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Mud Crab (*Scylla serrata*) population changes in Koggala Lagoon, Sri Lanka since construction of the groyne system

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*This study was conducted to determine the present status of the Mud Crab (*Scylla serrata *Forskal) population in Koggala Lagoon, including details on size at maturity, sex ratio and carapace width - body weight relationship. This Crab is the most common edible Crab species found in the lagoon, comprising 93.10% of total catch from crab pots and 89.86% of total catch from crab nets. Sex ratios (male:female) were 1:0.86 and 1:0.82 in crab pots and nets, respectively. Female crabs of various sizes were randomly sampled to determine size at maturity. The results indicate that size at maturity of females was 12.17 cm carapace width. Size at maturity of males could not be determined using external characteristics. Population parameters were estimated from length-frequency data collected in 2009 and 2011. Asymptotic carapace length (L_∞) and growth constant (K) were estimated to be 20.12 cm, 0.91 yr^{-1} in 2009 and 19.27 cm, 3.2 yr^{-1} in 2011, respectively. Exploitation rates were 0.32 in 2009 and 0.44 in 2011. There was a significant difference in Crab size between harvests by the crab nets versus traditional crab pots. Results indicate that* S. serrata *population is declining due to over-fishing as of increased fishing gear efficiency from traditional crab pots to modern crab nets. Commercial catches of crab net and crab pots comprised 85.7% and 72.0% of immature females, respectively, based on the size at first maturity revealed by this study. In order to maintain natural health of the Mud Crab population, immediate management action is needed to regulate fishing in Koggala Lagoon.*

Keywords: crab net, crab pot, exploitation, vulnerability status

Introduction

Koggala Lagoon (5° 58′ 59″ N and 80° 19′ 58″ E) is a shallow waterbody located in the southern part of Sri Lanka which has an area of 574 hectares and maximum depth of 3.2 m at the deepest site (Figure 1). A natural sand bar at the mouth of the lagoon seasonally separated the lagoon from the

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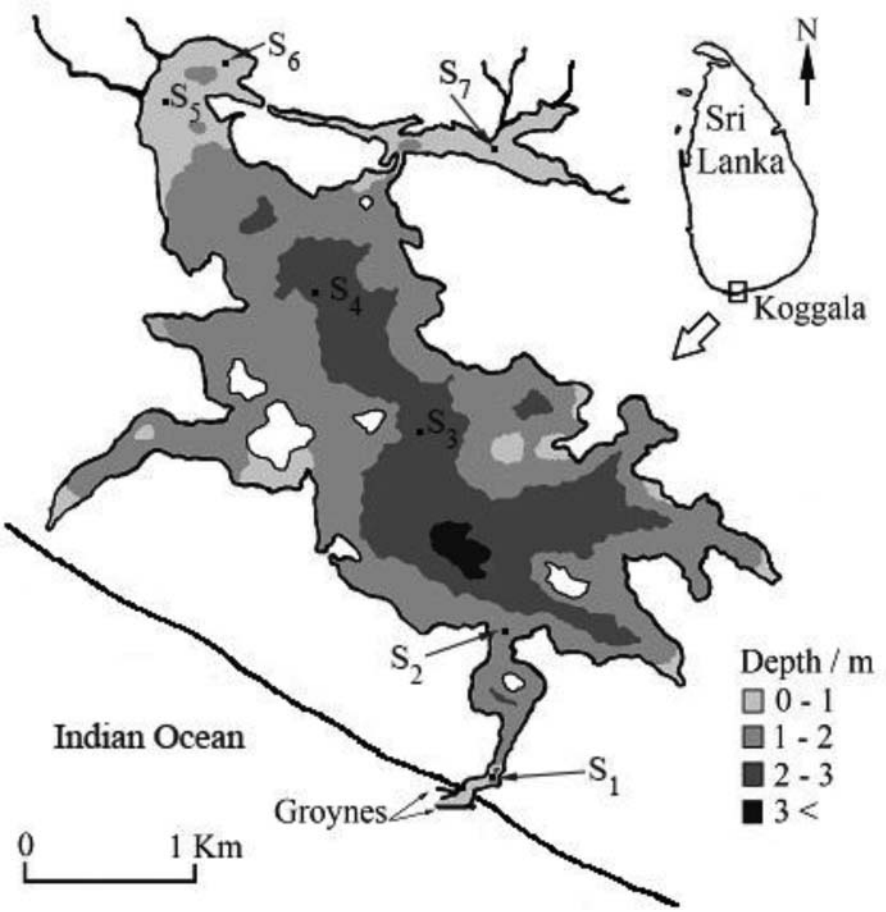

Figure 1. Map of Koggala Lagoon, Sri Lanka showing groynes, sampling stations and depth contours.

sea. The sand bar was removed manually whenever the water level exceeded high flood level during the rainy season. After removal of a large quantity of sand from the sand bar during development activity in 1994, the sand bar was formed further into the lagoon and erosion increased. As a remedial action, a groyne system was constructed at the lagoon mouth (Figure 1) and with that the seasonal formation of natural sand bar across the lagoon mouth ended. This led to a situation where the lagoon mouth is open throughout the year and increased salinity inside the lagoon (Gunaratne et al., 2010). This impacted the faunal and floral communities within the lagoon (Priyadarshana et al., 2007).

There are two commercially important Crab species, *Scylla serrata* and *Portunus pelagicus* in Koggala Lagoon. *S. serrata* is more dominant than *P. pelagicus* at present (G. P. Amarasekara, pers. comm.).

It is the only species of the family Portunidae that is closely associated with mangrove environments, and commonly known as the Mangrove Crab or Mud Crab, which is edible and commercially important (Overton et al., 1997). Adult Mud Crabs are generally found in muddy, mangrove-lined brackish waters, and the ovigerous females move offshore to spawn (Hill, 1994).

Fishermen involved in Koggala Lagoon claim that their harvest of large Mud Crabs was decreasing due to increased salinity as a result of the groyne construction and open lagoon mouth throughout the year (G. P. Amarasekara, pers. comm.). Several fish species such as *Etroplus suratensis* have been affected by this high saline condition (Amarasekara et al., 2012). Salinity and temperature were found to be the most important abiotic factors affecting Mud Crab survival (Ruscoe et al., 2004). Survival of *S. serrata* is not

significantly different among salinities between 5–40 ppt and has been known as a wide temperature and salinity tolerant species (Ruscoe et al., 2004). The optimal salinity for survival of *S. serrata* zoea larvae was found to be 32‰ (Baylon et al., 2001). Chang (1997) suggests that the suitable salinity for *S. serrata* is 20–35‰ salinity, whereas Baliao et al. (1999) indicated a salinity range of 10–35‰ and temperatures between 25°C and 30°C are suitable for polycultures (crabs, prawns, milkfish and seaweeds). Annual salinity of the Koggala Lagoon ranged from 16 to 30‰ and bottom temperatures varied between 27°C and 30°C. Information provided by the scientific literature indicated that the prevailing salinity is not the factor causing the reduction of Mud Crabs in the lagoon.

At present in Koggala Lagoon, crabs are caught by two gears: crab nets and traditional baited crab pots (Figures 2a and b). The efficiency of crab pots primarily depends on the attraction to the bait causing a feeding response by *S. serrata*. Most of the time, fishermen use fish (especially *Arius jella* and *Mugil* spp.) or shellfish as bait which is wired to the center of the bottom of the crab pot. About 15–25 crab pots per boat, manned by one or two fishermen, are set in the morning at intervals of 4–6 m apart in selected areas in the lagoon at a minimum depth of 1 m. After one or two hours, crab pots are lifted and after harvesting, the crab pot is re-baited and replaced. However, many fishermen turned to the crab fishery from the fin fishing using new crab nets. About 2 m × 100 m or more large crab nets are spread across the lagoon and they are left sitting on the bottom. After one or two hours, nets are lifted and entangled crabs are harvested.

The objective of this study was to determine reasons for declining crab numbers in Koggala Lagoon. In a changing population, the most important task is estimating population parameters, asymptotic length and growth coefficient. The asymptotic length (L_∞) is the theoretical maximum length that the species would reach if it lived indefinitely and growth coefficient (K) is a measure of the rate at which maximum size is attained (King, 1995).

Materials and methods

Comparison of morphometrics, sex and harvest of crab pots versus crab nets

This part of the study was conducted in January, 2009. Catch of crabs was collected from the fishermen in the Koggala Lagoon with respect to crab nets and crab pots. In many cases, a fisherman who uses crab nets handles only one net, but the mean number of traditional crab pots handled by an individual fisherman is 18. Therefore, harvest data from 18 crab pots were compared with harvest data of a crab net to equalize the fishing effort. Crabs harvested from 450 crab pots and 25 crab nets within four hours were used for analysis respectively.

Carapace width (CW), or the distance between the tips of the ninth antero-lateral spines of the carapace, of each crab was measured to the nearest mm with a Vernier caliper (Figure 2c) and the live weight of the crabs (BW) was measured to the nearest gram using a digital electronic balance with sensitivity to 0.1 g. Based on the shape of the abdomen, crabs were separated into male and female. Although the male crab has a narrow and

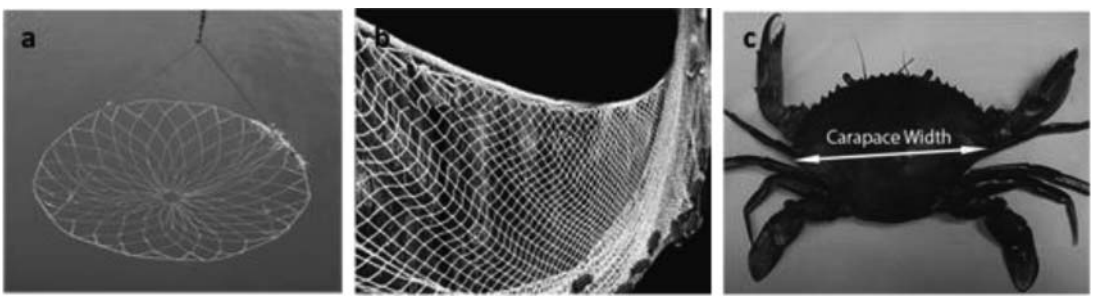

Figure 2. (a) Crab pot, (b) crab net and (c) carapace width of *Scylla serrata*.

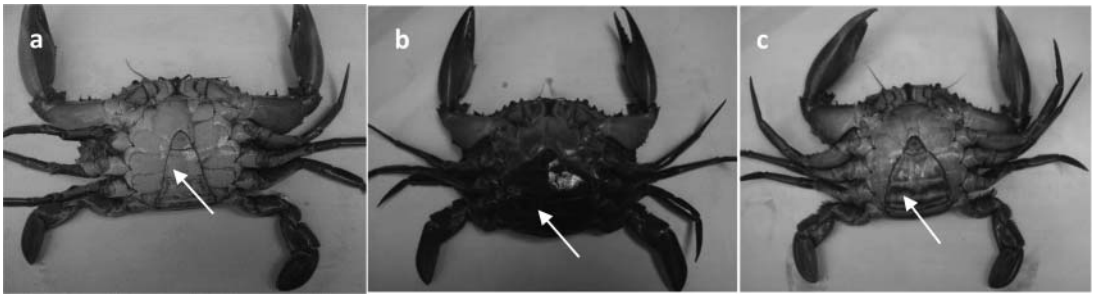

Figure 3. Assessment of sex and maturity by the stage of the abdomen: (a) immature/matured male; (b) matured female; (c) immature female.

straight abdomen, the female's is wider and more globular (Figure 3). CW and BW data were reported with their sex to determine the CW–BW relationship.

Further information about the fishery was gathered from interviews with crab fishers. A simple form was filled by the crab fishers immediately after each trip, including information about their fishing area, duration of the fishing trip, total catch and gears used.

A t-test was done to determine whether there was a significant difference between sizes of crabs caught by traditional crab pots versus the now more used crab nets.

Salinity and bottom temperature of the selected stations in the lagoon (Figure 1) were measured once a month throughout the year using a YSI-85 digital water quality meter.

Size at maturity

Between January 2009 to December 2009, crab samples were obtained by placing a crab net and 18 crab pots in the lagoon once a month. As maturity of male crabs could not be determined easily from external characteristics, size at maturity of only female crabs was determined from their carapace widths. Female crabs that had undergone the maturity that causes a widening and darkening of the abdomen were classified as mature females (Heasman, 1980; Figure 3). All other females were considered as immature. Crabs were grouped into size classes and the percentage of mature crabs in each class was calculated. The size of the carapace when 50% of crabs were mature was determined; this can be used as an appropriate measure of size at maturity in female crabs (Teixeira et al., 2009).

All crab samples were examined for external evidence of mating. Sometimes dark spots or abrasions on the underside of the male crab could be observed. These mating scars provide evidence that the male crab has recently mated (Figure 4).

Population dynamics of crabs, asymptotic length (L_∞) and growth coefficient (K)

During the period, January 2009 to December 2009 and again between January 2011 and December 2011 *S. serrata* crabs were collected weekly from two fish landing centers in the Koggala Lagoon. Carapace widths of the crabs were measured and recorded in order to calculate monthly size distribution.

The total asymptotic length (L_∞ cm) and growth coefficient (K yr^{-1}) of the Von Bertalanffy growth equation (Von Bertalanffy, 1938; Beverton and Holt, 1957) were calculated using monthly length frequency distribution data. Here asymptotic carapace width (CW_∞) was considered as the asymptotic length (L_∞).

$$L_\infty = CW_\infty$$

L_∞ and K value were determined using the ELEFAN I and ELEFAN II routines incorporated in FiSAT software following the Powell-Wetherall method (Wetherall et al., 1987). This method was used to provide an initial estimate of L_∞. This initial estimate of L_∞ was then considered as seed value to determine the value of K (Silvestre and Garces, 1989).

Month-wise Length frequency data were used to estimate the total asymptotic length (L_∞ cm) and growth coefficient (K yr^{-1}) of the Von Bertalanffy growth equation.

Figure 4. The underside of a male Mud Crab showing mating scars on abdominal plates.

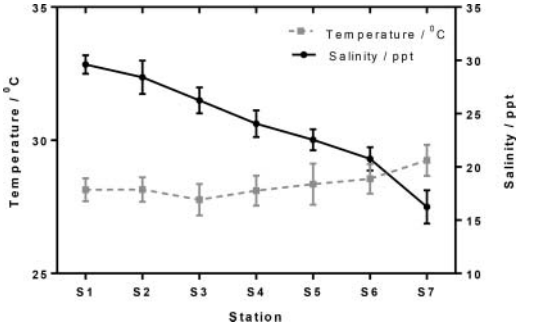

Figure 5. The mean annual spatial variations in (a) salinity (±SD) and (b) bottom temperature (±SD) of the Koggala Lagoon, Sri Lanka.

$$L(t) = L_{\infty}\,[1\text{-}\exp^{-K\,(t\text{-}to)}]$$

where L(t) = carapace length at time t.

Mortality estimation

Using FiSAT, the total mortality, Z (yr^{-1}) coefficient (Beverton and Holt, 1966) was estimated using the length converted catch curve by means of the final estimates L_{∞} and K and the length frequency distribution data for the species, *Scylla serrata*.

The rate of natural mortality M (yr^{-1}) for 2009 and 2011 were estimated using Pauly's empirical equation (Pauly, 1980).

$$\text{Log}_{10}\,M = 0.0066 - 0.279\text{Log}_{10}\,L_{\infty} + 0.06543\text{Log}_{10}K + 0.4634\text{Log}_{10}\,T$$

Here, T was taken as mean bottom temperature of the lagoon in the relevant year.

Fishing mortality rate F (yr^{-1}) for year 2009 and 2011 were obtained by subtracting M from Z (Silvestre and Garces, 1989).

$$F = Z\text{-}M$$

The exploitation ratio, E, for 2009 and 2011 were calculated by the following formula (Beverton and Holt, 1966; Gulland, 1971).

$$E = F/Z$$

Results

Water quality and crab harvest data

Mean monthly salinity of the lagoon ranged from 16.2 ppt to 29.6 ppt and bottom temperature ranged from 28.1°C to 29.3°C (Figure 5). The mean water temperature and salinity did not vary greatly between months, and did not

Table 1. Percentage of composition and sex ratio of Mud Crabs from Koggala Lagoon, Sri Lanka.

		Catch of crab pots				Catch of crab nets			
Species/sex		Total	%	% by species	Sex ratio (Male:Female)	Total	%	% by species	Sex ratio (Male:Female)
Scylla serrata	Male	29	50.00	93.10	1:0.86	34	49.28	89.86	1:0.82
	Female	25	43.10			28	40.58		
Portunus pelagicus	Male	2	3.45	6.90		3	4.34	10.14	
	Female	2	3.45			4	5.80		
Total		58	100.0	100.00		69	100.0	100.00	

Table 2. Carapace widths of Mud Crabs caught by crab pots and crab nets from Koggala Lagoon, Sri Lanka.

	Carapace width of Crabs caught by crab pots cm^{-1}		Carapace width of Crabs caught by crab nets cm^{-1}	
	Male	Female	Male	Female
Mean	11.09 (±SD2.69)	11.34 (±SD 3.04)	10.04 (±SD 2.59)	10.26 (±SD 2.92)
Total mean	11.21 (±SD 2.83)	10.14 (±SD 2.73)		
Max.	17.8	18.1	17.1	18.3
Min.	7.1	7.1	6.7	6.8
n	29	25	34	28
N	54	62		

affect monthly fluctuations of catch and growth of *S. serrata* in Koggala Lagoon during the study period.

S. serrata is the dominant Crab species in the lagoon accounting for 93.10% and 89.86% of the total catch of crab pots and nets, respectively. The sex ratio (male to female) of catch of crab pots and nets were 1:0.86 and 1:0.82, respectively. In addition to *S. serrata, P. pelagicus* was reported in low amounts (Table 1).

The carapace width (CW) - body weight (BW) relationship

The mean carapace width in both sexes caught by the crab pots was larger than that caught by the crab nets (Table 2). Females caught were larger than males in both gears. According to the relationship between body weight and carapace width of *S. serrata* harvested, the female crabs are generally heavier than male crabs (Figure 6).

The CW–BW relationship for females and males was estimated as: $y = 17.626e^{0.223x}$ ($R^2 = 0.993$; $n = 53$) and $y = 9.253e^{0.275x}$ ($R^2 = 0.985$; $n = 63$), respectively (Figure 6).

Independent sample t-test showed that there was a significant difference between the carapace widths of crabs caught by crab pots versus the crab nets ($P < 0.05$). The mean carapace width of crabs caught by the crab nets was 10.14 cm and that for the crab pots was 11.20 cm (Table 3).

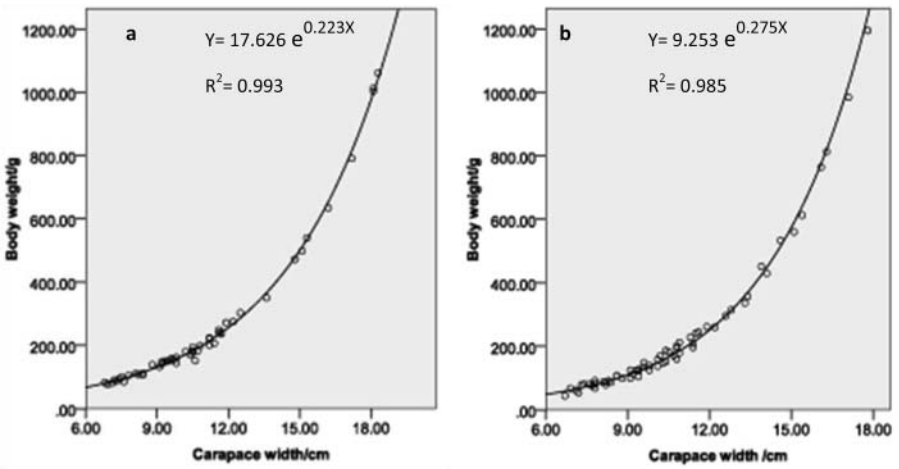

Figure 6. Morphometric relationship between body weight and carapace width of *S. serrata* (a) female and (b) male in Koggala Lagoon, Sri Lanka.

Table 3. Details of the t-test on carapace widths of crabs caught by crab nets versus crab pots.

Gear	Number of Crabs	Mean carapace width cm^{-1}	Standard deviation	Sig.
Crab net	62	10.14	2.73	0.042
Crab pot	54	11.20	2.83	

Size at maturity

130 female *S. serrata* were measured; the largest immature and the smallest mature females recorded were 15.2 cm and 9.8 cm CW, respectively. Size at maturity was 12.17 cm (Figure 7). Mating scars on males were rarely found; only 4% of 152 caught males exhibited mating scars. Immature females, which had CW less than the calculated size at first maturity of *S. serrata*, comprised approximately 72% of the catch by crab pots and 85.7% of the catch by crab nets, respectively.

Asymptotic length (L_∞) and growth coefficient (K)

The minimum and maximum carapace lengths varied between 6.8 cm and 15.9 cm and weights varied between 76 g and 1265 g. The value of asymptotic length (L_∞) and the growth coefficient (K) estimated by ELEFAN 1 were found to be 20.12 cm, 0.91 yr^{-1} in 2009 and 19.27 cm, 3.2 yr^{-1} in 2011.

Mortality and exploitation rate

Values for total mortality (Z), natural mortality (M) and fishing mortality (F) in 2009 were found to be 2.76 yr^{-1}, 1.89 yr^{-1}, and 0.87 y^{-1}.Those for 2011 were 7.81 y^{-1}, 4.40 y^{-1} and 3.41 y^{-1} respectively. Thus the exploitation rates were 0.32 in 2009 and 0.44 in 2011. As high fishing pressure is prevailing in the Koggala Lagoon, the exploitation rate has increased by 0.12 within two years. Crab population indicates that over-fishing conditions are rapidly increasing.

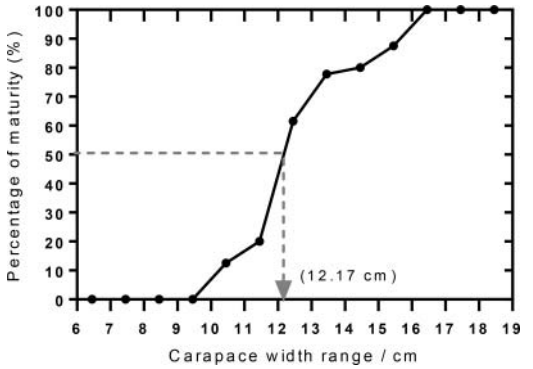

Figure 7. Size at maturity for female crabs of *S. serrata* sampled from Koggala Lagoon.

Discussion

The CW–BW relationship is frequently used in the studies of crustaceans. That relationship can be used to estimate edible meat from crabs of different sizes and the biomass of the population. Measuring CW of live crabs may somewhat difficult, therefore, the CW–BW relationship is useful to convert BW into CW.

In the study there could be observed a difference in abundance between sites, with *S. serrata* showing a high preference for the sub-littoral shallow waters close to mangroves. The present impoverished status of *S. serrata* stocks in Koggala Lagoon is also compounded by habitat destruction due to extensive mangrove clearance around the lagoon.

Although most of the life cycle of *S. serrata* is spent in brackish waters, females migrate offshore for spawning (Hill, 1994), especially in the main spawning period from April to November. In this study over 80% of the crabs observed near the lagoon mouth were female and of these 64% were ovigerous. There are at least two reasons for this change in choice of habitat at different stages: intolerance of larvae to estuarine conditions, especially low salinity during rainy seasons, and greater dispersal of larvae (Hill, 1994). *S. serrata* has a wide distribution in the Indo-Pacific region important (Overton et al., 1997), indicates an ability to colonise large geographical area. So the larvae appear to be capable of prolonged life at sea with high salinity. The young crabs enter the lagoon or estuary after larval development.

The slight predominance of male over female Mud Crabs in harvests of Koggala Lagoon is similar to that reported for the same species in Bangladesh (Ali et al., 2004) and Japan (Ogawa et al., 2011). Xiao and Kumar (2004) have described the reason for the male based catches of crabs using the blue swimmer crab, *P. pelagicus*. They pointed that the females are generally smaller than males due to slower growth rate and hence escape from the fishing gear more easily than males.

Mating scars on the sternum or forward walking legs, which are produced by abrasion with the female during coupling, are a functional indicator of recently mated male crabs (Knuckey, 1996). However, mating scars appeared rarely within the crab population in Koggala Lagoon indicating there were few chances for crabs to reproduce.

As the feeding activity is low during spawning period (Ogawa et al., 2011), there is less probability to catch them in baited crab pots than in the crab nets. In the crab pot method, crabs aggregate to the bait by using their sense organs. As sense organs are well developed in mature crabs, the bait attracts adult crabs better than young crabs. In the crab net method, crabs of all ages are trapped by their legs (most of the time they are posterior legs), when they are moving. As a crab net covers more than 250 m^2 and bears high hanging ratio, the efficiency of the gear is high and the number of crabs caught per hour of work is high. Therefore the number of immature crabs caught using crab nets is higher than that of crab pot. Fishermen clean and repair their crab nets by killing small entangled crabs which do not have commercial value. However, it is very important that the fishermen return the undersize crabs to their habitats without killing them.

In the crab pot method, the by-catch is minimal, and the retained catch is of high quality, the cost of fishing is low and pots do little damage to benthic communities. Therefore, the crab pot method is the more suitable one for achieving sustainable yields of Mud Crabs.

Mud Crabs are highly valued and provide an important source of income for fishermen throughout the surrounding area of the lagoon. With the low fish harvest of the Koggala Lagoon, *S. serrata* has been subjected to heavy, unregulated exploitation. The percentage of immature crabs in the fish landings is extremely high indicating overfishing.

For sustainable exploitation of this Mud Crab, management measures based on estimated harvestable biomass and size at first maturity are recommended. These measures should include gear selectivity and mesh size regulation. Selecting mesh sizes slightly higher than sizes at first maturity allows the Crabs to reproduce at least once before being recruited to the fishery. Preventing Crab harvesting during the reproductive season, a legal limitation for a number of crab pots are proposed to restore the prevailing population.

Conclusions

Scylla serrata population in the Koggala Lagoon is faced with over-exploitation due to usage of crab nets. Recently, the fishermen have given up the traditional crab pot method and instead show a tendency toward using the more environmentally harmful crab net method, which has led to reduced population. Due to declining fishing harvest, many fishermen have switched to the crab fishery along with increasing fishing effort. These harmful practices have caused the crab harvest to decline. Therefore, a proper management plan is required as a matter of priority.

The present study showed differential vulnerability to capture among *Scylla serrata* of different sizes, since immature Crabs and Crabs that are going to spawn were less vulnerable for capture using the traditional pots than were adults. Thus, the pot method is more suitable than crab net method for a long-term sustainable yield in the lagoon.

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