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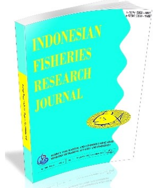

ASSESSMENT OF SEA CUCUMBER FISHERY IN THE MULLAITIVU COASTAL WATERS IN NORTH-EAST, SRI LANKA

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ABSTRACT

The sea cucumber is one of the key export-oriented fishery resources in Sri Lanka. There are some evidences for overexploitation of most of the sea cucumber species in the shallow coastal waters. The present study was undertaken with the aim to understanding the status of the sea cucumber fishery in the Mullaitivu district in the North-east Coast of Sri Lanka and to carry out a stock assessment on the key sea cucumber species presently harvested from this area. To achieve this objective, the sea cucumber fishing season in 2019 (March – August) was based and the personal logbook records of the 12 sea cucumber collectors were used as the primary data source. Two species, Bohadschia vitiensis and Holothuria spinifera were dominant contributing 83 % and 16 % to the total catch respectively. The average Catch Per unit Effort (CPUE) during the fishing season in 2019 was 178±224 individuals boat^{-1}day^{-1} and a sharp decline in the average monthly CPUE of both species was observed towards the end of the fishing season. The stock of the B. vitiensis in the Mullaitivu fishing ground was assessed using the depletion method. The initial stock size of B. vitiensis at the onset of the fishing season was estimated at 432,549 individuals and more than 90 % of the initial stock had been fished by the end of the fishing season. The study revealed that the stock of B. vitiensis along with other recorded species in the Mullaitivu waters is at a high risk at present.

Keywords: *Bohadschia vitiensis*; CPUE; Depletion; Overexploitation; Stock assessment

INTRODUCTION

Sea cucumber is one of the key export-oriented fishery resources in Sri Lanka. The sea cucumber fishery in Sri Lanka could be considered as a seasonal fishery. Due to the monsoon weather effect, the fishing season finishes when the sea becomes rough and turbid. Sea cucumbers were initially harvested by hand picking along the coast during the low tide period. Since the 1980's fishers have moved further towards offshore and collected sea cucumbers using snorkelling but at present by SCUBA (Self Contained Underwater Breathing Apparatus) diving as the stock became largely depleted (Kumara *et al*., 2005). At present, two underwater divers and a boat operator are permitted onboard for fishing operation and they use an outboard engine Fibber Reinforced Plastic (OFRP) boat to go to the sea. Though there are nearly 200 known species of sea cucumbers found in the waters around Sri Lanka, about 75 species inhabit the shallow coastal waters while nearly 50 species are abundant in inter-tidal areas (Kumara *et al*., 2005). Among them, about 21 species are considered commercially important (Dissanayake & Stefanson, 2010).

A rapid development in the fishery for sea cucumber in Sri Lanka began during the last decade mainly due to the end of the civil conflict in 2009. Previously, the sea cucumber fishery had been confined to the North-western (Puttlam and Mannar districts) and Eastern (Trincomalee to Kalmunai districts) coastal areas of the island. However, the harvesting area was further widened up to the North (Jaffna district) and North-east (Mullaitivu district) after the end of the civil conflict (Veronika *et al*., 2017). As a result of the development in the fishery, attractive prices were offered for the catch thus the incomes

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were also growing of the people who engaged in sea cucumber fishery (Dissanayake *et al*., 2010; Dissanayake & Athukoorala, 2010).

The fishery for sea cucumber in the Mullaitivu district in the North-east region commenced in 2015 (Veronika *et al*., 2017). The fishing season in the district normally starts in April when the sea is calm and clear and it continues up to August/September. At present, the sea cucumber resource in the Mullaitivu waters shows signs of depletion. The resource distributed in the shallow areas has declined rapidly and the divers mostly operate in deeper waters at present. On the other hand, there has not been any regular monitoring programme for collecting data in the sea cucumber fishery. Moreover, any comprehensive survey or stock assessment has not been undertaken for the sea cucumber resource in the North-east coastal waters. However, a couple of short-term studies have been undertaken in 2015 and 2017 in order to study the fisheries aspects of the sea cucumber fishery in the Mullaitivu district (Veronika *et al*., 2017 and Athukoorala *et al*., 2018) but none of them had concentrated on the assessment of the stock status of the sea cucumber fishery in the area. In this paper, we conducted a stock assessment using available catch-and-effort data to identify the recent abundance of the key sea cucumber species presently harvested from this area and how the resource was exploited over the fishing in 2019.

MATERIALS AND METHODS

Study area

In order to achieve the above objectives, a survey of fisheries records (personal logbook records) was carried out in 2019 in Mullaitivu coastal area based on sea cucumber collection centres. In Mullaitivu district, there were 12 sea cucumber collection centres located along the beach (Fig. 1).

Data collection

Personal logbook records maintained by the sea cucumber collectors were used as the primary data source. The logbook data collection was carried out from March to August, 2019 to cover the fishing season in 2019. Sea cucumber collectors normally maintain their own logbooks. Accordingly, the total landed catch per each boat by species in terms of number of individuals was extracted from the daily log book records of nine collectors who agreed to share the logbook data for this study. The information about monthly fishing efforts relevant to the remaining three collection centres was also obtained by directly interviewing respective collectors and the given information was further validated through the divers. The collection centre is run by the sea cucumber collector and he maintains his own team of divers. As collectors had recorded the species by their local names, scientific identification of the species in the

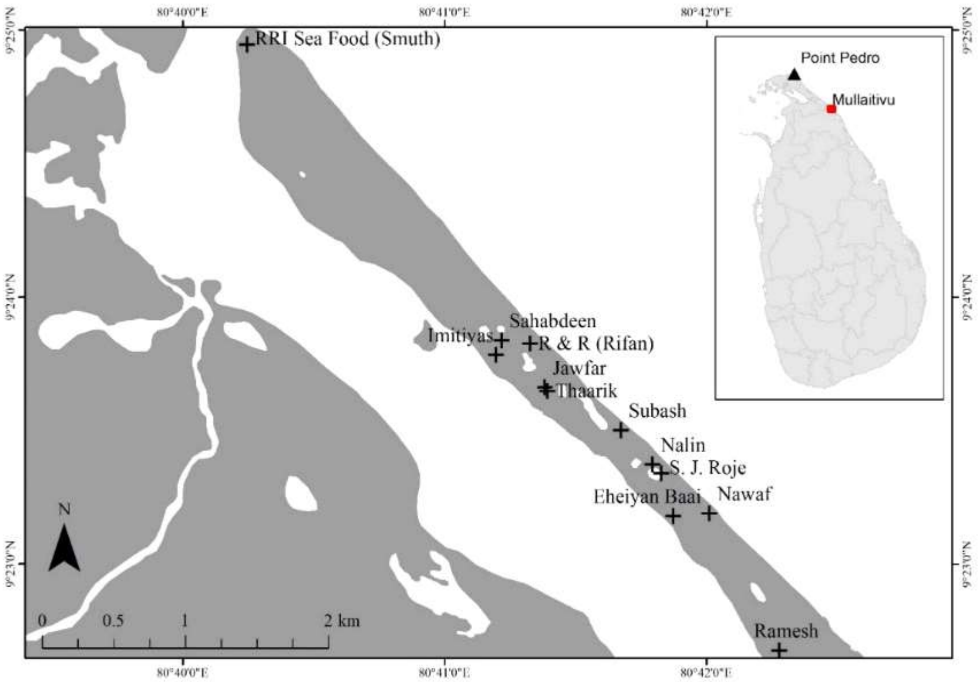

Fig. 1. The 12 sea cucumber collection centres located in the Mullaitivu coast (Sri Lankan map inset), that were used for data collection of the study in 2019.

field was done using available published literature and species identification guides (Conand, 1998; Dissanayake & Athukoorala, 2010; Purcell *et al*., 2012).

Total monthly catch estimate by species

For the present study, a single fishing trip was considered as one unit of effort. For each sea cucumber species, the monthly mean Catch Per Unit Effort (CPUE) in terms of catch in number of individuals boat^{-1} day^{-1} was estimated based on the logbook data. Accordingly, the total monthly collection of a sea cucumber species was estimated by multiplying the monthly mean CPUE and the total number of boats operated in the sea cucumber fishery in Mullaitivu waters during that month.

Stock assessment by a basic depletion method

The most abundant sea cucumber species in the Mullaitivu fishing ground, *Bohadschia vitiensis* (Semper, 1868), was assessed using a variant of the depletion model (Delury, 1947; Hilborn & Walters, 1992) to estimate the initial population size. This model is often used for estimating the initial population size of short-lived or ephemeral fisheries (Trianni, 2000).

The depletion method consisted of modelling the depletion of stock during the main fishing season and analysing the influence of cumulative effort on an abundance index (Royer *et al*., 2002). Application of the model relies on a number of assumptions, including whether the population is closed physically and demographically, constant catchability and constant natural mortality. Here, we estimated the catchability coefficient while the natural mortality is basically fixed at 0.6, which is a value obtained from the literature (Conand, 1990; Dissanayake & Stefanson, 2010; Romero-Gallardo *et al*., 2018).

Catch and effort data were pooled into 7-day periods for the analysis in order to reduce the measurement errors in the catch and increase the precision of the estimates. Here, we employed the following statistical models. Let *n* (= 12) be the total number of collectors, and among *n* collectors let *m* (= 9) denote the total number of collectors which provide catch information in addition to the effort. We aggregated weekly observed catch and efforts over *m* collectors as $C_t^* = \sum_{i=1}^{m} C_{t,i}^*$ and $E_t^* = \sum_{i=1}^{m} E_{t,i}$, respectively, where $C_{t,i}$ and $E_{t,i}$ are respectively catch and efforts for the *i*-th collector in the week *t*. Weekly reduction of abundance is due to the total fishing mortality over *n* collectors (F_t) as well as the natural mortality (*M*), and therefore we use a conventional recurrence formula for such a depletion process as

$$N_{t+1} = e^{-(F_t+M)} N_t, \ldots\ldots\ldots\ldots (1)$$

Where N_t is the number of cucumbers at the beginning of week *t*, and $F_t = q \sum_{i=1}^{n} E_{t,i} = qE_t$. *q* is the catchability coefficient. As mentioned above, the total catch is available for *m* collectors, and therefore the total expected catch by them can be expressed as

$$E[C_t^*] = \frac{F_t^*}{F_t+M}(1 - e^{-(F_t+M)})N_t, \ldots\ldots (2)$$

Where $F_t^* = q \sum_{i=1}^{m} E_{t,i} = qE_t^*$.

For the statistical estimation, we used the following observation model with the log-normal assumption for the observed aggregated catch:

$$\log(C_t^*) \sim N(\log(E[C_t^*]) - \frac{1}{2}\log\sigma^2, \sigma^2) \ldots (3)$$

Where an adjustment term in the mean is considered not to introduce the bias in the observation. We estimated the unknown parameters N_1, q and σ^2 by the maximum likelihood method, and their associated estimation errors were evaluated by the Fisher information matrix.

RESULTS AND DISCUSSION

Results

Status of the fishery for sea cucumbers

In 2019, there were 12 sea cucumber collection centres which had been owned by 12 collectors in the Mullaitivu district. Fishing operations are carried out by 6 to 7 m long Outboard motor Fibre Reinforced Plastic (OFRP) boats. For 2019, 595 OFRP boats were registered by Department of Fisheries and Aquatic Resources (DFAR) in the sea cucumber fishery in the Mullaitivu district. Though a large number of boats were registered in the fishery, a part of them were operated per day during the fishing season as the collectors use the boats interchangeably for maintenance purpose. Since a complete ban on night diving in sea cucumber fishery has been executed by the DFAR of Sri Lanka since April 2019, all fishing operations conducted targeting sea cucumber were confined to the day time.

Hand-picking by SCUBA diving is the only method used for sea cucumber collection in the area. For a fishing operation, a maximum of two SCUBA divers are allowed per boat to dive. As per the existing regulation, a boat could carry a maximum of three persons including the boat operator and could bring a maximum of 10 oxygen cylinders per single fishing operation. Normally boat leaves from the landing site around 8.00 am and returns to the landing site with the catch by around 2.00 pm. The sea cucumber catch is processed at the collection centre to produce beach-de-mer. Apart from sea cucumber, chanks (*Turbinella* spp.) are also collected by divers in case they come across chank shells within the diving area.

Species composition in the present catch

Stichopus naso (Semper, 1868) was the dominant sea cucumber species found in the landings in Mullaitivu district during the fishing season in 2019 and contributed over 95 % of the total catch in terms of number of individuals. Even though, the whole catch of *S. naso* had been taken exterior to Mullaitivu fishing ground as *S. naso* was not abundant in Mullaitivu waters. The fishing ground of *S. naso* was located further north at Point Pedro in the Jaffna district, about 70 km away the Mullaitivu coast (Fig. 1). The divers belonging to one collection centre had started harvesting of *S. naso* since the end of May. Then after, the divers belonging to some other collection centres who had been operating in the Mullaitivu waters also switched to the new fishing ground. By end of the July, the divers belonging to six collection centres had switched to the fishing ground in Jaffna waters and continued the collection of *S. naso* in that fishing ground until the end of the fishing season. As the entire catch of the *S. naso* had come outside the Mullaitivu waters, only the catch taken from Mullaitivu waters furthermore considered in order to analyse the species composition of the sea cucumber fishery in the Mullaitivu fishing ground. Accordingly, the species composition in the sea cucumber fishery in the Mullaitivu waters mainly consisted of *Bohadschia vitiensis* (Semper, 1868) and *Holothuria spinifera* (Théel, 1886) contributing 83.36 % and 15.83 % to the total catch respectively (Table 1). In addition, the relative abundance of *Thelenota anax* Clark, 1921 and *Stichopus herrmanni* Semper, 1868 in the catch were 0.06 % each respectively. Apart from sea cucumber species, chanks (*Turbinella* spp.) also appeared in the catch but contributed only a small percentage (0.69 % only).

Fishing effort, CPUE and production in the sea cucumber fishery

The fishing effort in the sea cucumber fishery in Mullaitivu waters in terms of number of boat days increased up to April but, it suddenly dropped in May (Fig. 2). Moreover, it remained steady during June – July and again further declined in August. The average CPUE in the sea cucumber fishery conducted in the Mullaitivu waters during the fishing season in 2019

Table 1. Species composition of the sea cucumber fishery based on the catch taken from Mullaitivu waters in 2019.

Family	Species	Common name	% in the catch	Market value
Stichopodidae	*Thelenota anax* Clark, 1921	Amber fish	0.06	Low
	Stichopus herrmanni Semper, 1868	Curry fish	0.06	Low
Holothuriidae	*Bohadschia vitiensis* Semper, 1868	Brown sandfish	83.36	Low
	Holothuria spinifera Théel, 1886	Brown fish	15.83	Low
Turbinellidae	*Turbinella* spp.	Chank shells	0.69	High

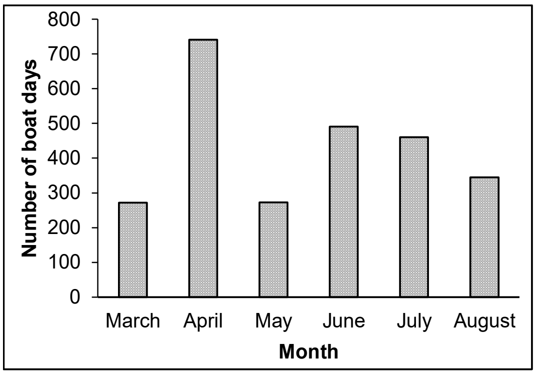

Fig. 2. The variation of monthly fishing effort in 2019 in terms of number of boat days in the sea cucumber fishery in Mullaitivu waters, Sri Lanka

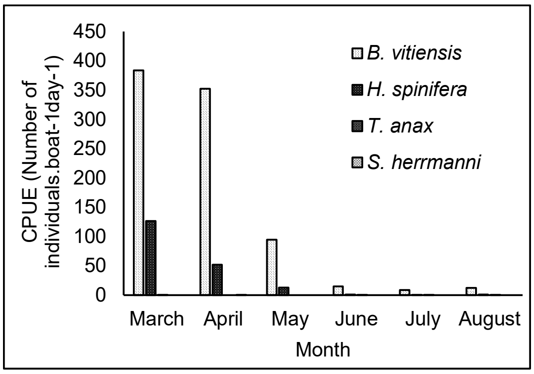

Fig. 3. The monthly variation of the average Catch Per Unit Effort (CPUE) in 2019 in the sea cucumber fishery in the Mullaitivu waters, Sri Lanka

was 178 ± 224 individuals boat^{-1}day^{-1}. A sharp decline in the average monthly CPUE of the two dominant species could be observed over the fishing season (Fig. 3).

Considering the monthly production in the sea cucumber fishery in the Mullaitivu district in 2019, the highest monthly production was reported in April (Fig. 4). After that, a sharp decline in the monthly production was observed till the end of the fishing season in August. There was a comparatively higher production of *B. vitiensis* in March and April but since May, the catch of this species has sharply declined. Similarly, the catch of *H. spinifera*, the next higher species reported in March and April, has also largely dropped since May. On the other hand, the relative contribution of other sea cucumber species and *Turbinella* spp. in the catch was insignificant throughout the fishing season.

Stock assessment for B. vitiensis in the Mullaitivu coastal waters

We conducted the stock assessment using a kind of depletion method based on the two assumptions of data period (a) from week 1 and (b) from week 3. The reason behind this treatment is that at the beginning of fishery, the observed CPUE is low and the fishery had not been well-started, and therefore it seems that the use of the data from a later week as being better. However, to show the sensitivity of results to the two assumptions, both results are shown.

According to the results for (a), the stock at the onset and end of the fishing season was respectively estimated at N_1 = 369,365 (SE = 77,780; 95 % CI = 244,461 - 558,087) and N_{23} = 14,827 (SE = 7476; 95 % CI = 5,520-39,831). When applying the data set for (b), the respective results were slightly different as N_1 = 432,549 (SE = 109,911, 95 % CI = 262,870 - 711,754) and N_{23} = 11,147 (SE = 5,725; 95 % CI = 4,073 - 30,503). The estimated catchability coefficient (q) was (a) q = 0.000922 (CV = 0.184) and (b) q = 0.00106 (CV = 0.184). Therefore, more than 90 % of the stock had been removed by the end of the fishing season in 2019. Some diagnostic plots and the process of exploitation of *B. vitiensis* are shown in Fig. 5.

Discussion

Harvesting and processing of sea cucumbers provide an important means of livelihood to the coastal ûshing community (Choo, 2004; Dissanayake & Stefansson, 2012). Since the inception of the sea cucumber fishery in the North-east coast of Sri Lanka in 2015, the fishing method (hand collection by SCUBA diving) and the type of fishing craft used in the fishery (OFRP boats with out-board engines) still remain unchanged. However, number of sea cucumber collection centres had increased from three in 2015 (Veronika *et al*., 2017) to 12 at present. Even though, the CPUE has drastically declined from 1500 individuals boat^{-1}day^{-1} in 2017 (Athukoorala *et al*., 2018) to 178 ± 224 individuals boat^{-1}day^{-1} at present. Further, the total production of sea cucumber in the Mullaitivu coastal waters has declined from 608,341 individuals in 2015 (Veronika *et al*., 2017) to 480,666 individuals in 2019. Moreover, when considering the species composition in the catch at the beginning of the fishery, it has completely altered at present. Some of the species recorded in previous studies such as *Actinopyga miliaris* and *Bohadschia marmorata* (Veronika *et al*., 2017; Athukoorala *et al*., 2018) are not recorded at present. The declining or disappearing of higher value sea cucumber species in the catch could be largely attributed to the overfishing of such species while natural factors such as degradation of habitats and change in the environment may also have slightly contributed to the declining abundance but the later impact is probably negligible compared to the former (Conand, 1990; Uthicke & Benzie, 2000; Hasan, 2019).

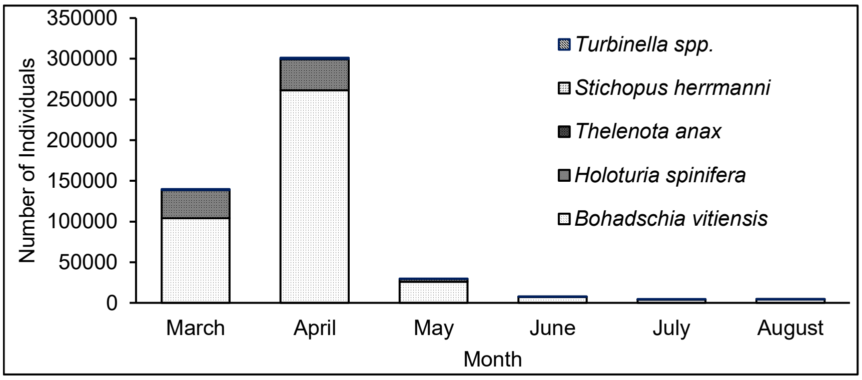

Fig. 4. The estimated monthly production of sea cumber fishery in Mullaitivu district in 2019.

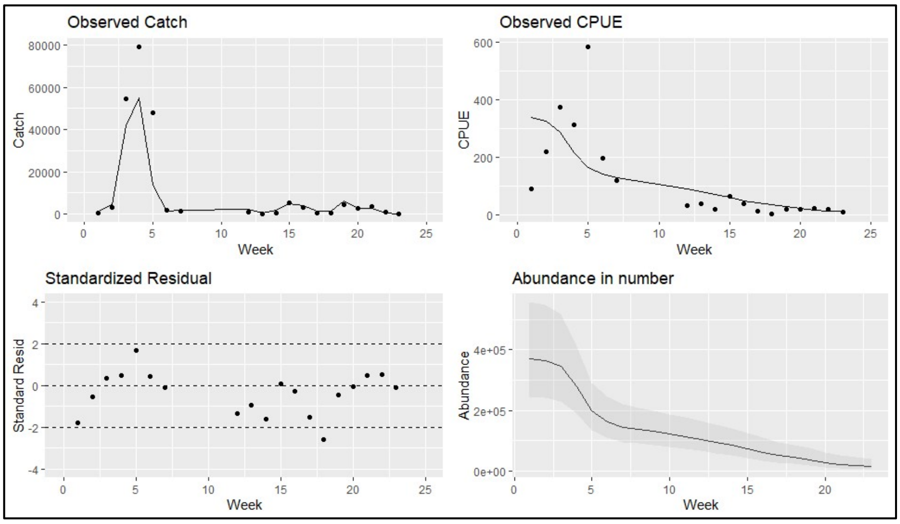

Fig. 5 (a). Results of analysis using data from week 1 of the fishing season in 2019 in the sea cucumber fishery in the Mullaitivu district, Sri Lanka. Although the parameters were estimated by fitting to the observed catch data, diagnostic plots were given for catch and Catch Per Unit Effort (CPUE), too. Standardized residuals show that the fitting was reasonably well. Declining trend of abundance in number process for *B. vitiensis* during the fishing season in 2019 was also shown with 95 % confidence intervals.

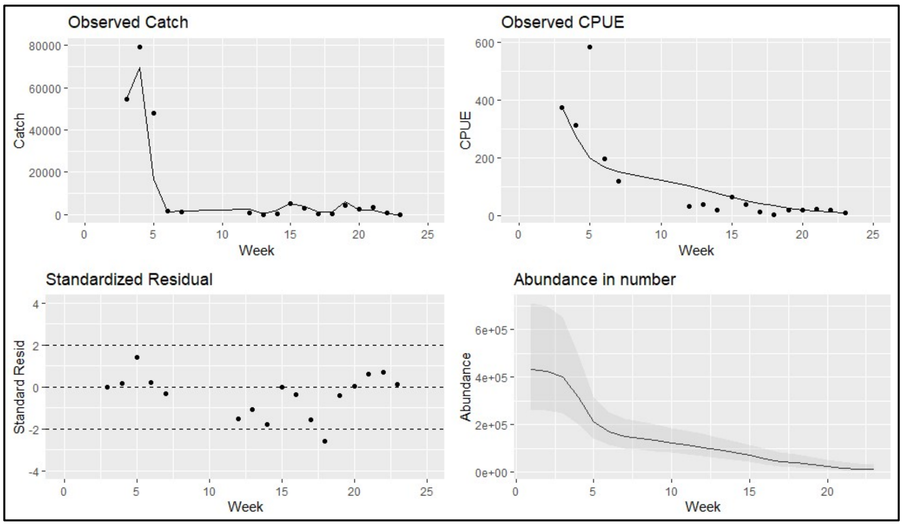

Fig. 5 (b). Results of analysis using data from week 3 of the fishing season in 2019 in the sea cucumber fishery in the Mullaitivu district, Sri Lanka. The model was used to extend back to the initial week using the observed effort data.

According to divers, sea cucumbers are not found in shallow depths at present. Thus, they have to go to deeper waters for sea cucumber collection. On the other hand, the shifting of the divers from Mullaitivu fishing ground to the Jaffna fishing ground for the collection of *S. naso* is remarkable since this species remained as a least concerned species (Dissanayake & Athukoorala, 2010; Dissanayake & Stefansson, 2012). This explains the fishers' behaviour which aims to catch valuable species first and when such species are not abundant or not found, they attempt to harvest low-value species (Hasan, 2019). The absence of high valued species in the present catch and tendency of traveling further for searching new fishing grounds of sea cucumber are clear signs of the resource depletion (Shepherd *et al*., 2004; Hasan, 2019). According to divers, the presence of *Turbinella* spp. (chank) in the present catch is considered as an opportunistic catch. Divers normally collect chanks when they encounter them while searching for sea cucumber species.

The fishing effort in the sea cucumber fishery in the Mullaitivu waters has considerably declined in the middle of the fishing season (in May) (Fig. 2) mainly due to the Easter day terrorist attack in Sri Lanka on 21st April, 2019 which made a larger impact on the Sri Lankan society including the fishing community. After the attack, almost all collectors stopped fishing operations in the sea cucumber fishery and it restarted operations at about the end of May and the fishery has been fully operational since June. The sharp decline in the production since June under the moderate fishing effort could presumably be attributed to the depletion of the sea cucumber resource in the Mullaitivu waters. The conspicuous catch decline in *H. spinifera* could probably be attributed to the banning of night diving since April. *H. spinifera* is known to be a nocturnal species thus is it readily found in the night time catch (Dissanayake & Stefanson, 2012; Purcell *et al*., 2012). However, *B. vitiensis* is normally recorded as a diurnal species (Long *et al*., 2010; Dissanayake & Stefanson, 2012; Purcell *et al*., 2012). The catch decline of this species since May could be due to overfishing.

Several studies have shown that the decreasing trend in the CPUE might be an indicator of the decrease in the abundance of the target sea cucumber species in their habitat (Purcell, 2010; Koike, 2017). However, the degree of conûdence in the use of CPUE as an index of species abundance varies with the type of behavioural interactions between the harvested sea cucumber species and the collectors (Purcell, 2010; Dissanayake & Stefanson, 2012). Further, the decline in the CPUE may be due to other factors such as low visibility in the water rather than a decline in abundance (Alfonso *et al*., 2004; Koike, 2017).

According to the stock assessment results of *B. vitiensis* in the Mullaitivu coastal waters, more than 90 % of the estimated stock at the beginning of the fishing season had been removed by end of the fishing season. The marked reduction in the size of the stock could be a result of the high fishing mortality. However, other factors might have contributed to the decline in the abundance but are probably negligible (Conand, 1990; Uthicke & Benzie, 2000; Hasan, 2019). In fisheries management, it is recommended to maintain the annual harvest up to 50 % of the virgin stock size in order to maintain a sustainable fishery (Uthicke, 2004; Choo, 2008). Even though due to the late maturity, density-dependent reproduction, and low rate of recruitment of sea cucumbers (Dissanayake & Stefanson, 2012; Hasan & El-Rady, 2012) some studies have suggested maintaining the exploitable level at a lower rate such as around 5 % of the initial stock size in order to avoid the collapse of the fishery due to over exploitation (Uthicke, 2004; Purcell, 2010). The sever case for the sea cucumber fishery is that if the fishery collapses due to over exploitation of the resources it will take several decades to restore the stocks in the habitat (Purcell, 2010; Hasan & El-Rady, 2012; Hasan, 2019). Since the current exploitation level of the *B. vitiensis* in the North-east coast of Sri Lanka has already exceed the limits which are required to maintain a healthy stock, urgent management measures have to be adopted to prevent the situation from worsening.

In the method, one of the key assumptions is constant catchability (q) over time. Normally before using CPUE in the model, the CPUE needs to be standardized to draw the real population trend by removing some other influencing parameters such as environmental and habitat conditions. For sea cucumber fishing operations in Mullaitivu waters, as the environmental conditions remained unchanged to some extent during the fishing season in 2019 and fishermen used their own fishing locations for the collection of sea cucumbers, the magnitude of change in catchability is expected to be low. Moreover, the number of divers who were on-board for sea cucumber collection and the number of oxygen cylinders used for SCUBA diving per fishing operation also remained constant. However, to improve the quality of underlying data of CPUE, the authors would cooperate with fishermen to acquire the necessary information for use of future assessment.

The model can be further extended to incorporate the random-effects into the catchability coefficients to account for their heterogeneity among collectors and uncertainty due to missing observations from some collectors. For the parameter estimation, the marginal likelihood via Template Model Builder (TMB) (Kristensen *et al*., 2016) can be used. However, this extension can be worth conducting when multiple year's data are available, and therefore we will continue obtaining such information for upcoming fishing seasons.

CONCLUSIONS

Based on the results of this study it can be concluded that the stock of *B. vitiensis* along with other recorded species in the sea cucumber fishery in the Mullaitivu district are heavily fished at present and there is a higher tendency of collapsing the stocks if the fishery will further continue without proper management. Therefore, it is urgently required to formulate a management plan and implement appropriate management strategies in order to ascertain the sustainability of the sea cucumber fishery in the Mullaitivu district of Sri Lanka. The results of this study could be made use of when preparing such a management plan.

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