



Shrimp Fishery in the Jaffna Lagoon, Sri Lanka: Ten Years After the Conflict

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Abstract

This study assessed the status of shrimp fishery in the Jaffna Lagoon a decade after the civil conflict. Fortnightly field visits from January 2022 to December 2023 were conducted to collect data from six major landing sites. Approximately 5,000 fishers were engaged in lagoon shrimp fishing, using fyke nets (89.8 %), lagoon seine nets (9.2 %), manual picking (0.3 %), and the kandi method (0.1 %). Shrimp CPUE was higher for lagoon seine nets (3.5 ± 1.5 kg fishermen⁻¹ day⁻¹) than fyke nets (1.6 ± 0.8 kg fishermen⁻¹ day⁻¹; $P < 0.05$; t-test). Total shrimp landings were 1,551 MT in 2022 and 1,331 MT in 2023, while bycatch landings were 1,202 MT in 2022 and 1,103 MT in 2023. Although catches declined slightly between years, the difference was not statistically significant ($P > 0.05$). Fifteen penaeid shrimp species were identified in the catches, including eight newly recorded species. *Penaeus semisulcatus* was the dominant species (44 %), followed by *Metapenaeus monoceros* (30 %) and *Metapenaeus moyebi* (12.9 %) – these three species accounted for over 85 % of the catch. A total of 50 bycatch species from 20 families were documented, with the Portunidae contributing the largest share (39 %), followed by the Terapontidae (25 %) and Gerreidae (18 %). Shrimp catch rates declined from the lagoon mouth toward the interior, while shrimp sizes increased along this gradient. The findings highlight intense fishing pressure on juvenile stages of *P. semisulcatus* and *M. monoceros* and highlight the need for sustainable management practices.

Keywords: Jaffna Lagoon, fyke net, seine net, CPUE, bycatch, *Penaeus semisulcatus*, *Metapenaeus monoceros*

Introduction

As an integral part of the global fisheries sector, the shrimp fishery plays a major role in providing livelihood opportunities and ensuring food security for numerous communities worldwide (Gillett, 2008). Both capture fisheries and aquaculture contribute to global shrimp production, representing 16 % of the products traded on the international markets in 2020 (FAO, 2022). However, wild shrimp catches have been reported to decline worldwide due to many reasons including overexploitation, harmful fishing practices, habitat degradation, and the impacts of climate change (Alam et al., 2022; Hossain et al., 2013; Lira et al., 2021; Munga et al., 2012).

Fast-growing, highly fecund penaeid shrimps dominate in the wild catches (Taylor et al., 2018; Turner, 1977). Mature adults of penaeid shrimps spawn in oceanic waters, and oceanic currents transport larvae to adjacent brackish water environments. Post-larval stages, mainly in the lagoons and estuaries, develop into sub-adults before moving back towards the ocean (Garcia, 1988). Despite their immaturity in lagoons and estuaries, these stages are traditionally targeted by small-scale fishers in many coastal nations (Pérez-Castañeda & Defeo, 2002; Raman et al., 2019; Razeq et al., 2009).

Sri Lanka, a small tropical island situated in the southeast of the Indian subcontinent (7.87° N, 80.77° E),

has more than 80 lagoons, many of which support small-scale shrimp fishing practices, providing livelihood opportunities for thousands of families (De Silva et al., 2013). Jaffna Lagoon, (9°26'N to 9°46'N, 79°52'E to 80°38'E), the largest lagoon in northern Sri Lanka, has supported a traditional and longstanding shrimp fishery for many decades (Chitravadivelu, 1990; Ragavan et al., 2021).

According to Chitravadivelu (1990), there was a highly productive shrimp fishery in the Jaffna Lagoon during the 1980s. The fishing practices primarily used four different types of fishing gear *i.e.*, stake net, drag net, hoop net, and kandi. The catches included *Metapenaeus monoceros*, *Penaeus semisulcatus*, *P. indicus*, *P. latisulcatus*, and *P. monodon*, with the majority coming from *M. monoceros* (63 % of the total harvest). Lagoon fishing activities were severely affected for around 30 years (from 1983 to 2009) due to prolonged civil war conditions. During this time, there were many restrictions on various aspects of the lagoon fisheries such as the number of fishers, fishing duration, capacity, and operation areas. With the end of the civil war in 2009, restrictions were gradually eased, and several incentives were introduced to improve fishers' livelihoods by strengthening the lagoon fishing practices.

However, scientific research, regular data collection, monitoring, and enforcement efforts were significantly affected during conflict and post-conflict periods. As a result, fishing activities were conducted without baseline data, making it impossible to assess the changes in fishing practices and management regulations during that period. Although several rapid assessments have been undertaken regarding fishery and aquaculture practices in the Jaffna Lagoon during the post-conflict period, detailed systematic analyses are still lacking. This gap poses a significant challenge to the sustainability of this valuable shrimp resource. Supporting this concern, a recent study by Ragavan et al. (2024) reported evidence of growth overfishing of *Penaeus semisulcatus* in the Jaffna Lagoon. Thus, the current situation calls for a more comprehensive approach to address these challenges and ensure the long-term sustainability of the lagoon's shrimp resources.

Therefore, this study aims to conduct a comprehensive assessment of shrimp fishing practices in the Jaffna Lagoon a decade after the conflict period. The findings of this study will provide a robust scientific foundation for developing management strategies that ensure the long-term sustainability of shrimp resources while supporting the livelihoods of lagoon fishers.

Materials and Methods

Ethical approval

Ethical clearance for this questionnaire survey was

obtained from the Ethics Review Committee, Faculty of Graduate Studies, University of Sri Jayewardenepura, Sri Lanka (FGS/ERCAS/2022/05/04).

Sampling sites

The Jaffna Lagoon (9°50'N and 79°50'E to 9°20'N and 80°30'E), extends across Jaffna and Kilinochchi districts covering an area of 450 km² in the Northern Province of Sri Lanka was selected for this study. Out of the 39 landing sites distributed across the lagoon, six major sampling sites, namely, Thampaddi (09°41'59.40"N, 79°51'56.56"E) Arali East (09°41'39.15"N, 79°57'21.93"E), Kakkaitivu (09°41'21.33"N, 79°59'47.00"E), Gurunagar (09°39'00.91"N, 80°01'10.27"E), Kovilakandy (09°38'16.66"N, 80°06' 43.21"E), and Kachchāi (09°38'28.85"N, 80°12'17.07"E) were selected for data collection (Fig. 1). These six sites were selected based on the number of registered boats and active fishers operating from each site. Given that the lagoon has been divided into three zones (Z(I), Z(II), and Z(III); Fig. 1), due to transportation infrastructure, three sampling sites from Z (I), two from Z (II) and one from Z (III) were carefully chosen to evaluate spatial variations in fishing practices.

Data collection

Catch and effort data of the shrimp fishery were collected at selected landing sites through bi-weekly field visits, from January 2022 to December 2023. On each sampling day, 40–50 % of fishing boats engaged in the shrimp fishery were randomly sampled. The boats to be sampled were selected through a systematic random sampling procedure using a random number table, and the total weight of shrimp and bycatch were recorded in each sampled boat. Fish and shellfish in the bycatch were identified to the lowest possible taxon (De Bruin, 1994; Lakshmi Pillai, 2015) and specimens that could not be identified were preserved in 5 % formalin and brought to the laboratory of the Department of Fisheries, University of Jaffna, Sri Lanka for further analysis.

Fishers were interviewed to collect information such as gear used, fishing duration, fishing area, and number of hauls in an operation. The active number of fishing boats and fishers was also recorded on each sampling day. A random and representative shrimp sample of ~1 kg was collected from each sampling site on each sampling day following the sampling approach outlined by De Croos & Stefánsson (2011). The collected shrimp samples were packed, labelled, and placed in an ice box and immediately transported to the Department of Fisheries, University of Jaffna, Sri Lanka for further analysis.

In the laboratory, shrimp were identified based on their meristic and morphometric features (De Bruin et al., 1994; Lakshmi Pillai, 2015). Shrimp specimens were sorted according to species, and their composition was assessed. The total length (TL from the tip of the

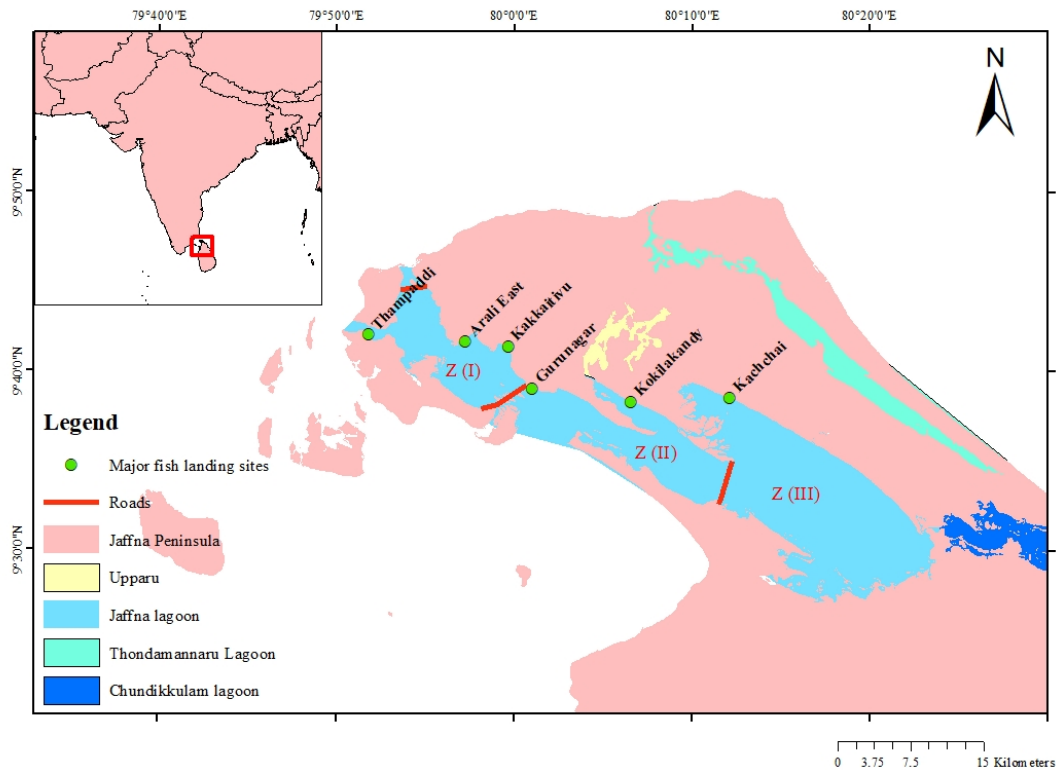


Fig. 1. Map illustrating the location of Jaffna Lagoon and its zonation. The red line denotes major roads across the lagoon, dividing the area into Zone 1 (Z1), Zone 2 (Z2), and Zone 3 (Z3). The green dots denote the six major fish landing sites selected for the study within each zone.

rostrum to the tip of the telson), carapace length (CL: the length between the eye socket and the posterior tip of the cephalothorax), and total weight (TW) were measured individually to the nearest 0.1 mm and 0.001 g using a digital vernier calliper and electronic balance, respectively.

Data on the socio-economic characteristics of fishers (age, gender, education, occupation, fishing experience, income, etc.) were collected through structured interviews with 100 randomly selected fishers from major landing sites during the study period.

Data analyses

Collected catch and effort data were used to estimate the average catch rate (in kg fishermen⁻¹ day⁻¹) of shrimp and bycatch separately. Temporal variations in the shrimp-to-bycatch ratio were also calculated. Monthly variations in total shrimp and bycatch landings were estimated as a product of the respective mean catch rate and total monthly fishing effort. The contribution of major shrimp species to the total shrimp catches and different marine megafauna (i.e., fish, crabs, and molluscs) and major bycatch families to the total bycatch was analysed. The proportion of immature *P. semisulcatus* and *M. monoceros* in the catch samples were assessed using the length at 50 % maturity of each species from published literature (CMFRI, 2014; Manaşırlı, 2014).

The catch rates (CPUE) for shrimp and bycatch across different fishing methods were log-transformed using $\ln(\text{CPUE} + 1)$ to account for the log-normal distribution of catch data (Gulland, 1983). Pairwise *t*-tests were subsequently conducted on the log-transformed CPUE data to assess differences in catch rates between the two years (2022 and 2023). Changes in fishing effort and total shrimp and bycatch landings were compared using Wilcoxon signed-rank tests, as these data did not meet the assumption of normality. Descriptive statistics were also employed to characterise the socio-economic parameters of the fishers. All statistical analyses were performed in R Studio (version 2024.12.2).

Results

Fishing gear and crafts operated in the lagoon shrimp fishery

A total of 5000 fishers engaged in shrimp fishing activities in the Jaffna Lagoon throughout the year using four different fishing methods: fyke nets, lagoon seine nets, the kandi method, and manual picking. Of these, fyke nets (89.8 %) were widely used, followed by lagoon seine nets (9.2 %), manual picking (0.9 %) and the kandi method (0.1 %).

Fyke nets, a passive gear, are predominantly used in the lagoon shrimp fishery throughout the year. The fyke net consists of four main parts: a straight leader,

round concentrating chambers, cone-shaped cod ends (mesh size = 15 mm), and wings (mesh size = 20 mm) (Fig. 2a). Fishers typically operate these nets during the nights between the full moon and the new moon. On average, each fisher possesses four fyke nets.

Lagoon seine nets, an active fishing gear, are employed in the shallow waters of the lagoon. Lagoon seine nets (Fig. 2b) closely resemble a bottom trawler net and are operated primarily by two fishers, typically at night and during low tide. These nets consist of 15 mm mesh in the wings and 10 mm mesh in the cod end and are dragged through seagrass beds to harvest shrimp. Fishing activity is generally restricted to 20–25 days per month, with an average of five hauls per trip.

The kandi is a passive fishing method primarily operated in shallow waters. It is a seasonal fishing practice and mainly conducted from February to May. This gear consists of two main components: fence nets (20 mm mesh) and cod ends with 15 mm mesh (Fig. 2c). Typically, 6–10 fence nets, each 6–10 m in length, are arranged in a zigzag pattern and supported with coconut petioles, while cod ends are fixed at the corners to trap shrimp. The number of fishing days and the operational pattern of kandi are similar to those of the fyke nets. Manual picking represents another seasonal fishing method, mainly undertaken by fisherwomen during the same period. Both practices are confined to specific areas of the lagoon.

The spatial distribution of shrimp fishing practices in the Jaffna Lagoon was analyzed across three zones

(Table 1). Fyke net operations were observed throughout the lagoon, with the highest number of fishers recorded in Zone I, followed by Zones II and III. Lagoon seine net fishing was predominantly concentrated in Zone II, although some fishers from Zone I also used this method. Manual picking and the kandi method were practiced by fewer fishers and were primarily limited to Zone I and Zone II, respectively.

A total of 1,200 registered fishing crafts, including both mechanised and non-mechanised categories, were engaged in the Jaffna Lagoon shrimp fishery during the 2022–2023 study period. Of these, mechanised traditional boats (MTRBs) constituted 47 % of the total, outboard fiberglass reinforced plastic boats (OFRPs) accounted for 22 %, and non-mechanised traditional boats (NTRBs) made up the remaining 31 %.

Variations in fishing efforts, catch rate, and total catch of shrimp and bycatch

Fyke net fishers dominated the lagoon shrimp fishery compared to lagoon seine net fishers. The highest fishing effort for lagoon seine net was recorded from February to August 2022 (450 fishers), while the lowest effort was in January 2022 (350 fishers) (Table 2). For fyke nets, the peak fishing effort was observed from January to February in both years, with 4,400 fishers, whereas the lowest effort was recorded in September 2022, involving 3,000 fishers (Table 2). However, no statistically significant differences in fishing effort were observed between 2022 and 2023 ($P > 0.05$; Wilcoxon signed-rank test).

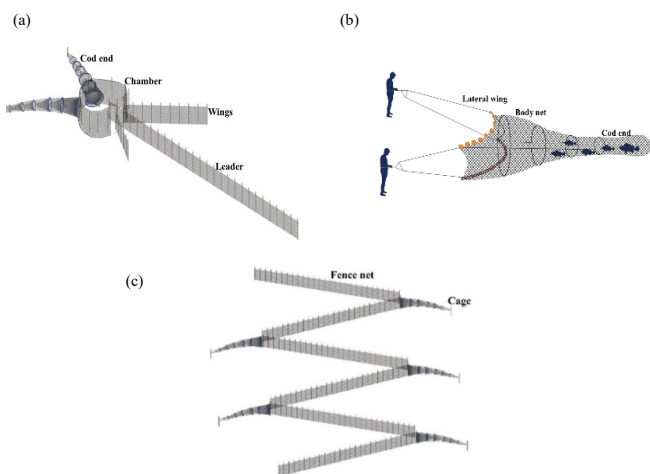


Fig. 2. Diagrammatic representation of the general structure of the primary fishing methods employed in the Jaffna Lagoon shrimp fishery: (a) fyke nets, (b) lagoon seine nets, and (c) kandi fishing method.

Table 1. Spatial variation in the number of active fishers using each fishing gear across the three zones in Jaffna Lagoon, Sri Lanka, from January 2022 to December 2023.

Zones	Number of fishers			
	Fyke net	Lagoon seine net	Kandi	Manual picking
Zone I	2540	50	0	45
Zone II	1200	400	5	0
Zone III	660	0	0	0

Table 2. Monthly variation in fishing effort (number of fishers), shrimp CPUE (kg fisherman⁻¹ day⁻¹), bycatch CPUE (kg fisherman⁻¹ day⁻¹), total shrimp production (MT), total bycatch production (MT), and the shrimp-to-bycatch ratio in major shrimp fishing methods in the Jaffna Lagoon, Sri Lanka, from January 2022 to December 2023.

Years	Month	Fishing effort		CPUE				In (CPUE+1)				Total production				Shrimp: bycatch ratio	
		(No of fishers)		Shrimp (Kg fisherman ⁻¹ day ⁻¹)		Bycatch (Kg fisherman ⁻¹ day ⁻¹)		Shrimp		Bycatch		Shrimp (MT)		Bycatch (MT)		FN	LS
		FN	LS	FN	LS	FN	LS	FN	LS	FN	LS	FN	LS	FN	LS		
2022	January	4400	350	3.9±1.7	2.1±1.9	2.8±1.2	0.8±0.2	1.59	1.13	1.34	0.59	240.24	16.29	172.48	6.16	1.4	2.6
	February	4400	400	2.1±1.8	2.7±1.5	1.2±1.9	1.2±0.3	1.13	1.31	0.79	0.79	129.36	23.45	73.797	10.56	1.8	2.2
	March	4400	450	1.5±0.9	2.9±1.8	1.0±1.7	1.4±0.1	0.92	1.36	0.69	0.88	94.618	28.71	60.368	13.86	1.0	1.0
	April	4400	450	1.6±1.7	2.8±2.5	0.9±1.5	1.0±0.2	0.96	1.34	0.64	0.69	100.41	27.23	55.933	9.9	1.6	2.1
	May	4100	450	1.2±0.9	3.6±1.8	1.1±1.0	1.7±0.3	0.79	1.53	0.74	0.99	71.061	35.15	65.666	16.83	1.0	1.0
	June	3850	450	1.5±1.1	6.4±5.1	2.1±1.0	2.2±0.4	0.92	2	1.13	1.16	82.898	62.96	111.03	21.78	1.0	2.9
	July	3800	450	1.6±1.2	8.1±5.6	1.9±0.9	4.1±0.5	0.96	2.21	1.07	1.63	85.652	80.44	100.55	40.59	1.3	1.0
	August	3100	450	0.6±0.9	4.2±2.7	1.7±1.8	2.3±0.2	0.47	1.65	0.99	1.19	27.863	41.43	72.218	22.77	1.0	1.8
	September	3000	450	0.5±0.5	1.2±1.2	0.7±1.5	0.6±0.1	0.41	0.79	0.53	0.47	22.596	11.88	30.408	5.94	2.6	1.0
	October	3050	450	0.7±0.8	4.2±1.8	0.6±1.6	1.8±0.4	0.53	1.65	0.47	1.03	31.769	41.14	27.243	17.82	1.0	2.0
	November	3200	400	1.8±1.1	3.6±2.9	1.5±0.8	1.9±0.3	1.03	1.53	0.92	1.07	81.267	31.9	68.723	16.72	1.2	1.9
	December	4000	370	2.9±0.8	2.7±2.5	3.2±2.0	0.9±0.2	1.36	1.31	1.44	0.64	161.28	21.61	181.44	7.326	1.0	2.9
															1.1	1.0	



Table 2. Continued.

Years	Month	Fishing effort		CPUE				In (CPUE+1)				Total production				Shrimp: bycatch ratio	
		(No of fishers)		Shrimp (Kg fishermen ⁻¹ day ⁻¹)		Bycatch (Kg fishermen ⁻¹ day ⁻¹)		Shrimp		Bycatch		Shrimp (MT)		Bycatch (MT)			
		FN	LS	FN	LS	FN	LS	FN	LS	FN	LS	FN	LS	FN	LS		FN
2023	January	4400	400	2.1±1.2	3.1±2.8	1.0±1.8	1.3±0.3	1.13	1.41	0.69	0.83	128.13	27.37	60.614	11.44	2.1:	2.4:
	February	4400	450	1.8±0.9	3.4±1.5	1.0±1.1	1.6±0.4	1.03	1.48	0.69	0.96	108.66	33.66	63.571	15.84	1.0	1.0
	March	4300	450	1.4±0.5	2.6±1.0	1.6±1.0	1.2±0.3	0.88	1.28	0.96	0.79	84.4	25.25	94.032	11.88	1.7:	2.1:
	April	4200	450	1.3±0.9	3.1±0.6	0.7±1.0	1.1±0.2	0.83	1.41	0.53	0.74	79.145	30.74	39.043	10.89	1.0	1.0
	May	4100	450	1.1±0.6	3.6±2.1	1.0±1.2	1.7±0.3	0.74	1.53	0.69	0.99	62.336	35.64	54.76	16.83	1.1:	2.1:
	June	3850	450	1.2±1.1	4.5±3.8	2.0±1.4	1.5±0.3	0.79	1.71	1.1	0.92	63.71	44.55	105.64	14.85	1.0	1.0
	July	3800	450	1.4±0.9	5.5±4.2	2.0±1.3	2.4±0.5	0.88	1.87	1.1	1.22	76.289	54.45	108.53	23.76	1.0:	2.3:
	August	3100	450	0.8±1.0	2.0±2.4	1.9±1.1	0.7±0.1	0.59	1.1	1.07	0.53	32.637	19.8	84.543	6.93	1.4	1.0
	September	3000	450	0.8±0.7	2.6±1.9	0.7±1.5	0.9±0.3	0.59	1.28	0.53	0.64	34.272	25.3	29.82	8.91	1.0:	2.8:
	October	3050	450	0.8±1.2	3.1±2.5	0.6±1.0	1.0±0.2	0.59	1.41	0.47	0.69	33.391	30.25	27.243	9.9	1.0	1.0
	November	3200	420	1.9±1.4	4.2±3.3	2.0±1.2	1.6±0.4	1.07	1.65	1.1	0.96	82.88	38.44	90.048	14.784	1.2:	3.1:
	December	4000	420	2.9±1.4	2.1±2.3	3.2±1.2	0.8±0.2	1.36	1.13	1.44	0.59	160.16	19.45	179.2	7.392	1.0:	2.6:
	Average	3795.8 ± 546.0	433.8 ± 23.4	1.6 ± 0.8	3.5 ± 1.5	1.5 ± 0.8	1.5 ± 0.7	0.9 ± 0.3	1.5 ± 0.9	0.9 ± 0.3	86.5 ± 38.9	33.6 ± 14.9	81.5 ± 40.7	14.3 ± 7.4	1.1	2.3:	
								0.3	0.3	0.3	0.3				1.0	1.0	

FN indicates Fyke Nets, and LS indicates Lagoon Seine Nets.

Lagoon seine net reported a higher shrimp catch rate (ln(CPUE+1)) than fyke net throughout the study period except in January 2022 and December in both years ($P < 0.05$; t-test). The shrimp catch rate in the lagoon seine net showed a gradual increase starting in January 2022, peaking in July (8.1 ± 5.6 kg fishermen⁻¹ day⁻¹), then declining sharply to reach its minimum value in September (1.2 ± 1.2 kg fishermen⁻¹ day⁻¹). Although there was a slight increase in the catch rates in October (4.2 ± 1.8 kg fishermen⁻¹ day⁻¹), the overall trend remained predominantly downward. Despite minor temporal variations, the trend in 2023 closely mirrored that of 2022. Unlike lagoon seine nets, fyke nets exhibited a distinct seasonal pattern. The shrimp catch rate in fyke nets showed a continuous decline from January (3.9 ± 1.7 kg fishermen⁻¹ day⁻¹) to September (0.5 ± 0.5 kg fishermen⁻¹ day⁻¹), followed by an increasing trend from October to December (2.9 ± 0.8 kg fishermen⁻¹ day⁻¹). This pattern was consistent across both years. Although the estimated shrimp catch rates (ln(CPUE+1)) were higher in 2022 compared to 2023, the difference was not statistically significant ($P > 0.05$; pair-t-test).

The bycatch from lagoon seine nets was consistently lower than the shrimp catch, with no distinct trend. However, during the study period, the highest bycatch rate for lagoon seine nets was recorded in July 2022 (4.1 ± 0.5 kg fishermen⁻¹ day⁻¹), while the lowest was observed in September 2022 (0.6 ± 0.1 kg fishermen⁻¹ day⁻¹). The fyke net exhibited much higher bycatch than shrimp catch mainly from June to September and during December with the highest value in both years.

The estimated total shrimp landings in the Jaffna Lagoon were 1,551 MT in 2022 and 1,331 MT in 2023. Similarly, total bycatch landings were 1,210 MT in 2022 and 1,090 MT in 2023. While a slight decline in catches was observed, the difference was not statistically significant ($P > 0.05$; Wilcoxon signed-rank test). As an average 72 % of shrimp catch and 85 % bycatch are landed from fyke nets while the rest is from lagoon seine nets, respectively.

Although there are temporal variations in the shrimp: bycatch ratio with respect to fishing gear types, the average ratios during the study period were 1.1:1.0 for fyke nets and 2.3:1.0 for lagoon seine nets.

Shrimp species composition

This study recorded a total of 15 shrimp species, viz., *Penaeus semisulcatus*, *Penaeus indicus*, *Penaeus monodon*, *Penaeus latisulcatus*, *Penaeus japonicus*, *Metapenaeus monoceros*, *Metapenaeus affinis*, *Metapenaeus elegans*, *Metapenaeus dobsoni*, *Metapenaeus lysianassa*, *Metapenaeus moyebi*, *Metapenaeopsis stridulans*, *Metapenaeopsis mogiensis*, *Macrobrachium equidens* and Alpheidae spp in the Jaffna Lagoon shrimp catches. Among these, *P. semisulcatus* made the highest contribution (44 %) followed by *M. monoceros* (30 %) and *M. moyebi* (12.90

%), *P. indicus* (5.2 %), *M. affinis* (1.7 %), *P. monodon* (1.6 %), *M. elegans* (1.5 %), and *M. lysianassa* (1.4 %). The contribution of other shrimp species was less than 1 %, and they were grouped under 'Others' (Fig. 3).

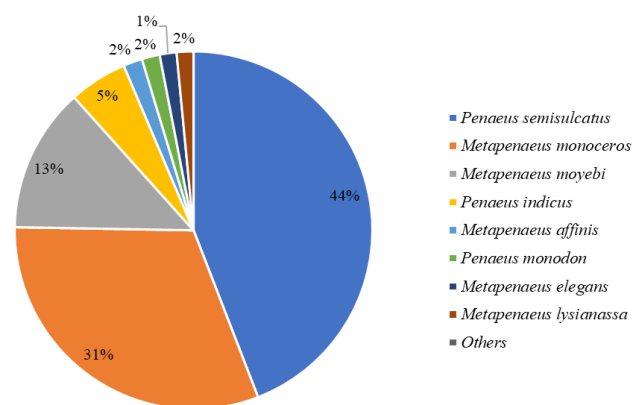


Fig. 3. Contribution of major shrimp species (% by weight) to the total shrimp landings in the Jaffna Lagoon shrimp fishery from January 2022 to December 2023.

Monthly variations in the percentage contributions of the two major shrimp species, *P. semisulcatus* and *M. monoceros*, to the total lagoon shrimp production were assessed (Fig. 4). The contribution of *P. semisulcatus* ranged from 31 to 58 % having the peak contribution in December 2023 (58 %). The *M. monoceros* contribution ranged from 21 to 42 % with the highest contribution of 42 % in September 2022. Together, these two species typically accounted for more than 75 % of the lagoon shrimp production (Fig. 4).

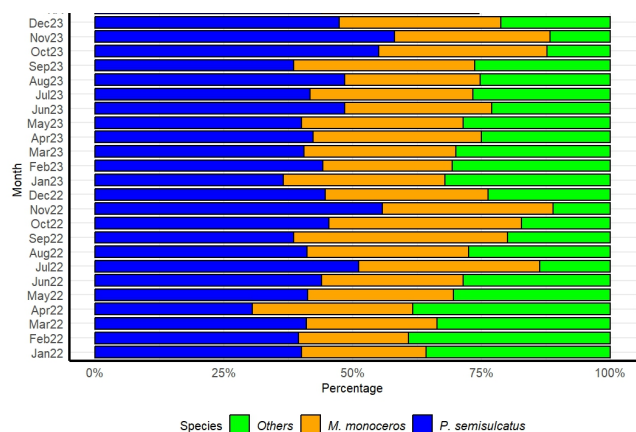


Fig. 4. Monthly variations in the contribution (% by weight) of major shrimp species to the total shrimp production in the Jaffna Lagoon shrimp fishery from January 2022 to December 2023.

Bycatch composition

The bycatch was primarily composed of finfish (58.5 %), crabs (38.6 %), and molluscs (2.9 %; Fig. 5a). This study identified 50 finfish and shellfish species belonging to 20 families: Portunidae, Terapontidae,

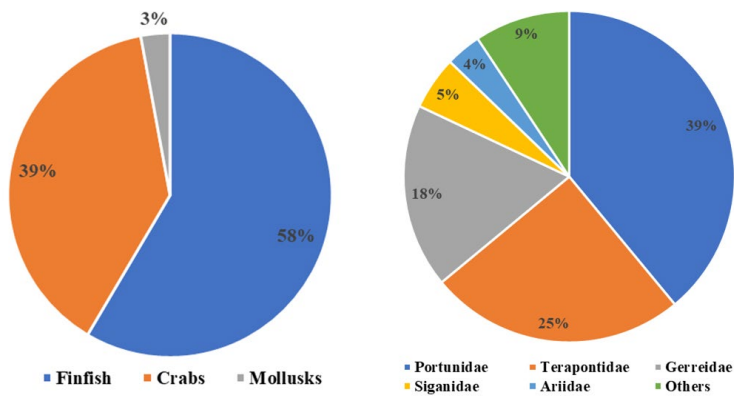


Fig. 5. (a) Contribution of finfish, crabs, and molluscs (% by weight) to the total bycatch in the Jaffna Lagoon shrimp fishery; (b) Contribution of finfish and shellfish families (% by weight) to the total bycatch in the Jaffna Lagoon shrimp fishery from January 2022 to December 2023.

Gerreidae, Siganidae, Ariidae, Carangidae, Sepiidae, Lethrinidae, Loliginidae, Lutjanidae, Mullidae, Hemiramphidae, Cichlidae, Platycephalidae, Plotosidae, Triacanthidae, Sillaginidae, Belonidae, Clupeidae, and Leiognathidae (Table 3).

The Portunidae family contributed the highest percentage to the bycatch (39 %), followed by Terapontidae (25 %), Gerreidae (18 %), Siganidae (5.2 %), and Ariidae (3.47 %). Families contributing less than 2 % to the total bycatch landings were grouped under "others." Together, the Portunidae, Terapontidae, and Gerreidae families accounted for approximately 80 % of the total bycatch throughout the study period (Fig. 5b).

Monthly variations in the percentage contribution (by weight) of families Portunidae, Terapontidae, and Gerreidae to the total bycatch landings in the Jaffna Lagoon shrimp fishery were computed and compared (Fig. 6). The percentage contribution of the family Portunidae ranged from 26 to 52 % and they are more predominant in the catches from November to December period. Similarly, the percentage contribution from families Terapontidae and Gerreidae ranged from 12 to 45 % and 9 to 25 %, respectively. The highest contribution of Terapontidae was recorded in July, while Gerreidae exhibited their peak contribution in August.

Spatial variation in catch rate and size distribution of shrimps

Spatial variations in catch rates from fyke nets were greatest from Gurunagar at the lagoon mouth (2.25 ± 2.20 kg fishermen⁻¹ day⁻¹) and lowest in the Kachchai region in the interior (1.15 ± 0.94 kg fishermen⁻¹ day⁻¹). Log-transformed CPUE ($\ln[CPUE + 1]$) analysis confirmed a statistically significant decline along this gradient from the lagoon mouth toward the interior (One-way ANOVA, $P < 0.05$) (Fig. 7).

Similarly, spatial variations in the average size of two major shrimp species; *P. semisulcatus* and *M. monoceros* were computed and compared (Fig. 8). In both these species, smaller individuals were more abundant near the lagoon mouth (Thampaddi landing

site) while larger individuals were observed in more interior parts of the lagoon, particularly at Gurunagar and Kachchcai landing sites.

Length distribution of major shrimp species

The total length of *P. semisulcatus* ranged from 4 to 23.4 cm, while in *M. monoceros* it ranged from 3 to 13.6 cm (Fig. 9). A comparison of the length frequency distributions with their respective lengths at 50 % maturity (L_m) values (14.9 cm for *P. semisulcatus* and 11.0 cm for *M. monoceros*) indicates that 99.9 % of *M. monoceros* and 98.9 % of *P. semisulcatus* were below their respective L_m . This strongly suggests that the current fishing practices in the lagoon are leading to the growth overfishing of these shrimp species.

Socio economic of shrimp fishers

The fishing community predominantly consists of traditional fishers (82 %), with men forming a significant majority (89 %) (Table 4). The age distribution is skewed toward younger and middle-aged individuals, with 73 % falling between the ages of 18 and 50. Education levels vary, with a notable proportion of fishers having completed primary (37 %) or secondary education (23 %) (Table 4).

A large majority (89 %) of fishers are involved in alternative livelihoods, with 38 % engaged in labor-related jobs in addition to fishing (Table 4). Regarding fishing crafts, 42 % of fishers own their equipment, while 58 % hire it. Investment in fishing gear ranges from USD100 to USD500. Income from fishing also varies, with the majority of fishers earning between USD150 and USD200 per month (36 %), followed by those earning USD200 to USD250 (28 %) and USD100 to USD150 (21 %) (Table 4).

Discussion

Shrimp fishery

This study provides a comprehensive analysis of the shrimp fishery in the Jaffna Lagoon, focusing on key aspects such as fishing pressure, fishing method,

Table 3. Identified bycatch species within families in the Jaffna Lagoon shrimp fishery during the study period from January 2022 to December 2023.

Family	Species	Family	Species
Portunidae	<i>Scylla serrata</i>	Loliginidae	<i>Sepioteuthis lessoniana</i>
	<i>Portunus pelagicus</i>		<i>Loligo duvaucelii</i>
	<i>Portunus sanguinolentus</i>	Lutjanidae	<i>Lutjanus russellii</i>
	<i>Thalamita crenata</i>		<i>Lutjanus johnii</i>
Terapontidae	<i>Pelates quadrilineatus</i>	Mugilidae	<i>Crenimugil seheli</i>
	<i>Terapon puta</i>		<i>Liza melinoptera</i>
	<i>Terapon jarbua</i>	Hemiramphidae	<i>Hemiramphus archipelagicus</i>
Gerreidae	<i>Gerres oblongus</i>		<i>Hemiramphus far</i>
	<i>Gerres abbreviatus</i>		<i>Hyporhamphus dussumieri</i>
	<i>Gerres filamentosus</i>	Cichlidae	<i>Etrplus suratensis</i>
	<i>Gerres oyena</i>		<i>Oreochromis mossambicus</i>
Siganidae	<i>Siganus canaliculatus</i>	Platycephalidae	<i>Thysanophrys chiltonae</i>
	<i>Siganus lineatus</i>	Plotosidae	<i>Plotosus canius</i>
	<i>Siganus javus</i>		<i>Plotosus lineatus</i>
	<i>Siganus vermiculatus</i>		<i>Plotosus limbatus</i>
	<i>Siganus stellatus</i>	Triacanthidae	<i>Triacanthus biaculeatus</i>
	<i>Siganus virgatus</i>	Sillaginidae	<i>Sillago sihama</i>
Ariidae	<i>Nemapteryx caelata</i>	Belonidae	<i>Strangylura leiura</i>
Carangidae	<i>Carangoides malabaricus</i>	Clupeidae	<i>Nematalosa nasus</i>
	<i>Selaroides leptolepis</i>		<i>Sardinella albella</i>
	<i>Atule mate</i>		<i>Amblygaster sirm</i>
	<i>Carangoides coeruleopinnatus</i>	Leiognathidae	<i>Aurigequula fasciata</i>
Sepiidae	<i>Sepia latimanus</i>		<i>Karalla dussumieri</i>
	<i>Sepiella inermis</i>		<i>Karalla daura</i>
Lethrinidae	<i>Lethrinus ornatus</i>		<i>Gazza achlamys</i>

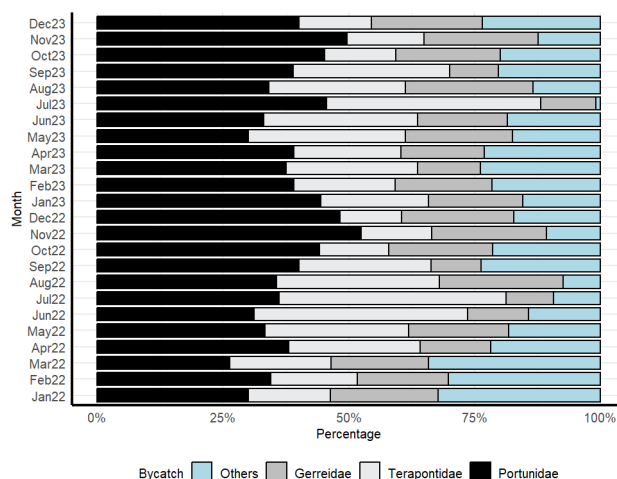


Fig. 6. Monthly variations in the contribution (% by weight) of major bycatch families to the total bycatch landings in the Jaffna Lagoon shrimp fishery from January 2022 to December 2023.

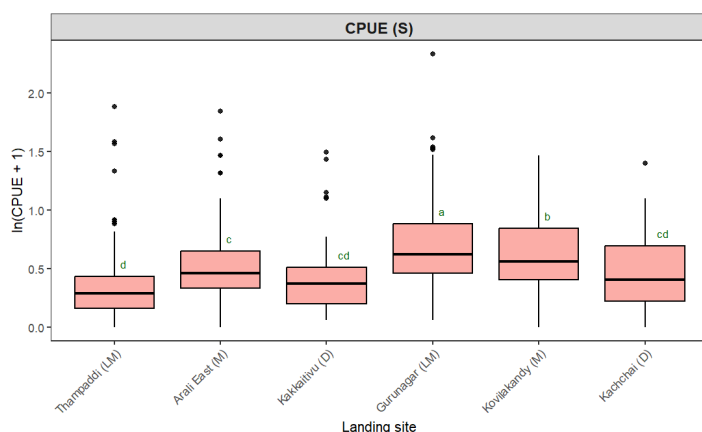


Fig. 7. The boxplot shows the variation in shrimp catch rates ($\ln(\text{CPUE}+1)$) from fyke nets across different landing sites in the lagoon. Black dots indicate outliers, and the letters 'a,' 'b,' 'cd,' 'c' and 'd' highlight significant differences in shrimp catch rates ($\ln(\text{CPUE}+1)$) among the sites. LM denotes fishing grounds located closest to the lagoon mouth; D refers to fishing grounds situated at the greatest distance from the lagoon mouth; and M represents fishing grounds positioned at intermediate distances between the LM and D zones.

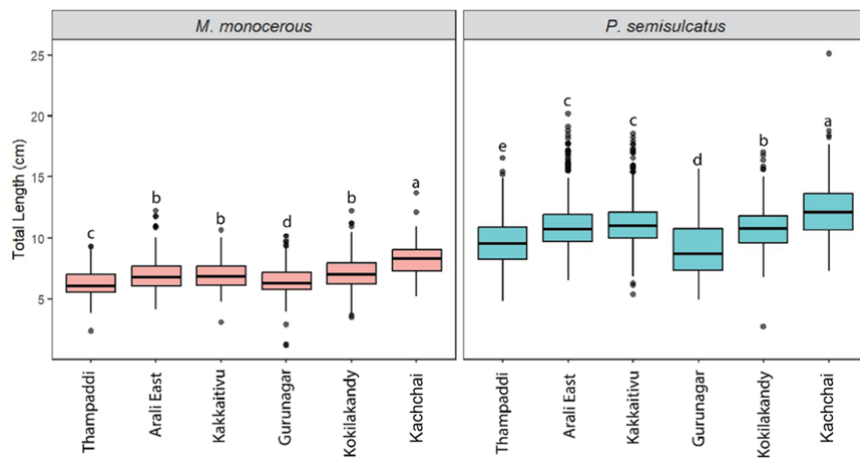


Fig. 8. Spatial variations in the mean total length of the two major shrimp species, *Metapenaeus monoceros* and *Penaeus semisulcatus*, landed from fyke nets across selected landing sites in the Jaffna Lagoon. Outliers are represented by black dots, and the letters a, b, and c denote significant differences in total length among landing sites for each species.

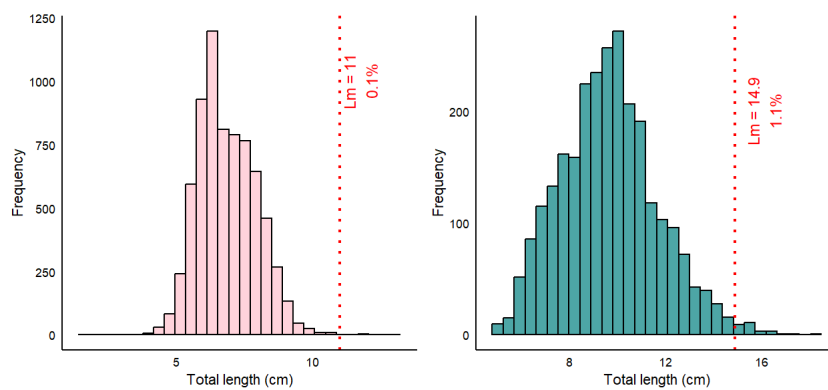


Fig. 9. Length frequency distribution of *Metapenaeus monoceros* (left) and *Penaeus semisulcatus* (right) collected from the Jaffna Lagoon, Sri Lanka, from January 2022 to December 2023. Red dots line represents the length at 50 % maturity (L_m) for each species. Percentages of individuals equal to or greater than L_m are indicated in each graph.

Table 4. Demographic and socio-economic parameters of the Jaffna Lagoon shrimp fishers from January 2022 to December 2023.

Parameter and category	Percentage of responses (%)	Parameter and category	Percentage of responses (%)
Fisher		Processing	5 %
Traditional fishers	82 %	Small business	8 %
Non-Traditional fishers	18 %	Labour work	38 %
Gender		Others	30 %
Men	≈89 %	None	11 %
Women	≈11 %	Fishing crafts ownership	
Age Group		Own	42 %
<18	0 %	Shared with family and friends	58 %
18-30	21 %	Average investment (USD)	
31-40	25 %	0-100	5 %
41-50	23 %	100-200	13 %
51-60	16 %	200-300	12 %
>60	13 %	300-400	25 %
Education		400-500	31 %
Illiterate	6 %	500-600	14 %
Primary education (Grade 1-5)	37 %	Average monthly income (USD)	
Secondary education (Grade 6-10)	23 %	0-50	0 %
GCE O/L levels completion	19 %	50-100	9 %
GCE A/L levels completion	12 %	100-150	36 %
Certificate and Diploma	2 %	150-200	28 %
Graduates	1 %	200-250	21 %
Postgraduates	0 %	250-300	6 %
Other occupations		300-350	0 %
Agriculture and animal husbandry	8 %	>350	0 %

catch rates, species composition, and spatial variation. The results revealed very high number of fishers' engage in the shrimp fishery in the Jaffna Lagoon. The numbers of active fishers are higher than the reported trawl fishers and the number of trawlers in the adjacent coastal waters. This elevated fishing pressure within the lagoon ecosystem poses a substantial risk of overexploitation of shrimp resources. Similarly, high fishing pressure on lagoon fisheries has also been reported in the other lagoon in Sri Lanka (de Croos & Pálsson, 2013).

According to Chitravadivelu (1990), various fishing gear types, including stake nets (Sirahuvalai), hoop nets, drag nets, and manual collection have been used to catch shrimps in the Jaffna Lagoon. Anecdotal evidence suggests that stake nets (Sirahuvalai) were the predominant gear used in the lagoon's shrimp fishery in the 1980s. However, during the civil war period, night fishing practices were restricted, forcing fishers to shift their activities to the morning hours. This change significantly reduced shrimp catches in the stake nets due to the burrowing behaviour of shrimps in the morning hours.

As a result, many stake net fishers gradually transitioned to use hoop nets, which were primarily limited to a small area of the lagoon (Chitravadivelu & Arulpragasam, 1983). Over time, these hoop nets were modified into fyke nets, which eventually became the primary gear for shrimp fishing in the Jaffna Lagoon. Even after the restrictions on fishing hours were lifted, fishers continued to use fyke nets due to their high efficiency, ease of operation, and low cost. This shift aligns with findings from other studies (Collins et al., 2015; Connell et al., 2018; Hicks et al., 2015).

Similar patterns of gear shifting have been documented globally. For example, in China, stow nets used for shrimp fishery in the 1970s were replaced by trawls in 1984 due to the overexploitation of finfish species (Chen, 1999). Small-scale fishers in Indonesia used lift nets, push nets, beach seines, set nets, and gillnets to catch shrimp, but they later switched to trawl fishing due to the influence of neighbouring countries (Butcher, 2004; Gillett, 2008). Traditional fishing practices in Thau lagoon in France and Tanzanian fisheries were replaced with more efficient fishing gear to improve selectivity, yields, and target of other species (Crespi, 2002; Katikiro, 2014).

Before the conflict, shrimp fishing in the Jaffna Lagoon primarily relied on non-mechanised traditional fishing crafts (Chitravadivelu & Arulpragasam, 1983). However, in the post-conflict period, the use of mechanised fishing crafts has increased significantly. This shift has been largely driven by government-led fishing craft mechanization programs and post-civil war subsidy schemes. Mechanised fishing crafts have enabled fishers to access distant fishing grounds more effectively and operate more fishing gear, thereby increasing fishing effort and the potential for resource

over-exploitation.

Although the use of mechanised crafts in inland waters of Sri Lanka is prohibited under the Fisheries Act No. 2 of 1996, the operation of mechanised fishing craft in Jaffna Lagoon has been documented (de Croos & Pálsson, 2013; Katupotha, 2016). Similarly, mechanised crafts are commonly used in lagoon fisheries in various countries worldwide (Mpomwenda et al., 2022; Rabbitt et al., 2019; Ray and Garada, 2018).

Shrimp catch rates

The difference in catch rates between fyke nets and lagoon seine nets could be due to several factors, including catchability coefficient, fish behaviour, and fisher behaviour. Fyke nets, as passive traps, capture organisms that enter into the net. In contrast, lagoon seine nets are actively dragged by fishers who often rely on their local ecological knowledge to identify areas with high shrimp densities. This active approach, combined with the sweeping action of the seine net, generally results in higher shrimp catch rates compared to the passive nature of fyke nets. However, larger shrimp and fish species escape easily from lagoon seine nets due to their faster swimming speeds, while smaller shrimp are more likely to be trapped. As a result, lagoon seine nets harvest a higher quantity of smaller shrimp and have lower bycatch rates than fyke nets.

According to Chitravadivelu (1991), drag nets and hoop nets were regarded as highly efficient fishing methods in the lagoon shrimp fishery. In 1986, drag nets recorded an average catch rate of 5.88 kg gear⁻¹day⁻¹, which increased to 6.35 kg gear⁻¹day⁻¹ in 1987. Similarly, hoop nets achieved average catch rates of 4.38 kg gear⁻¹day⁻¹ in 1986 and 3.48 kg gear⁻¹day⁻¹ in 1987. These high catch rates sustained the use of these gear types for decades, eventually evolving into the present-day lagoon seine nets and fyke nets. However, the current catch per unit effort (CPUE) of fyke nets is significantly lower than the CPUE reported for hoop nets in the 1980s, raising concerns about potential overfishing and the long-term sustainability of the shrimp fishery in the Jaffna Lagoon.

The decline in catch rates due to excessive fishing effort, overfishing, and environmental changes have been widely discussed (Ainsworth et al., 2008; Barbosa-Filho et al., 2020; Bender et al., 2013; Giglio et al., 2015; Lozano-Montes et al., 2008). In Turkey's seas, the CPUE decreased by nearly 400 % from 1967 to 2010, despite a 700 % increase in total fishing effort (Ulman & Pauly, 2016). Similarly, a decline in CPUE was reported in the Gulf of Thailand, dropping from 298 kg h⁻¹ in 1961 to around 20 kg h⁻¹ in the early 1990s (Kongprom et al., 2003). A reduction in fyke net CPUE compared to hoop net operations in the 1980s further supports these findings. However, fishers have increased the number and size of fyke nets to compensate for the reduced catch rate. Although this

strategy is temporarily effective, it exacerbates overfishing and further depletion of lagoon shrimp resources.

Although there is no significant variation in the shrimp catch rate of lagoon seine nets at present compared to their original structure, the drag nets of the 1980s, the long-term ecological risk may be high due to increased net size and the addition of thicker chains. These modifications make the nets more effective in harvesting shrimp by disturbing the bottom substrate. Similarly, increased fishing capacity through mechanisation and gear modifications has been reported in various fisheries, including the Deep-Sea Red Shrimp fishery in the Northwest Mediterranean Sea (Gorelli et al., 2016) and the brown shrimp fisheries in the North Sea (Steenbergen et al., 2015).

Monthly shrimp catch rates in the Jaffna Lagoon are influenced by environmental factors, particularly sea surface temperature (SST) and water currents. During the Northeast monsoon (November–December), increased precipitation in Northern Sri Lanka results in a decrease in SST. As ectothermic organisms, shrimp may exhibit altered vertical distribution in response to these cooler temperatures, potentially ascending towards the surface. Concurrently, strong water currents during this period may concentrate shrimp near the surface, increasing their vulnerability to capture by fyke nets, which target organisms within the water column. Conversely, during the warmer months (May–July), elevated SSTs may drive shrimp to deeper depths, reducing their accessibility to surface-oriented gear like fyke nets. This shift in shrimp behaviour may contribute to a seasonal variation in catch rates, with higher catches observed in fyke nets during the cooler months and potentially increased catches in lagoon seine nets, which target demersal species, during warmer months.

The shrimp and bycatch landings observed in this study were lower than the values reported by Silva et al. (2013). This decline suggests potential overfishing driven by the high levels of fishing effort currently employed.

Shrimp and bycatch diversity

The emergence of new shrimp species in lagoon catches, such as *M. affinis*, *M. elegans*, *M. dobsoni*, *M. lysianassa*, *M. moyebi*, *M. stridulans*, *M. mogiensis*, *M. equidens*, and shrimp from the *Alphidae* family, may indicate overfishing of previously dominant shrimp species. On the other hand, this aligns with global observations of changes in species distribution due to climate change and other environmental factors (Davis et al., 2020; Nuon et al., 2024). Similar biodiversity shifts have been documented in Iceland, where new species have been identified as a result of changing ocean conditions (Astthorsson et al., 2007; Valtýsson and Jonsson, 2018). Climate change-induced shifts from lower to higher latitudes have been widely

reported, resulting in increased species richness in mid- and high-latitude oceans and decreased biodiversity in tropical regions (Bindoff et al., 2019; Cheung et al., 2009; Jones and Cheung, 2015). The presence of new shrimp species in the Jaffna Lagoon, previously reported in the lower latitudes of Sri Lanka, (De Bruin, 1994; de Croos & Pálsson, 2013) suggests a similar regional shift in species diversity.

According to Chitravadivelu (1991), *M. monoceros* comprised 62.75 % of the shrimp catch in the Jaffna Lagoon, while *P. semisulcatus* accounted for 28.50 %. However, this study indicates a decline in the relative abundance of *M. monoceros* and an increase in the abundance of *P. semisulcatus*. This shift in species composition may be attributed to several factors. Overfishing of *M. monoceros* could have significantly reduced its population density, creating an ecological niche for *P. semisulcatus* to expand. Additionally, climate change-induced alterations in water temperature, salinity, and food availability may have given *P. semisulcatus* a competitive advantage, as it exhibits broader environmental tolerance compared to *M. monoceros*. However, further research is needed to fully understand the causes of this shift in species composition.

Similar bycatch species have also been reported in other Sri Lankan lagoons, such as Negombo and Batticaloa (Harris et al., 2023), as well as in lagoons and estuaries in India (Jesintha et al., 2021) and Bangladesh (Chowdhury et al., 2011). This suggests the widespread distribution of these species across the south Asian region. However, due to the limited scientific literature on bycatch species from the pre-conflict period, it is difficult to compare bycatch composition before and after the civil war.

Spatial variation

Spatial variations in the Jaffna Lagoon shrimp fishery are influenced by geomorphology, physical oceanographic conditions, benthic and microhabitat conditions, and varying fishing pressures. Fishing grounds near the larger lagoon mouth, e.g., Gurunagar, exhibit higher catch rates and greater species diversity. In contrast, Zone 3 experiences high salinity during the dry season, which affects shrimp distribution and fishing activities. Similar spatial variations in shrimp abundance due to salinity are observed in the Chilika lagoon, India (Barik et al., 2022), and varying temperature and salinity in Carretas-Pereyra, Mexico (Velázquez-Velázquez et al., 2008).

Local migration of shrimps within the lagoon was observed, with smaller shrimps located near the lagoon mouth and larger individuals found in inner regions. This pattern is commonly seen in some other lagoons, including Carretas-Pereyra coastal lagoon in Mexico (Rivera-Velázquez et al., 2008). Large quantities of post-larval stages are brought into the lagoon by high tidal currents, initially settling in

seagrass beds and using them as feeding grounds. Early juvenile stages, being weak swimmers, are carried further into inner regions of the lagoon by high tidal currents as they grow. Once they reach subadult stages, the number of individuals declines due to high mortality rates. These subadults then swim and migrate away from the lagoon, facilitated by low tidal currents (Garcia, 1988).

Length composition

Chitravadivelu (1991) reported that the length ranges for *P. semisulcatus* and *M. monoceros* were 2–17.8 cm and 2–10.5 cm, respectively. This study observed maximum sizes larger than those reported by them. While increased fishing pressure typically leads to a decline in fish sizes due to fishing-induced and natural selection processes (Favro et al., 1979; Law & Grey, 1989). However, some studies, such as those on *Pandalus borealis* in Newfoundland and Labrador, have shown that decreasing stock density can lead to increased individual sizes due to density-dependent growth (Koeller et al., 2007). This suggests that the observed increase in shrimp sizes in the Jaffna Lagoon could potentially be a consequence of reduced stock density.

The study indicates growth overfishing of major shrimp species, aligning with De Bruin (1994). He identified *Metapenaeus elegans* and *Metapenaeus moyebi* as the only species completing their entire life cycle within the lagoon and other species rely on the lagoon as a critical nursery ground. This vital ecological role of the lagoon is essential for maintaining healthy shrimp populations. However, the excessive exploitation of these juveniles threatens the long-term sustainability of shrimp fisheries.

Similarly, studies on major bycatch families, such as Portunidae, Terapontidae, and Gerreidae, reveal that most species exhibit a life cycle that includes a juvenile phase within the lagoon. These species spawn in the sea, and their juveniles subsequently migrate to and utilize the lagoon environment for growth and development (Allen, 1991; Castillo-Rivera et al., 2010; Razek et al., 2009; Vieira & Calazans, 2015). This aligns with the broader understanding of lagoons as vital nursery grounds for various fish and shellfish species, as widely recognized in the scientific literature (Bristol and Simone, 2019; Tournois et al., 2017). This could indicate potential growth overfishing of these resources; however, further studies are needed to confirm this.

The exploitation of juvenile fish taken as bycatch within the lagoon ecosystem has profound ecological and socio-economic implications. By targeting young, immature individuals, these fisheries disrupt natural recruitment processes, potentially leading to growth overfishing and ecosystem-wide imbalances (Coll et al., 2008). This can cascade through the food web, disrupting predator-prey relationships and

compromising the overall health of the lagoon (Scheffer et al., 2005). Moreover, the over-exploitation of these valuable juvenile resources has severe repercussions for the fishing communities that depend on them. Reduced recruitment of adult fish translates to diminished catches, decreased income for fishers, and heightened competition for dwindling resources, ultimately undermining the long-term sustainability of these species and disrupting the natural recruitment processes of these populations.

This study underscores the urgent need for effective management interventions to promote the long-term sustainability of the lagoon shrimp fishery and support the livelihoods of its fishers. Globally, various strategies have been proposed in similar contexts to promote resource and livelihood sustainability. For instance, Chávez-Rosales et al. (2008) recommended reducing the number of fishers and providing alternative livelihoods in coastal lagoons in Mexico. Kapetsky (1981) emphasized the importance of limiting fishing effort by controlling the number of fishers and the types of fishing gear employed. Furthermore, numerous studies (e.g., Macbeth et al., 2005) have highlighted the benefits of modifying fishing gear designs and mesh sizes to enhance selectivity and minimize bycatch. Kapetsky (1981) also stressed the significance of restricting fishing activities near lagoon mouths, while temporal closures have been recognized as an effective tool for resource conservation (Yıldız et al., 2020).

Conclusion

This study reveals that the Jaffna Lagoon shrimp fishery is characterized by high fishing pressure, unsustainable practices, and potential over-exploitation. The findings highlight the urgent need for effective management interventions to ensure the long-term sustainability of the fishery and support the livelihoods of its fishers. Immediate actions are necessary to control fishing pressure by limiting the number of fishers and restricting the use of number of gears. This should be followed by a gradual transition, providing fishers with alternative livelihoods through capacity development programs.

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Author contributions: N. Ragavan: Investigation, formal analysis, writing - original draft. Sivashanthini Kuganathan: Methodology, supervision, writing - review

and editing. D.C.T. Dissanayake: Conceptualisation, methodology, supervision, writing - review and editing.

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