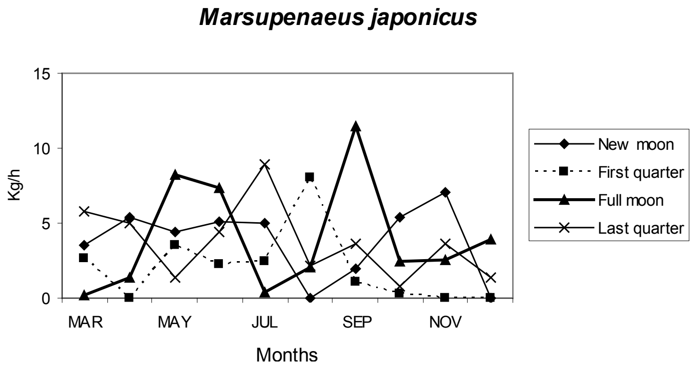

Fig 4. Lunar variation in CPUE of *Marsupenaeus japonicus* harvested at night in 25-70 m on Sofala Bank, Mozambique.

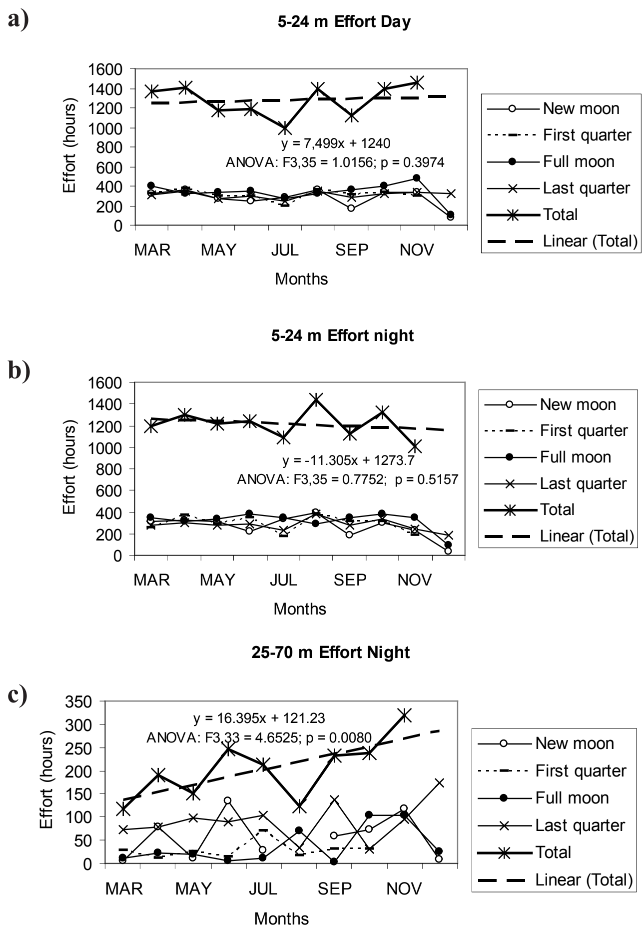

Fig. 5. Fishing effort during each lunar phase and total effort per month expended in a) trawling at day in 5 – 24 m on Sofala Bank, Mozambique, b) trawling at night in 5-24 m, and c) trawling at night in 25-70 m.

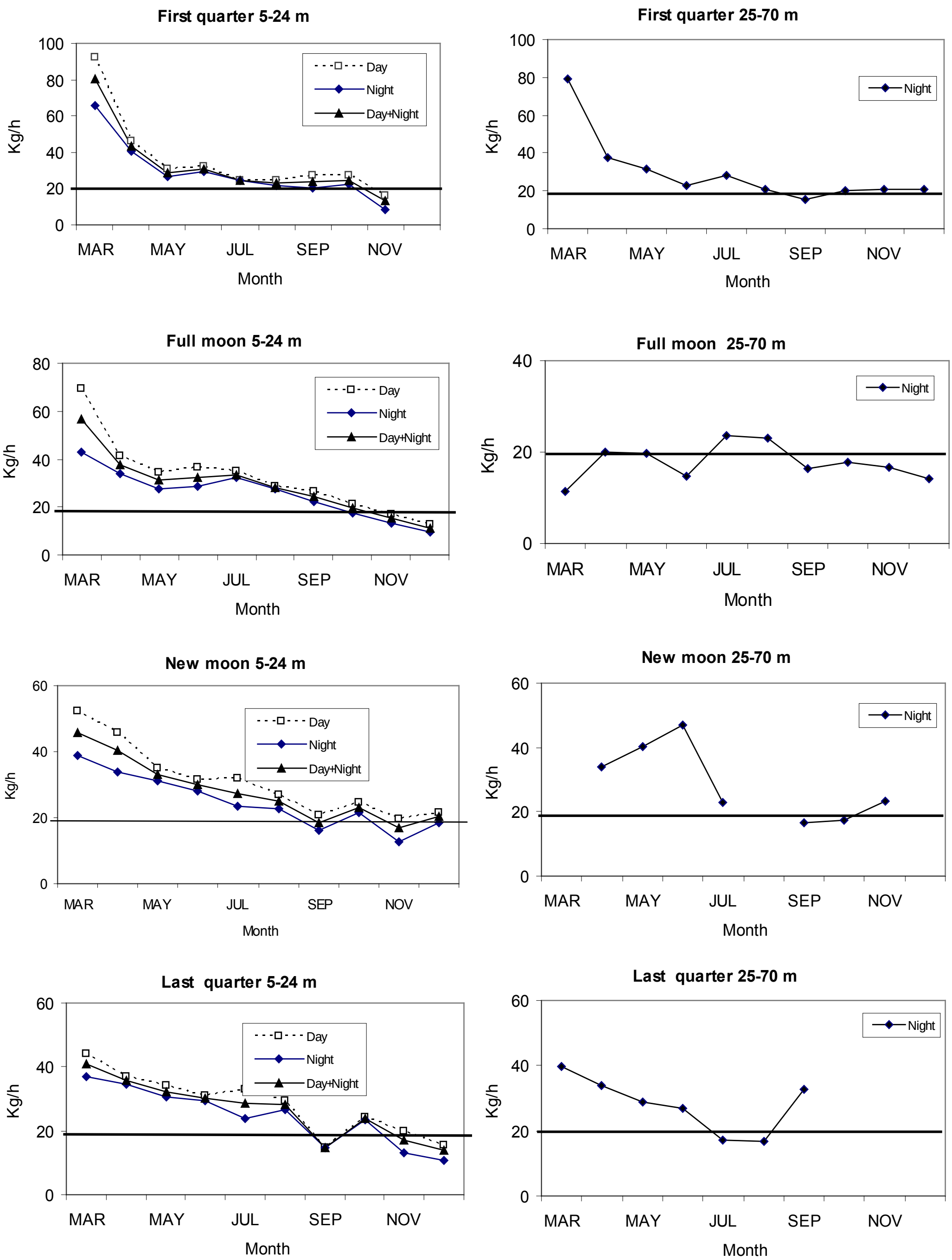

Fig. 6. CPUE of shrimp trawlers during different lunar phases, times of day and at 5-24 m (left) and 25-70 m (right) on the Sofala Bank, Mozambique. The horizontal line reflects the break-even profitability at 18.9 kg/h. Note: y-axes are at different scales to afford greater clarity.

Figure 6 shows that the profitability of the fishing season in shallow water declined from March to December, regardless of time of trawl; in deeper water, this trend was not apparent except during the first lunar quarter.

Overall, March-May was more profitable than June-December within each lunar phase, at both day and night. In the predominantly banana shrimp area (5-24 m), the daytime profit margins were 37-54% higher in March-May than in June-December. Similarly, at night, profit margins were 29-50% higher in the first fishing period than the second (Fig. 6). Over the entire fishing season, day profit margins were 7-30 % higher than the night-time margins.

Additionally, the profit margins varied with the course of the lunar cycle, particularly during the first fishing period, being highest during the first quarter, decreasing to a low point in the last quarter then increasing again with the new moon (Fig. 6).

The right hand side of Figure 6 shows the relationship between income of the fleet and the operating costs at 25-70 m, these depths being subject to significant fishing only at night. It is evident that profits were attained in the new and waxing and waning lunar phases in both periods of the fishing season, with March-May being more profitable (up to 48% more) than June-December. However, the full moon was typically unprofitable. The profit margins respectively covered only 94% and 96% of the operating costs during each fishing season.

A comparison of the economic performance of night fishing in the two depth ranges, 5-24 m and 25-70 m, indicated that the deeper zone was more profitable during the last quarter lunar phase and new moon in both March-May (respectively

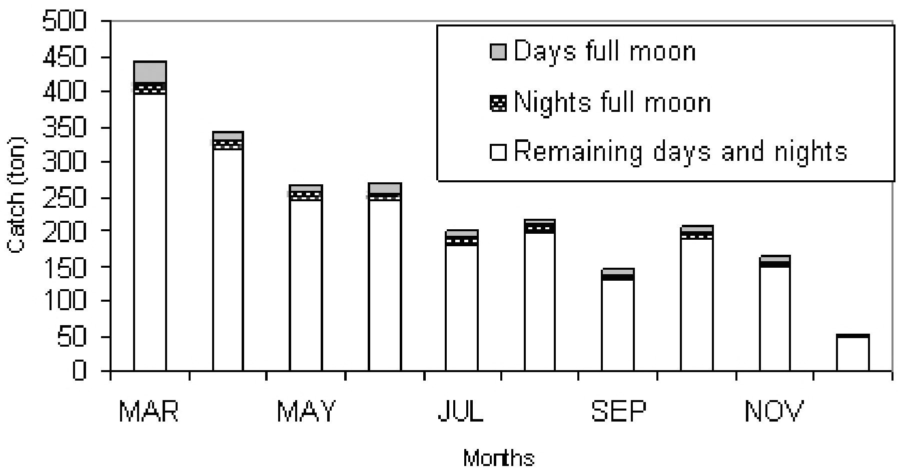

Fig. 7. Monthly shrimp landings (t) by the experimental fleet in 2001 on Sofala Bank, Mozambique, showing the proportion of the catch harvested at new and full moon.

by 7% and 4%) and June-December season (respectively by 8% and 27%). Conversely, the shallow zone yielded higher profit margins than the deeper zone during the first lunar quarter and full moon in March-May (respectively by 1% and 84%) and in June-December (respectively by 1% and 20%).

The preceding relationships between profitability, depth and lunar phase provide a basis to assess the potential economic benefits of short-term closures in the Sofala Bank shrimp fishery.

Impact of spatial full moon closures

The preceding results suggest that there is some potential to improve the economic performance of the industrial fleet. The impact of a series of fishery closures over the three days around each full moon were assessed for the period from June to the end of the fishing season in December (9–month fishing season) and for June-August (in a 6.5-month fishing season scenario). Two closure options were considered: (1) closures only at night and (2) closures during both day and night. In each case, the option assessed was for the complete closure of the fishery i.e. all depths to 70 m, since a closure in the deeper zone alone (25-70 m) would be unlikely to achieve an effort/cost reduction, as a shift in effort to the shallow (open) zones could be expected. The impact assessment was undertaken by quantifying the expected effort reduction, the reduction in catch, and the net effect on profit.

Figure 7 presents the 2001 monthly catches, showing the contribution of the catch taken during the full moon (three nights and days) relative to the total catch by the experimental fleet of 2 100 t during the fishing season (15 March-15 December). Shrimp caught during the three full moon nights between June and December totalled 56 t, which represents only 2.7% of the total landings by the experimental fleet during this period. The catch taken during both the day and night over these full moon periods was 125 t or 5.9% of the total catch harvested by the experimental fleet.

Assuming a 6.5 month trawling season (15 March–30 August), the catch

Table 4. Profits (US$) from shrimp fishing by the experimental fleet on the Sofala Bank in 2001over different periods and the relative profit improvement from fishery closure over full moon.

	Profits			
	Baseline: no closure (in Million US$)		% improvement from full moon closures, June to end of fishing season	
Fishing season scenario	night	day + night	nights*	day+ night**
March-December	0.9	2.3	+ 5.2 %	+ 6.7 %
March-August	1.0	2.3	+ 1.8 %	+ 3.2 %

* closure option 1, ** closure option 2

of shrimp would have totalled 1700 t. The closure of full moon nights from June to August would have resulted in a loss in catch of 32 t, while a closure of both day and night harvesting would have resulted in the loss in harvest increasing to 65 t (4%; Fig. 7).

The fishing effort assessment (Table 3) revealed that 2 515 trawl hours (3.8% of the annual effort) were spent harvesting during the three full moon nights between June and December and 5 058 trawl hours (7.7%) were spent during both the day and night full moon periods. In considering the shorter fishing season, the full moon periods from June to August contributed 1 101 trawl hours (2.6%) to the harvest at night and 2 093 trawls hours (5.0%) during both day and night (Table 3).

A profit margin assessment was carried out, based on the above catch and effort information and on the fleet profitability. It is estimated that profit would have improved by 5.2% if there had been a three night closure during the full moon periods from June to December (option 1), while closing the fishery for three days and nights over full moon (option 2) would have resulted in a 6.7% improvement in profit (Table 4). These calculations were re-run assuming a shorter fishing season of 6.5 months, with closures from June to August, resulting in profit improvements of 1.8 % and 3.2 % using fishery closure options 1 and 2 respectively (Table 4).

DISCUSSION

The results of this study have revealed significant differences in the CPUE of the nocturnally active shrimp, *Melicertus latisulcatus*, relative to lunar phase, with full moons yielding the lowest CPUE. This finding corroborates the results of Penn (1976) for an Australian shrimp fishery for *M. latisulcatus*. The varying CPUE is a consequence of changes in the species' behaviour in response to a range of environmental factors. *M. latisulcatus* is thought to burrow in sand as a predator-avoidance mechanism (Tanner & Deakin, 2001). This behaviour has also been observed in *Marsupenaeus japonicus* (Egusa &Yamamoto, 1961) and many other penaeid shrimps during periods of high light intensity (Barnes, 1985; Wassenberg & Hill, 1994; Griffiths, 1999). A consequence of burrowing is that they avoid capture by the fishing gear. An important point to note is that, on the Sofala Bank, the nocturnally active *M. latisulcatus* and *M. japonicus* occur more offshore than the diurnally active 'banana' shrimp which are found closer inshore (Brinca *et al.*, 1983; Palha de Sousa *et al.*, 2006). Therefore, declines in catchability of *M. latisulcatus* during full moon have a negative impact on the profitability of the fleet in the 25-70 m zone, as shown in the profitability assessment.

As demonstrated by these results, and earlier studies (Dr L. Palha de Sousa, IIP, unpubl. data.), Sofala Bank trawlers fish mostly at depths shallower than 25 m, where they obtain the highest catches of banana shrimps. In the first two to three months of the fishing season, the intensity of effort is similar in both day and night, but then shifts to deeper waters (25-70 m) and increases at night in the latter half of the season as banana species become less abundant (Palha de Sousa *et al*., 2006). The fact that relatively low effort was recorded in this study at 25-70 m during full moon indicates that crews are avoiding these depths to some extent because they are unprofitable. Anecdotal evidence indicates that vessel captains know that *Melicertus latisulcatus* catches are low at full moon.

Despite the general belief that banana shrimps are more diurnally active, a laboratory experiment revealed that *Metapenaeus monoceros* juveniles burrow during daylight hours in the presence of predatory fish (Macia *et al*., 2003). It is therefore possible that *M. monoceros* may burrow, as do congenerics in Western Australia (Ruello, 1973). Differences in behavioural characteristics of the target species may affect their temporal and spatial distribution, patterns in abundance and, ultimately, their catchability by the fleet. However, because *F. indicus* and *M. monoceros* were not separated onboard, it was not possible to assess this.

Closed seasons are important for the biological and economic management of tropical shrimps that are fast-growing and short-lived, to control fishing effort, prevent growth overfishing and maximize catch value (Watson *et al*., 1993). Ye (1998) showed that the benefits of seasonal closures were greater at higher levels rather than at lower levels of fishing effort, with more benefit in the value per recruit than the yield per recruit. Palha de Sousa *et al*., 2006 provide a detailed description of the closed seasons on Sofala Bank, which were first introduced in 1991 following sharp declines in the shrimp catches and growth overfishing at high levels of fishing effort. The main objective of the closed seasons was to protect the recruitment of juveniles of the main species, *F. indicus*, to the fishery and to make larger and more valuable shrimps available when the fishing season opens. While these objectives were achieved, in recent years (2008 - 2009), fishery closure has also become a tool to test ways of decreasing fishing effort and operational costs in the fishery by expanding the season from 3.5 to 6 months (pers. obs.) due to the financial difficulties in the fishing industry (Dr. L. Palha de Sousa, IIP, unpublished data). Thus, closed seasons are potentially an important management tool to maximize the value of the Sofala Bank shrimp fishery at its high level of exploitation (Palha de Sousa *et al.,* 2006).

Aspects of shrimp distribution and behaviour, and fleet operations, profitability and fishing effort were considered in a semi-quantitative evaluation of two proposed closure options (night closure and day + night closure) in the June-December season. This evaluation was also re-run assuming a shorter fishing season of 6.5 months ending in August to take into account the current (2008-2009) fishing on Sofala Bank. Assuming that the 'experimental' fleet activity is representative of the remainder of the industrial shrimp fishing fleet on the Sofala Bank, a closure of the fishery for three days and nights over full moon (option 2) from June to December would result in approximately 8% reduction in effort versus a 5% reduction in June–August, with a respective catch reduction of about 6% versus 4% in the two scenarios. It is assumed that most of the loss in catch during the three closed days and nights would still be available to harvest during the ensuing open periods. The day + night closure option is preferable as a closure at night alone would result in an increase in the daylight effort at 5-24 m, which would reduce profitability as the profits from daylight catches are below average at this time, particularly at full moon.

Although profits gained from the closure could not be accurately quantified, it was estimated that application of the day + night closure (option 2) over June to December would generate a 6.7% improvement in profitability of the fishery. The improvement would be 3.2% if the closure was implemented in June–August, assuming the shorter fishing season scenario. These improvements would probably result from considerable savings in operational costs, as fuel would not be used for unprofitable trawling over the full moon periods. Vessel captains and company managers have reported on many occasions that fuel represents 50% or more of the harvesting cost and that as much as 85-90% of their fuel is spent in trawling operations, the remainder being used for sailing. Other foreseeable economic benefits would emanate from the closure, especially in the current (2008 - 2009) situation. The Sofala Bank shrimp fishery is experiencing financial problems due to low shrimp prices from competition with aquaculture products and high fuel costs (Dr L. Palha de Sousa, IIP, unpublished data). Preliminary indications are that the operating cost of US$214.6 per vessel hour in 2007-2008 had risen to US$264 at the start of 2009. These figures are 24% and 38% higher than the 2001 estimate used for the experimental fleet in this study, the increases being attributable to rising fuel prices. In addition, the average shrimp price at this time fell below that of the 2001 level of US$8.7, so the 2007-2009 profitability would have been even further reduced. This is borne out by the large number of trawlers which did not operate in the second half of 2008 (pers. obs.).

The profitability analysis has indicated that it would be economically beneficial to implement the proposed closure during full moons. Although the benefits would be lower in the current scenario of a 6.5–month fishery, the closure would further benefit the fishery when it eventually returns to the 9-month fishing season.

Should such a closure be implemented by the fishery management authority, a number of changes could be introduced in fleet planning to operate more efficiently over the lunar cycle. For instance, trawlers could return to their home port for maintenance over the three-day closure every 27 days as opposed to the current average of three days in every 45. Alternatively, anchoring at sea could be considered to allow onboard maintenance and the crew to rest. However, for closure to be successfully implemented, enforcement capacity would need to be improved and the current management measures supplemented with associated technology such as a Vessel Monitoring System (VMS).

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