International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 5
ISSN: 2088-5334

Mangroves and the Sustainability of Longtail Shad Fish (*Tenualosa macroura*) in Riau Province Water, Indonesia

Vivin Seygita [a,*], Sulistiono [b], Cecep Kusmana [c], Gatot Yulianto [b]

[a] *Study Program of Natural Resources and Environmental Management Science, Postgraduate School, IPB University, Bogor, Indonesia*
[b] *Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia*
[c] *Department of Silviculture, Faculty of Forestry, IPB University, Bogor, Indonesia*
Corresponding author: [*]vivin_seygita@apps.ipb.ac.id

***Abstract*— Mangroves are crucial to fisheries as nurseries; they can be used as spawning and feeding grounds for fish, including Longtail Shad fish (*Tenualosa macroura*). The objective of the study was to analyze the mangrove vegetation used as Longtail Shad fish spawning ground. It was carried out from January to May 2021, using a checkered line method with six sampling stations. Each station was placed in three transects with three plots for each transect. Density, relative density, frequency, relative frequency, dominance, relative dominance, and importance value index were included in the vegetation analysis. There were 13 true mangrove types and 1 mangrove associate type at the study locations. The highest mangrove density was found at Station 3 with 3300.48 Ind/Ha, categorized as good. The highest mangrove coverage was found at Station 2, with an exceptionally dense category (76.34%). The regression analysis revealed a substantial relationship between density and mangrove and the water salinity at a 0.002 significance value (<0.05). Based on the gut content analysis in establishing the fish's eating habits, the type of food consumed by the Longtail Shad fish was mostly mangrove litter, representing 44.66% of the total stomach contents. The result of the study clearly shows that mangroves are crucial for Longtail Shad fish. A good mangrove ecosystem will provide good water quality for the migration process of longtail shad fish and produce mangrove litter as fish food. Mangrove ecosystem management can support the management of Terubuk fisheries.**

***Keywords*— Endemic fish; fisheries management; longtail shad fish; mangrove.**

Manuscript received 15 Mar. 2022; revised 16 Apr. 2022; accepted 20 Jun 2022. Date of publication 31 Oct. 2022.

I. INTRODUCTION

Indonesia is an archipelagic country, with three-fourths of its regions consisting of the sea. As a maritime country, it has abundant marine resources such as fisheries and coral reefs that preserve tremendous marine resources in the Indonesian waters [1]. High community growth and rapid development activity in the coastal area for various purposes increase the ecological pressure on the ecosystem and coastal and marine resources. This condition can surely threaten the ecosystem and the availability and sustainability of resources either directly (land conversion) or indirectly (various development activities generating pollution) [2], [3]. These threats can cause decreased population and scarcity of several aquatic biotas, including Longtail Shad fish (*T. macroura*). The Longtail Shad fish or *Terubuk* fish is an endemic species found in Bengkalis, Meranti Islands, and Siak District water, Riau Province [4]. It has a high economic value, mainly in its eggs which can cost up to 175 USD/kg in dry or salted conditions. It is an iconic fish that became the pride of the community in Riau, as the Longtail Shad fish figure is abundantly used in various regional attributes, such as district symbol, market name, ship name, and so forth. Nowadays, the Longtail Shad fish population continues to decrease. The International Union for Conservation of Nature declares that *T. macroura* species is included in near-threatened species [5]. Besides, through the Decree of Minister of Marine and Fisheries Affairs Number 59 of 2011, the Indonesian Ministry of Marine and Fisheries Affairs declares that the Longtail Shad fish is a limited protected fish species. It lives in Malacca Strait and spawns in the Siak River estuary. The regular spawning migration of male and female Longtail Shad fish occurs during the full moon and new moon in Bengkalis Strait waters [6]. The Longtail Shad fish enters Bengkalis within a month.

Meanwhile, they enter Meranti Islands and Siak District waters on full moon periods (13, 14, 15, and 16 lunar days) and new moon periods (28, 29, 30, 1 lunar day), with the peak in August, September, October, and November [7]. The

Bengkalis and Lalang Straits are the spawning habitats for Longtail Shad fish around Bengkalis, Meranti Islands, and Siak District administrative regions. There is a mangrove ecosystem around Bengkalis and Lalang Straits. However, seawater and land pressure led to the degradation of the mangrove ecosystem. The mangrove forest degradation along the Bengkalis Strait occurs exceptionally with a high loss rate [8]. This condition can disrupt the ecological function of mangrove forests as spawning grounds, feeding grounds, and nursery grounds for most marine biota, such as fish, prawns, and crabs, with high economic values [9], [10]. This study aimed to analyze: 1) the mangrove community structure along the Longtail Shad fish spawning habitat waters, 2) the effect of mangrove quality on water quality and plankton abundance, and 3) Longtail Shad fish feeding habit. The study results are expected to describe the mangrove forest ecosystem in Bengkalis, Meranti Islands, and Siak District coastal area following the Decree of Indonesian Minister of Environment Number 201 of 2004 on the standard criteria and correction of mangrove damage. It is also expected to provide scientific contributions that can be used as basic data in regulating mangrove and Longtail Shad fish resource management and preservation.

II. Materials and Method

A. Location and Period

This study was carried out from January to May 2021 in the mangrove forest area spread along with the spawning ground habitat of Longtail Shad fish at Bengkalis, Meranti Islands, and Siak District, Riau Province, Indonesia. The study locations were divided into six represented sampling points for primary data, namely Teluk Latak, Kuala Alam, and Ketam Putih villages located in the administrative area of Bengkalis Regency, Tanjung Padang Village in Meranti Islands Regency, Tanjung Kuras, and Bunsur Village in Siak Regency. The study location and sampling stations are presented in Fig. 1.

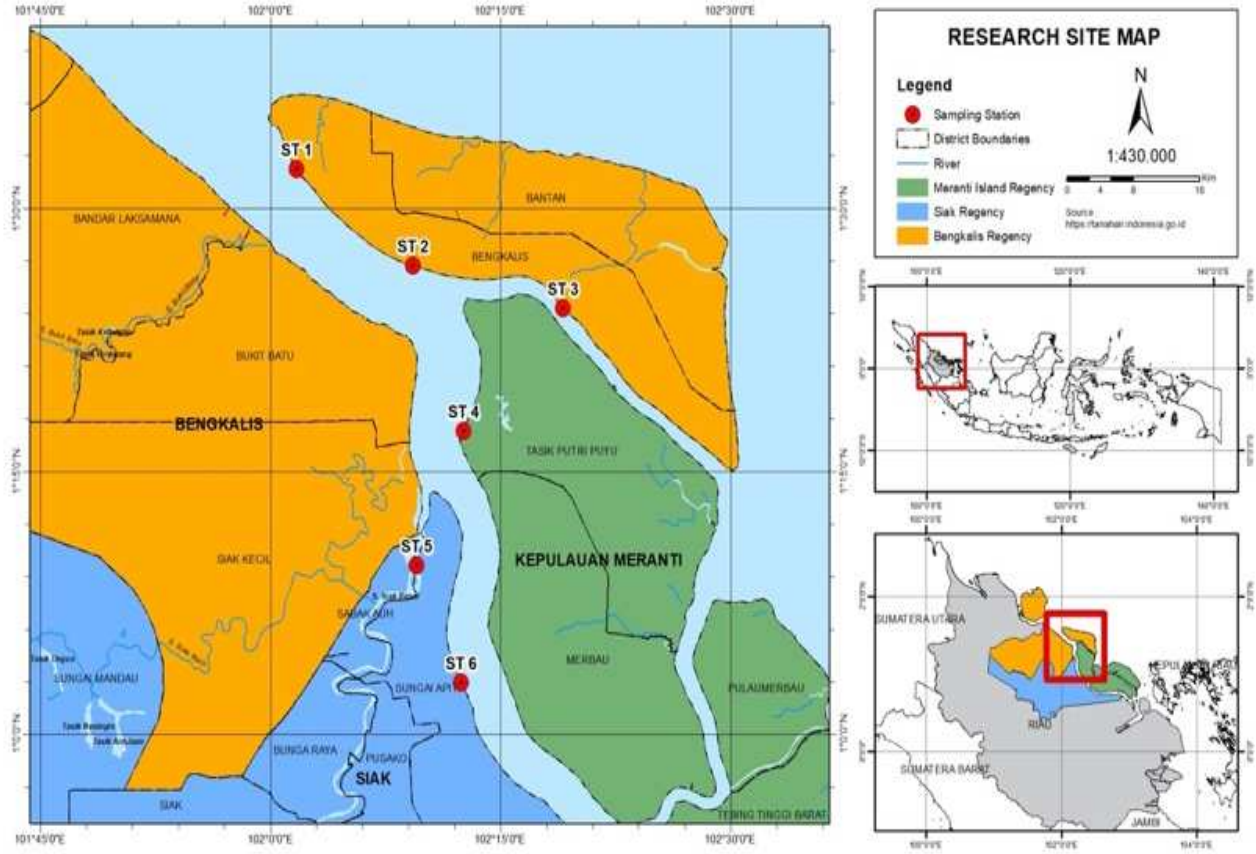

Fig. 1 Geographic location of the study area

B. Materials and Data Sampling Method

The tools used in the research included measuring tape for the diameter of mangrove trunks and transect lines, writing instruments to record measurement results, cameras for documentation, mangrove identification guidebooks, tissue, and 10% formalin to preserve fish samples.

The data used in this study are primary and secondary. Primary data consisted of data on mangrove vegetation and the stomach contents of *terubuk* fish, while secondary data were in the form of water quality and abundance of plankton obtained from the results of previous studies.

The mangrove coverage area was obtained from the Ministry of Environment satellite imagery analysis of Landsat 8 (mangrove forest coverage area map of Ministry of Environment in 2019). For validation, a ground check was performed in the field. The vegetation data measurement and sampling methods were based on the representative location. The study location was divided into six stations for sampling. A perpendicular line from the beach direction at 100 m was

pulled from each station, and three observation plots of 10 x 10-meter size were placed along the following line. Vegetation analysis activities were carried out on sample plots of a certain size adapted to the level of vegetation growth, namely 1) measuring plots for seedling level with an area of 2 mx 2 m, 2) measuring plots for sapling level with an area of 5 mx 5 m and 3) tree-level measuring plot with an area of 10 mx 10 m as shown in Fig. 2.

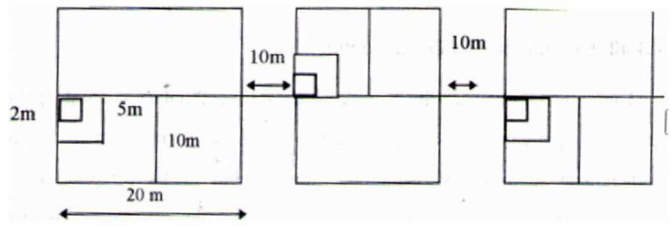

Fig. 2 Squared line design method [11]

In each sampling square, identification was performed on each mangrove species based on the mangrove identification guide from Wetland International [12]. The total individual from each species and diameter at the breast height (DBH) was counted (tree diameter was more than 4 cm and tree height was more than 1 m). To identify the gut content (feeding habit), 30 fish samples were taken from each station for analysis through gastric surgery in the laboratory.

C. Data Analysis

From the collected vegetation data, vegetation analysis included density, relative density, frequency, frequency, dominance, relative dominance, and importance value index [10]. The vegetation parameter was calculated using Eqs. 1, 2, 3, 4, 5, 6, and 7.

$$\text{Population Density (D)} = \frac{\sum \text{number of individuals}}{\text{total area sampled}} \quad (1)$$

$$\text{Relative Population Density (RPD)} = \frac{\text{density for a species}}{\text{total density for all species}} \text{x} 100\% \quad (2)$$

$$\text{Frequency (F)} = \frac{\text{number of plots in which a species occurs}}{\text{the total number of plots sampled}} \quad (3)$$

$$\text{Relative Frequency (RF)} = \frac{\text{frequency value for a species}}{\text{total frequency value for all species}} \text{x} 100\% \quad (4)$$

$$\text{Dominance (D)} = \frac{\text{total of basal area of each tree of a species from all plots}}{\text{total area of all the measured lots}} \quad (5)$$

$$\text{Relative Dominance (RD)} = \frac{\text{D for a species}}{\text{total dominance for all species}} \quad (6)$$

$$\text{Importance Value Index (IVI)} = \text{RD} + \text{RF} + \text{RD} \quad (7)$$

Mangrove coverage percentage at the study location was determined using the on-screen manual digitation method based on land coverage class visible in high-resolution imagery satellite and performed a confirmation of the existing condition in the field. The imagery satellite data used were *Landsat* images as satellite imagery-captured programs with *Landsat* satellite. The *Landsat* satellite produced high-quality images for the whole world every 16 days. This image was provided by the United States of Geological Surveys (USGS) that can be accessed in public. The *Landsat 8* image has a 28.5 m pixel resolution with one higher resolution band at 15 m pixel. In identifying the mangrove quality in the study location, the mangrove density and coverage parameters were compared to those of the Decree of the Indonesian Ministry of Environment Number 201 of 2004 on the standard criteria and correction of mangrove damage as presented in Table 1.

TABLE I
STANDARD CRITERIA AND CORRECTION OF MANGROVE DAMAGE [13]

	Criteria	Coverage (%)	Density
Good	Extremely dense population	≥75	≥1500
	Intermediate	≥50-<75	≥1000-<1500
Damaged	Rarely dense population	<50	<1000

Linear regression statistical analysis was used to identify the influence of the independent variables on the dependent ones. In the present study, the independent variables consisted of mangrove density and coverage, while the dependent variables were water quality and plankton abundance.

The normality test was carried out using the Shapiro-Wilk test as the n-sample was too small (<50). The correlation test between mangrove density and coverage with water quality and plankton abundance was carried out, assuming that the mangrove ecosystem was positively correlated with water quality and plankton abundance [14]–[16].

The Longtail Shad fish gut content analysis was performed in the Bio Macro Laboratory, Division of Eco-biology and Conservation of Aquatic Resources, Department of Aquatic Resources Management, IPB University. The total length and weight of fish samples were initially measured. The abdominal parts, starting from the anus to the vertebrae direction until the operculum, were dissected down to the ventral fin direction. The fish gut tract was taken and kept in 4% formalin before its intestine length, intestine weight, and gut tract volume were measured. The gut content analysis was performed by dissecting the stomach to take the internal organ and dividing the content based on types.

III. Results and Discussion

A. Mangrove Vegetation Characteristics

Based on the mangrove vegetation analysis in Teluk Latak, Kuala Alam, Ketam Putih, Tanjung Padang, Tanjung Kuras, and Bunsur Village, there were 13 true mangrove types, namely *Scyphiphora hydrophyllacea, Hippomane Mancinelli, Avicennia alba, Bruguiera gymnorrhiza, Bruguiera sexangula, Bruguiera parviflora, Rhizophora Apiculata, Rhizophora mucronata, Nypa fruticans, Sonneratia caseolaris, Sonneratia ovata, Sonneratia alba, Xylocarpus granatum,* and 1 mangrove associate type, namely *Thespesia populnea.*

As many as 13 mangrove species found in the study location were true mangroves, and only one mangrove associate type was found, namely, *Thespesia populnea*. Abundant true mangroves in the study location were thought to be due to the environmental condition of either the substrate or salinity; which could be tolerated by various mangrove species. The adaptability, diversity, and dominance of mangroves highly depend on the ecological and environmental conditions of the area [17]. Salinity in the study location ranged from 25 to 30‰. The true mangrove is the main component of the mangrove ecosystem that is well-

adapted to high salinity through morphological and physiological adaptations. This mangrove type can only grow in the mangrove forest, while the mangrove associate type can grow in a land vegetation environment [18]. Station 1 in Teluk Latak Village and Station 3 in Ketam Putih Village had more heterogenous mangroves due to more abundant mangrove types compared to other stations, which tended to have homogenous mangrove types. Each station's most common mangrove types were *A. alba, N. fruticans*, and *R. apiculata.* These three mangrove types are included in the most common mangrove types found on the beach and downriver [19].

B. Density (D) and relative density (RD)

The highest population density in mangrove tree vegetation level was observed in *S. hydrophyllacea* found in Station 3 at 1,200 Ind/Ha, and the lowest population density was found in *R. apiculate* at Station 6 with 11 Ind/Ha. Furthermore, the highest population density in sapling level was obtained from *S. ovatia* with 1050 in Station 6, and the lowest population density was obtained from *X. granatum* in Station 1 with 66.67. The highest population density in seedling level was at 100, consisting of *N. fruticans, R. apiculata, T. populnea, A. alba* in station 1, *S. alba, A. alba, S. ovata* in station 2, *X. granatum, R. apiculata, S. alba, A. alba, N. fruticans* in Station 3, *N. fruticans, A. alba, R. mucronate* in the station 5. Meanwhile, the lowest population density was found in *R. apiculate* at Station 2 with 80. In Station 4, sapling and seedling mangrove vegetations were absent. The mangrove vegetation density value based on tree, sapling, and seedling levels are presented in Table 2.

TABLE II
POPULATION DENSITY (D) IN THE STUDY LOCATION

Sampling Stations	Mangrove Types	Tree level density (Ind/Ha)	Sapling level density (Ind/Ha)	Seedling level density (Ind/Ha)
Station 1	*Nypa fruticans*	100	100	100
	Scyphiphora hydrophyllacea	300	333.33	0
	Hippomane mancinella	287.5	100	0
	Bruguiera sexangula	225	0	0
	Rhizophora Apiculata	250	400	100
	Xylocarpus granatum	700	66.67	0
	Sonneratia ovata	100	0	0
	Thespesia populnea	100	433.33	100
	Avicennia alba	0	133.33	100
Station 2	*Sonneratia alba*	466.67	425.5	100
	Avicennia alba	266.67	220	100
	Rhizophora Apiculata	1150	450	80
	Sonneratia caseolaris	100	212.8	0
	Sonneratia ovata	0	425.5	100
	Rhizophora mucronata	100	851.1	0
Station 3	*Xylocarpus granatum*	360	100	100
	Rhizophora Apiculata	457.14	342.86	100
	Bruguiera sexangula	250	100	0
	Bruguiera gymnorrhiza	100	0	0
	Scyphiphora hydrophyllacea	1200	0	0
	Bruguiera parviflora	100	0	0
	Rhizophora mucronata	233	0	0
	Sonneratia alba	300	400	100
	Avicennia alba	300	233.33	100
	Nypa fruticans	0	100	100
Station 4	*Nypa fruticans*	100	0	0
	Thespesia populnea	40	0	0
Station 5	*Sonneratia caseolaris*	500	400	0
	Nypa fruticans	112.5	100	100
	Bruguiera sexangula	100	0	0
	Avicennia alba	100	0	100
	Rhizophora mucronata	466.67	240	100
	Avicennia marina	100.00	0	0
	Rhizophora Apiculata	633.33	233.33	0
Station 6	*Sonneratia ovata*	61	1050.00	0
	Avicennia alba	33	366.67	0
	Rhizophora Apiculata	11	460.00	0

The highest relative population density in the tree-level was observed in *N. fruticans* with 71.43 at Station 4 and the lowest relative population density was found in *H. Mancinelli* with 28.40 at Station 1. The highest relative population density in sapling level was obtained in *S. ovata* at Station 6 with 55.95, and the lowest relative population density was obtained in *X. granatum* at Station 1 with 4.26. The highest relative population density of mangrove types in seedling level was found at 33.33, containing *N. fruticans*, *A. alba*, and *R. mucronata* in Station 5. The lowest relative population density was found at 20, containing *X. granatum, R. Apiculata, S.alba, A.alba* dan *N. fruticans* in station 3. The relative population density in tree, sapling, and seedling levels in each station is presented in Table 3.

TABLE III
RELATIVE DENSITY (RD) IN TREE, SAMPLING, AND SEEDLING LEVELS AT THE STUDY LOCATION

Sampling Stations	Mangrove Types	Tree level relative density (Ind/Ha)	Sapling level relative density (Ind/Ha)	Seedling level relative density (Ind/Ha)
Station 1	*N. fruticans*	3.70	6.38	25
	S.hydrophyllacea	14.81	21.28	0
	H. mancinella	28.40	6.38	0
	B. sexangula	11.11	0	0
	R. apiculata	18.52	25.53	25
	X. granatum	17.28	4.26	0
	S. ovata	123	0	0
	T. populnea	4.94	27.66	25
Station 2	*A. alba*	0	8.51	25
	S. alba	27.63	16.46	26.32
	A. alba	10.53	8.51	26.32
	R. apiculata	60.53	17.41	21.05
	S. caseolaris	0.66	8.23	0
	R. mucronata	0.66	32.92	0
	S. ovata	0	16.46	26.32
Station 3	*S. alba*	27.63	16.46	26.32
	A. alba	10.53	8.51	26.32
	X. granatum	10.91	7.84	20
	R. apiculata	13.85	26.87	20
	B. sexangula	7.57	7.84	0
	B. gymnorrhiza	3.03	0	0
	S. hydrophyllacea	36.36	0	0
	B. parviflora	3.03	0	0
	R. mucronata	7.07	0	0
Station 4	*S. alba*	9.09	31.34	20
	A. alba	9.09	18.28	20
	N. fruticans	71.43	0	0
	T. populnea	28.57	0	0
	S. caseolaris	24.84	41.10	0
Station 5	*N. fruticans*	5.59	10.27	33.33
	B. sexangula	4.97	0	0
	A. alba	4.97	0	33.33
	R. mucronata	23.19	24.66	33.33
	A. marina	4.97	0	0
Station 6	*S. ovata*	47.59	55.95	0
	A. alba	33.10	19.54	0
	R. apiculata	19.31	24.51	0

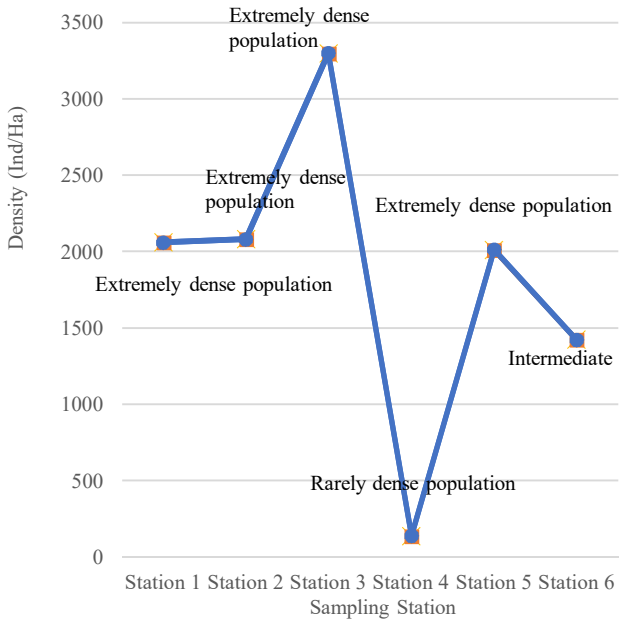

Fig. 3 Mangrove density in the study location

The highest density value per station was found at Station 3 in Ketam Putih Village, and the lowest density value per station was found at Station 4 in Tanjung Padang Village. Based on the Decree of Indonesian Minister of Environment Number 201 of 2004 about standard criteria and correction of mangrove damage, the mangrove density at Stations 1, 2, 3, and 5 are categorized as extremely dense. Station 6 is categorized as intermediate, and station 4 is categorized as rarely dense [13]. The density value in each station is presented in Fig. 3.

C. Frequency (F) and relative frequency (RF)

The highest frequency value at tree-level was found in *S. alba* at Station 2 and *S. ovata* at Station 6 with a frequency value of 1. The highest frequency value in sapling level was found in *X. granatum* and *R. apiculate* at Station 3 with 0.78. At the seedling level, the highest type frequency was obtained from *A. alba* at Station 1 with 0.89. The frequency values in tree, sapling, and seedling levels in the study location are presented in Table 4.

TABLE IV
FREQUENCY (F) IN TREE, SAPLING, AND SEEDLING LEVEL ON THE STUDY LOCATION

Sampling Stations	Mangrove types	F in tree level	F in sapling level	F in seedling Level
Station 1	*N. fruticans*	0.33	0.33	0.11
	S. hydrophyllacea	0.44	0.33	0
	H.mancinella	0.89	0.22	0
	B. sexangula	0.44	0	0
	R. Apiculata	0.67	0.33	0.11
	X. granatum	0.22	0.11	0
	S. ovata	0.11	0	0
Station 2	*T. populnea*	0.22	0.33	0.33
	A. alba	0	0.44	0.89
	S. alba	1	0	0.11
	A. alba	0.67	0.56	0.78
	R. apiculata	0.89	0.67	0.56
	S. caseolaris	0.11	0.11	0
	R. mucronata	0.11	0.11	0
	S. ovata	0	0.11	0.33
Station 3	*X. granatum*	0.56	0.78	0.22
	R. apiculata	0.78	0.78	0.56
	B. sexangula	0.22	0.11	0
	B. gymnorrhiza	0.11	0	0
	S. hydrophyllacea	0.11	0	0
	B. parviflora	0.11	0	0
	R. mucronata	0.33	0	0
	S. alba	0.33	0.11	0.22
	A. alba	0.33	0.33	0.33
	N. fruticans	0	0.11	0.22
Station 4	*N. fruticans*	0.33	0	0
	T. populnea	0.44	0	0
	S. caseolaris	0.33	0.22	0
Station 5	*N. fruticans*	0.89	0.11	0.44
	B. sexangula	0.11	0	0
	A. alba	0.11	0	0.56
	R. mucronata	0.33	0.56	0.22
	A. marina	0.11	0	0
Station 6	*R. apiculata*	0.33	0.33	0
	S. ovata	1.00	0.22	0
	A. alba	0.78	0.33	0
	R. apiculata	0.44	0.56	0

The highest relative frequency value in tree-level was found at Station 3 with *R. apiculata* at 233.33, while the lowest relative frequency value was found in *S. ovata* at 0.11 at Station 1. The highest relative frequency value in sapling level was found in *R. apiculata* at Station 6 at 50, and the

lowest relative frequency was found at 5, containing *B. sexangula, N.* fruticans, and *S. alba* in Station 3. The highest relative frequency value in seedling level was found in *A. alba* with 61,54 at station 1 and the lowest relative frequency value was 6,25 in *S. alba* at Station 2. The relative frequency in tree, sapling, and seedling levels at the study locations is presented in Table 5.

TABLE V
RELATIVE FREQUENCY (RF) IN TREE, SAPLING, AND SEEDLING LEVEL ON THE STUDY LOCATION

Sampling stations	Mangrove types	RF in tree level	RF in sapling level	RF in seedling level
Station 1	*N. fruticans*	0.33	15.79	7.69
	S. hydrophyllacea	0.44	15.79	0
	H. mancinella	0.89	10.53	0
	B. sexangular	0.44	0	0
	R. Apiculata	0.67	15.79	7.69
	X. granatum	0.22	5.26	0
	S. ovata	0.11	0	0
	T. populnea	0.22	15.79	23.08
	A. alba	0	21.05	61.54
Station 2	*S. alba*	180	6.67	6.25
	A. alba	120	0	43.75
	R. apiculate	160	40	31.25
	S. caseolaris	20	6,67	0
	R.mucronata	20	6.67	0
	S. ovata	0	6.67	18.75
Station 3	*X. granatum*	166.67	35	14.29
	R. apiculate	233.33	35.00	35.71
	B. sexangular	66.67	5	0
	B. gymnorrhiza	33.33	0	0
	S. hydrophyllacea	33.33	0	0
	B. parviflora	33.33	0	0
	R. mucronata	100	0	0
	S. alba	100	5	14.29
	A. alba	100	15	21.43
	N. fruticans	0	5	14.29
Station 4	*N. fruticans*	100	0	0
	T. populnea	133.33	0	0
Station 5	*S. caseolaris*	33.33	18.18	0
	N. fruticans	88.89	9.09	36.36
	B. sexangular	11.11	0	0
	A. alba	11.11	0	45.45
	R. mucronata	33.33	45.45	18.18
	A. marina	11.11	0	0
	R. apiculate	33.33	27.27	0
Station 6	*S. ovata*	45	20	0
	A. alba	35	30	0
	R. apiculata	20	50	0

D. Dominance and relative dominance

Commonly, each successive vegetation condition to occupy one area is influenced by the optimal adaptability to soil salinity, granulometry, and nutrient concentrations. The sediment loads transported by rivers, soil nutrient concentrations, and vegetation structure revealed high fluvial and anthropogenic influences on forests, and these conditions are promoting colonization by alluvial forest species [20]. The dominance value of mangrove vegetation in the study location is presented in Table 6.

TABLE VI
DOMINANCE (D) OF MANGROVE VEGETATION AT THE STUDY LOCATIONS

Sampling stations	Dominance value in tree level	Dominance value in sapling level	Dominance value in the seedling level
1	*H. Mancinelli* (1017.42)	*S. hydrophyllacea* (0.31)	*A. alba* (0.89)
2	*A. alba* (210,722.64)	*R. apiculata* (0.51)	*A. alba* (0.53)
3	*S. alba* (2,580,041.56)	*R. apiculata* (0.53)	*R. apiculata*(0.49)
4	*N. fruticans* (97.39)	-	-
5	*S. caseolaris* (508.73)	*R. mucronata* (0.43)	*N. fruticans* (0.85)
6	*S. ovata* (610.81)	*R. apiculata* (0.44)	-

From all stations, mangrove vegetation at tree level with the highest dominance value was obtained with *S. alba* at Station 3, while the lowest dominance value was obtained with *N. fruticans* at Station 4. At Station 1, the vegetation type in tree-level was dominated by *H. mancinella* with 1017.42, while *S. hydrophyllacea* dominated the vegetation in sapling level with 0.31 and *A. alba* dominated the vegetation type in seedling level with 0.89. At Station 2, the vegetation type which dominated the vegetation in tree-level was *A. alba* with 210,722.64, then *R. apiculata* (0.51) dominated the vegetation in sapling level, and *A. alba* dominated the vegetation in seedling level with 0.53. The vegetation types that dominated at Station 3 in the tree, sapling, and seedling levels were *S. alba* (2,580,041.56), *R. apiculata* (0.53), and *R. apiculata* (0,49), respectively. At Station 4, vegetation in sapling and seedling levels were absent, as the vegetation type that dominated was that of the tree level, namely *N. fruticans* with 97.39. The dominance values at Station 5 were *S. caseolaris* with 508.73 (tree level), *R. mucronata* with 0.43 (sapling level), and *N. fruticans* with 0.85 (seedling level). At Station 6, the vegetation type in tree level was dominated by *S. ovata* (610.81), and the vegetation type at the sapling level was dominated by *R. apiculata* with 0.44. Meanwhile, seedling-level vegetation was absent at that station. The high dominance value of *S. alba* (2,580,041.56) at Station 3 was since *S. alba* were found in large sizes with wide stem diameters. The relative dominance value in tree, sapling, and seedling levels in the study location is presented in Table 7.

TABLE VII
RELATIVE DOMINANCE VALUE OF MANGROVE VEGETATION IN THE STUDY LOCATION

Sampling stations	RD in tree level	RD in sapling level	RD in seedling level
1	*H. mancinella* (49.32)	*S. hydrophyllacea* (30.67)	*A. alba* (88.57)
2	*A. alba* (98.71)	*R. apiculata* (50.88)	*A. alba* (53.03)
3	*S. alba* (99.70)	*R. apiculata* (52.73)	*R. apiculata* (48.57)
4	*N. fruticans* (82.05)	-	-
5	*S. caseolaris* (40.91)	*R. mucronata* (42.70)	*N. fruticans* (84.86)
6	*S. ovata* (71.98)	*R. apiculata* (44.39)	-

The highest relative mangrove dominance value in tree-level was found in *S. alba* (99.70) at Station 3, and the lowest relative dominance value was found in *S. caseolaris* (40.91) at Station 5. In terms of sapling level, the highest relative dominance was obtained from *R. apiculata* (52.73) at Station 3 and the lowest relative dominance value was found in *S. hydrophyllacea* (30.67) at station 1. Meanwhile, in terms of seedling level, the highest relative dominance value was found in *A. alba* (88.57) at Station 1 and the lowest relative dominance value was found in *R. apiculata* (48.57) at Station 3.

E. Mangrove Coverage Percentage

Riau Province has the third largest mangrove ecosystem área in Indonesia, with 213,459.21 hectares [21]. The mangroves of Riau Province are scattered along river mouths and coastlines in seven districts/cities, including the coast of Bengkalis Regency, Meranti Islands, and Siak, which are the best spawning sites for fish. However, various pressures both from the sea and land cause mangrove damage with a very high level of loss [8]. Over the last two decades (2000-2019), the area and distribution of mangroves in Riau Province decreased from 180,952.1 hectares to 161,655.5 hectares, with an average decline in area of 2,495.9 hectares per year. The total reduction in Bengkalis Regency is 2,514.15 hectares, while those of Meranti Islands and Siak Regency were 3,780.40 hectares and 423.43 hectares, respectively [22].

The exploitation of mangroves in Indonesia has occurred systematically since 1800, including shrimp farming and timber extraction [23]. In Bengkalis Regency, Meranti Islands, and Siak, in addition to the conversion of mangrove land for various purposes and abrasion, mangrove damage also occurs due to the use of mangrove wood as firewood, building materials, and raw materials for making charcoal [24]. Mangrove cutting does not only affect mangrove coverage but also causes mangrove community structural changes. The mangrove coverage percentage in the study location is shown in Fig. 4.

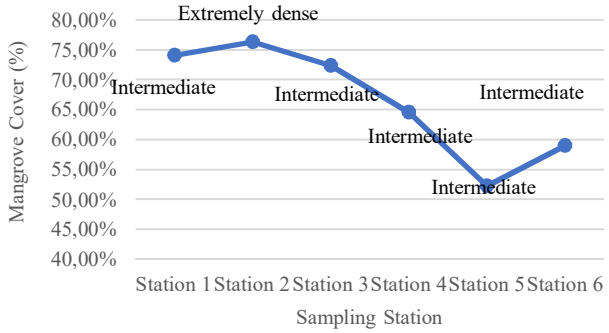

Fig. 4 Mangrove coverage in the study location

The highest mangrove coverage was found in Kuala Alam Village (station 2), categorized as extremely dense according to the Decree of Indonesian Minister of Environment Number 201 of 2004. Meanwhile, the mangrove coverage in stations 1,3,4,5, and 6 were included in an intermediate category. The high mangrove cover in Kuala Alam Village is thought to be caused by replanting activities, the growing awareness of the community not to damage mangroves, and the active role of mangrove monitoring community groups.

High mangrove coverage at station 2 is thought to be due to high mangrove replanting activities in the area, along with the growing awareness of the community not to cut down mangroves and the active role of community groups in monitoring mangroves. Meanwhile, the low mangrove cover at station 5 is thought to be due to the station's position in a watershed area, which has a lot of negative influence from land and anthropogenic activities.

F. Importance Value Index

Plant dominance in mangrove forest composition can also be described based on the importance value index (IVI). The higher the importance value of one type, the higher its dominance level in the community. The highest IVI value in one type gives a greater chance of sustaining its growth and preservation [25]. The IVI values in the study location are presented in Table 8.

TABLE VIII
IMPORTANCE VALUE INDEX OF MANGROVE VEGETATION IN TREE, SAPLING, AND SEEDLING LEVELS

Growth level	Sampling stations	Species name	Importance index value (IVI)
Tree	1	*H. mancinella*	104.38
	2	*A. alba*	133.23
	3	*S. alba*	120.33
	4	*N. fruticans*	196.34
	5	*S. caseolaris*	80.76
	6	*S. ovata*	164.57
Sapling	1	*S. hydrophyllacea*	67.74
	2	*R. apiculata*	108.29
	3	*R. apiculata*	114.60
	4	-	-
	5	*R. mucronata*	112.82
	6	*R. apiculata*	118.90
Seedling	1	*A. alba*	175.11
	2	*A. alba*	123.10
	3	*R. apiculata*	104.29
	4	-	-
	5	*N. fruticans*	154.56
	6	-	-

The importance value index of mangrove vegetation in the tree, sapling, and seedling levels had the highest value in *H. mancinella* with 104.38, along with *S. hydrophyllacea* with 67.74, *A. alba* with 175.11 at Station 1, *A. alba* with 133.23, *R. apiculata* with 108.29, *A. alba* with 123.10 at Station 2, *S. alba* with 120.33, *R. apiculata* with 114.60, *R. apiculata* with 104.29 at Station 3, *N. fruticans* with 196.34 at Station 4, *S. caseolaris* with 80.76, *R. mucronata* with 112.82, *N. fruticans* with 154.56 at Station 5, *S. ovata* with 164.57 at Station 6. At station 4, mangrove vegetation in sapling level was absent, while mangrove vegetation in sapling and seedling levels were absent at Station 6.

G. Mangrove environmental condition

Mangrove forests provide a crucial estuarine ecosystem service (ecological, economic, and social values) for coastal communities. However, they are threatened by rising sea levels, anthropogenic impacts, and climate fluctuations [26],[27]. The environmental condition of the habitat is an important factor in the growth of mangroves [28]. Mangrove species diversity, stand structure, and zoning pattern is influenced by environmental parameters [29]. On the other hand, the existence of a mangrove ecosystem affects environmental quality, such as maintaining the balance of the biological cycle in the environment [15] and maintaining biodiversity [30]. The environmental quality is presented in Table 9.

TABLE IX
SUMMARY OF PHYSICAL AND CHEMICAL QUALITY MEASUREMENTS AT THE SAMPLING STATION [31]

Parameters	Unit	St.1	St.2	St.3	St.4	St.5	St.6
Temperature	°C	28.9	26.7	30	30.3	30.3	29.0
Water transparency	m	0.50	0.83	0.40	0.27	0.52	0.63
Salinity	‰	28	28	30	27	25	27
Dissolved Oxygen (DO	mg/L	7.6	7.9	6.8	7.8	5.9	7.4
Biochemical Oxygen Demand (BOD)	mg/L	10	11	0.8	10	3	10
Nitrate (NO_3)	mg/L	0.683	0.818	2.196	0.617	1.935	0.731
Phosphate (PO_4)	mg/L	0.016	0.010	1.666	0.006	1.442	0.008
Lead (Pb)	mg/L	0.002	0.003	0.094	0.003	0.056	0.002

The average temperature in the study location ranged from 26.7 to 30.3ºC. According to the Decree of the Indonesian Ministry of Environment Number 51 of 2004, standard seawater quality for mangroves should be between 28 and 32°C. The temperature range in the study location was included in a good category for mangrove growth, except in Station 2, which was under the standard quality. The low temperature occurred as the measurement was performed during the rain. The factors that influence the water temperature include sunlight intensity and water depth. Temperature is crucial in the photosynthesis process [32]. Seawater surface temperature is an indicator to identify the fish species' availability in the waters. Each fish species has a certain temperature tolerance to survive, which influences the fish availability and distribution in the waters. There is a quite strong positive correlation between seawater surface temperature and fish-catching products [33].

The salinity in the study location ranged from 25 to 30‰. The lowest salinity value was 25‰ at Station 5, including Siak River waters as Longtail Shad fish conservation area. The salinity range in this study location was included in a good category for mangrove growth based on the Decree of Indonesian Minister of Environment Number 51 of 2004 as a good salinity value for mangrove growth should be maximumly 34 ‰. Salinity has been considered the primary driver of mangrove growth [34],[35],[36].

The Nitrate (NO_3) concentration in the study location ranged from 0.617 to 2.196 mg/L. The highest concentration was observed at Station 3, while the lowest was observed at Station 4. The phosphate concentration (PO_4) in the spawning habitat of Longtail Shad varied from 0.006 to 1.666 mg/L, as the highest concentration was measured at Station 3, while the lowest was measured at Station 4. Based on the Decree of Indonesian Minister of Environment Number 51 of 2004, nitrate and phosphate concentrations in Longtail Shad fish spawning habitat were considerably high and passed the minimum threshold standard for marine biota.

Coastal waters continuously receive nutrients from a whole range of both external and internal sources (natural and anthropogenic drivers) [37–[39]. A high concentration of Nitrate and phosphate in the coastal area is derived from anthropological activities, including agriculture, plantations, industries, and households along the coast [40]. Pollution caused by anthropogenic waste could be a significant factor in the reduction of mangrove biodiversity [41]–[43].

The Phytoplankton compositions comprised *Trichodesmium* sp., *Coscinodiscus* sp., *Nitzschia* sp., *Chaetoceros* sp., and *Planktoniella* sp. The most commonly found was *Trichodesmium* sp. at 37,293-596,688 cells/m^3, while *Planktoniella sp.* was the least commonly found at 16,842 cells/m^3. Zooplankton composition comprised *Tintinnopsis* sp., *Nauplius, Leprotintinnus* sp., *Calanus* sp., *Oithona* sp., *Arcella* sp., *Oncaea* sp., *Eucalanus* sp., *Steenstrupiella* sp., and *Balanus* sp. The most common type of zooplankton found was *Tintinnopsis* sp. at the abundance level of 9,624- 54,135 cells/m^3, while the least common type of zooplankton found was *Steenstrupiella* sp. at the abundance level of 1,203 cells/m^3. A good mangrove ecosystem has an impact on the nutrient richness and plankton diversity in the waters [16]. Besides, anthropogenic activities such as terrestrial run-off and effluent discharge may impact the phytoplankton community in the waters [44]. Physicochemical variables, including total phosphate, temperature, and salinity, were the most important factors influencing the variation of phytoplankton community structure [45]. The compositions and abundance levels of phytoplankton and zooplankton in the study location are presented in Figs. 5 and 6.

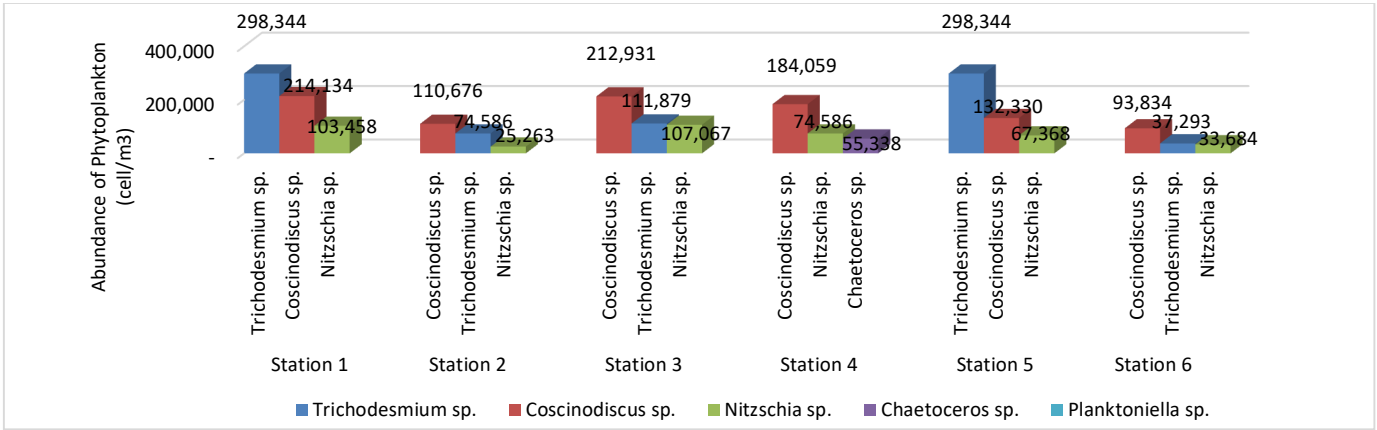

Fig. 5 Compositions and abundance of phytoplankton in spawning habitat of *T. macrura* [31]

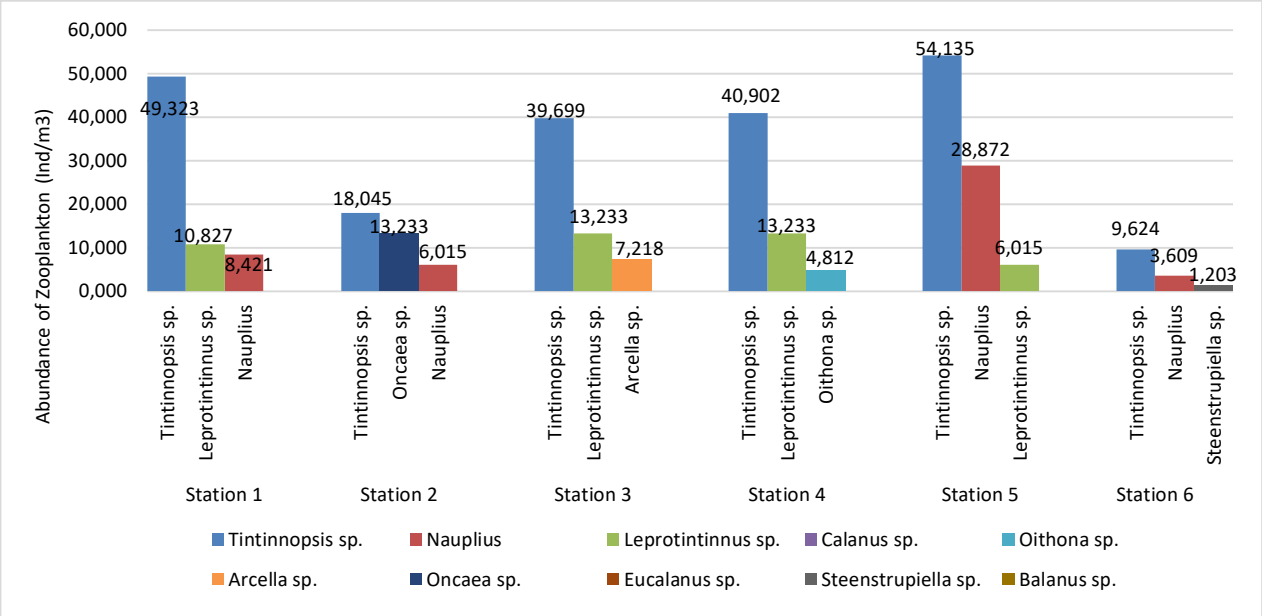

Fig. 6 Zooplankton compositions and abundance in *T. macroura* spawning habitat [31]

H. Mangrove quality correlation with water quality and plankton abundance

Based on the normality test, the data had a normal distribution pattern, including temperature, brightness, salinity, DO, Nitrate, BOD, phosphate, Pb, and the abundances of *Coscinodiscus*, *Nitzschia*, *Tintinopsis, Leprotintinnus,* and mangrove density and coverage. Meanwhile, abnormal distribution data were found in the abundances of *Tricosdesmium* and *Nauplius*. The linear regression analysis test results in the influence of mangrove quality on water quality and plankton abundance are presented in Table 10.

TABLE X
THE INFLUENCE OF MANGROVE DIVERSITY AND COVERAGE ON WATER QUALITY AND PLANKTON ABUNDANCE

Parameter	F	Sig	Conclusion
Temperature	0.050	0.952	No significant influence
Brightness	0.081	0.924	No significant influence
Salinity	88.546	0.002	Significant influence
DO	0.724	0.554	No significant influence
Nitrate	0.663	0.577	No significant influence
BOD	2.263	0.252	No significant influence
Phosphate	0.067	0.937	No significant influence
Pb	0.073	0.931	No significant influence
Trichodesmium phytoplankton abundance	0.319	0.749	No significant influence
Coscinodiscus phytoplankton abundance	1.923	0.290	No significant influence
Nitzschia phytoplankton abundance	0.198	0.830	No significant influence
Tintinopsis zooplankton abundance	0.079	0.926	No significant influence
Leprotintinnus zooplankton abundance	1.842	0.301	No significant influence
Nauplius zooplankton abundance	1.936	0.288	No significant influence

The simultaneous test for the influence of mangrove density and coverage on temperature, brightness, DO, Nitrate, BOD, phosphate, Pb, *Tricosdesmium* phytoplankton abundance, *Coscinodiscus* phytoplankton abundance, *Nitzschia* phytoplankton abundance, *Tintinopsis* zooplankton abundance, *Leprotintinnus* zooplankton abundance, and Nauplius zooplankton abundance obtained a significance value of > 0.05. This result shows that mangrove density and coverage have no significant effect on these parameters. However, there was a simultaneous influence on both variables on water salinity level with a significance level of 0.002.

In the partial influence test, the mangrove coverage variable partially influenced the salinity with a regression coefficient of 24.439. Meanwhile, the mangrove density variable had no significant influence on salinity. Although the literature shows the role of salinity in mangrove growth, there are also discussions that mangrove roots can absorb Na+ and Cl^- which can affect water salinity [46].

The highest mangrove coverage was observed at station 2, while the lowest was at station 5. However, the salinity at station 2 was higher than that of station 5, because station 5 was located in the waters of the Siak river, influenced by freshwater. Thus, the salinity levels tended to be lower. The present study recommends further research to examine the relationship between mangrove coverage and salinity levels at that location.

Salinity is an important factor in the life of marine biota. High salinity could harm plants and animals, alter fish and bird habitats, and reduce estuaries' capacity to provide such important services (seafood production and the protection of shorelines from erosion). The condition occurs at low salinity [47].

As anadromous fish, Longtail Shad fish lives in the sea and return to their natal grounds to spawn [48], [49]. In migratory fish, aquatic environmental conditions affect fish migration processes and the total population [50]. Salinity is one of the important factors for Longtail Shad fish spawning migration. The salinity required for Longtail Shad fish spawning is

between 17.7 and 34.7‰ [6]. Like other *Tenualosa* species, longtail shad fish can tolerate a wide range of salinities, so they are found in marine, estuarine, and freshwater environments [51].

I. Longtail Shad Fish Gut Content Analysis

Based on the gut content analysis performed to identify the feeding habit of Longtail Shad fish, the average value of the most common feed types consumed by the fish was obtained from Bengkalis waters along with Meranti Islands and Siak District, Riau Province, as shown in Fig.7.

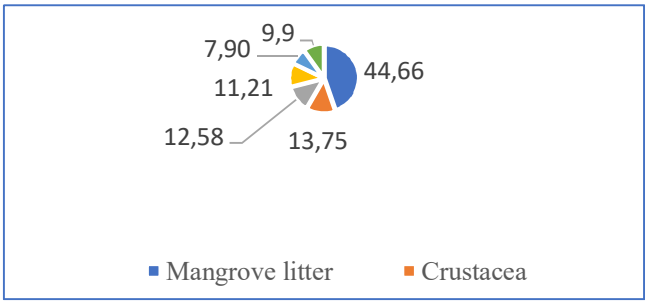

Fig. 7 Longtail shad fish gut content analysis

The most consumed feed type was mangrove litter, representing 44.66% of the total gut content. This result differed from that of previous research explaining that 71.33% of the gut contents of longtail shad fish was sawdust (from sawmills activity located along the watershed, dumping sawdust waste into the waters). The sawdust waste accumulates in the mouth of the river, which is a spawning route for longtail shad fish. Thus, it is consumed by fish [52]. This condition is presumably because the use of natural forest wood, threatening the preservation of natural resources and the environment, has now begun to be regulated and limited by the government so that many sawmills are no longer operating.

In correlation with the coastal fishery commodities, mangrove functions as a nursery, spawning, and feeding grounds for various marine biota [53]–[56]. Mangrove ecosystem is crucial in beach fisheries development. The mangrove forest ecosystem provides environmental services, such as feed, shelter, and high primary producing organisms for various fish types [57]–[59]. The primary water production around mangroves is reasonably high for water fertility. Leaves, twigs, flowers, and other litter from mangroves can be utilized by the macrofauna, such as crabs, which will be decomposed by microbes attached to the water base and cooperatively form a food chain. Higher aquatic animals, such as bivalves, gastropods, juvenile fish, prawns, and crabs utilize the detritus. The organic materials from mangrove litter are the main food chain of the food web in the ecosystem [60], [61].

Litters produced by mangrove trees as flowers, twigs, or leaves are the important basis for fish production in the downriver and coastal area. Organic materials from mangrove forest litter determine the fish and invertebrate livelihood. Mangrove ecosystem availability strongly correlates with fisheries diversity and productivity [62]–[64]. It positively influences fisheries resources, whereas the correlation between mangrove ecosystems and fish resources is extremely strong [65], [66].

IV. Conclusion

In the study location, there were 15 mangrove species and families, consisting of 13 true mangrove species and 1 mangrove associate species. Based on the Decree of the Indonesian Minister of Environment Number 201 0f 2004 on the standard criteria and correction of mangrove damage, the mangrove quality was assessed from density and coverage parameters. The density value at each sampling station was extremely dense (Stations 1, 2, 3, and 5), except stations 4 and 6 were categorized as rare and intermediate, respectively. Meanwhile, the coverage values were included in the intermediate category at Stations 1, 3, 4, 5, and 6 and extremely dense at station 2. The simultaneous influence test of mangrove density and coverage on temperature, brightness, salinity, DO, Nitrate, BOD, phosphate, Pb, Tricosdesmium phytoplankton abundance, and the abundances of Coscinodiscus, Nitzschia, Tintinopsis, Leprotintinnus, and Nauplius had a significant value of>0.05. this value indicated that there was no simultaneous influence on both variables in the parameters, except salinity which had the F value of 88.546 and p-value of 0.002 < 0.05, indicating that there was a simultaneous influence on both variables in the salinity level.

In partial influence test. Mangrove coverage variable is the variable that partially influences the salinity level by obtaining the regression coefficient of 24.439. Meanwhile, mangrove coverage had no significant influence on salinity. The gut content analysis was performed to identify the feeding habit of Longtail Shad fish. The average value of commonly consumed feed types by Longtail Shad fish in Bengkalis, Meranti Islands, and Siak District water was identified. The most consumed feed type found in Longtail Shad fish gut was mangrove litter, with 44.66% of the total gut content. This condition indicates that mangrove availability is extremely important for Longtail Shad fish.

Acknowledgment

The Riau provincial government sponsored this research through the Riau Provincial Personnel Agency.

References

[1] ICBS, *Marine and Coastal Resource Statistics. Indonesian Central Bureau of Statistics*. 2018.

[2] S. Sandoval Gallardo, T. Fossile, D. F. Herbst, A. Begossi, L. G. Silva, and A. C. Colonese, "150 years of anthropogenic impact on coastal and ocean ecosystems in Brazil revealed by historical newspapers," *Ocean Coast. Manag.*, vol. 209, Aug. 2021, doi: 10.1016/j.ocecoaman.2021.105662.

[3] S. Perera-Valderrama, A. Hernández-Ávila, H. Ferro-Azcona, D. Cobián-Rojas, J. González-Méndez, H. Caballero-Aragón, E. de la Guardia-Llansó, A. Ramón-Puebla, Z. Hernández-González, L. Espinosa-Pantoja, and A. Lara, "Increasing marine ecosystems conservation linking marine protected areas and integrated coastal management in southern Cuba," *Ocean Coast. Manag.*, vol. 196, Oct. 2020, doi: 10.1016/j.ocecoaman.2020.105300.

[4] IMMFA, *Decree of Indonesian Ministry of Marine and Fisheries Affairs. Number Kep.59/Men/2011: Limited Protection Status for Longtail Shad Fish*. 2011.

[5] IUCN, "The IUCN Red List of Threatened Species," 2021.

[6] S. J. M. Blaber, D. T. Brewer, D. A. Milton, G. Sedana Merta, D. Efizon, G. Fry, and T. Van Der Velde, "The Life History of the

Protandrous Tropical Shad Tenualosa macrura (Alosinae: Clupeidae): Fishery Implications," 1999. [Online]. Available: http://www.idealibrary.com

[7] IMMFA, "Guidelines for longtail shad fish population monitoring. Indonesian Ministry of Marine and Fisheries Affairs," 2015.

[8] K. Amri, G. Winarso, and M. Muchlizar, "Water environment quality and fish potention production in Bengkalis shads conservation (Tenualosa macrura bleeker, 1852)," *Indones. J. Fish. Res*, vol. 24, no. 1, pp. 37–49, Mar. 2018, doi: 10.15578/jppi.1.1.2018.37-49.

[9] P. S. E. zu Ermgassen, N. Mukherjee, T. A. Worthington, A. Acosta, A. R. da Rocha Araujo, C. M. Beitl, G. A. Castellanos-Galindo, M. Cunha-Lignon, F. Dahdouh-Guebas, K. Diele, C. L. Parrett, P. G. Dwyer, J. R. Gair, A. F. Johnson, B. Kuguru, A. Savio Lobo, N. R. Loneragan, K. Longley-Wood, J. T. Mendonça, *et al.*, "Fishers who rely on mangroves: Modelling and mapping the global intensity of mangrove-associated fisheries," *Estuar. Coast. Shelf Sci.*, vol. 247, Dec. 2020, doi: 10.1016/j.ecss.2020.106975.

[10] S. C. Gnansounou, M. Toyi, K. V. Salako, D. O. Ahossou, T. J. D. Akpona, R. C. Gbedomon, A. E. Assogbadjo, and R. Glèlè Kakaï, "Local uses of mangroves and perceived impacts of their degradation in Grand-Popo municipality, a hotspot of mangroves in Benin, West Africa," *Trees, For. People*, vol. 4, Jun. 2021, doi: 10.1016/j.tfp.2021.100080.

[11] C. Kusmana, "Survey methods and vegetation data interpretation," *IPB Press*, 2017.Y. R. Noor, M. Khazali, and I. N. N. Suryadiputra, "Guidelines for the introduction of mangroves in Indonesia. Wetlands International Indonesia Programme. Directorate General of Forest Protection and Nature Conservation," 1999.

[12] IME, *Minister of environment regulation number 201/KepmenLH/2004 about guidelines for mangrove plant rehabilitation through forest and land rehabilitation movement*. 2004.

[13] A. F. Bernardino, G. N. Nóbrega, and T. O. Ferreira, "Consequences of terminating mangrove's protection in Brazil," *Mar. Policy*, vol. 125, no. December 2020, pp. 2020–2022, 2021, doi: 10.1016/j.marpol.2020.104389.

[14] P. E. R. Nugroho, Suryanti, and W. P. Pudjiono, "Analysis of Changes in Mangrove Area in the North Coast of Central Java Province Indonesia," vol. 16, no. 3, pp. 208–218, 2020.

[15] S. J.-L. Xu, S. C.-Y. Chan, B. Y.-K. Wong, H.-C. Z. F.-L. Li, N. F.-Y. Tam, and F. W.-F. Lee, "Relationship between phytoplankton community and water parameters in planted fringing mangrove area in South China," *Sci. Total Environ.*, vol. 817, 2022.

[16] J. K. Singh, "Structural characteristics of mangrove forest in different coastal habitats of Gulf of Khambhat arid region of Gujarat, west coast of India," *Heliyon*, vol. 6, no. 8, Aug. 2020, doi: 10.1016/j.heliyon.2020.e04685.

[17] L. Wang, M. Mu, X. Li, P. Lin, and W. Wang, "Differentiation between true mangroves and mangrove associates based on leaf traits and salt contents," *J. Plant Ecol.*, vol. 4, no. 4, pp. 292–301, Dec. 2011, doi: 10.1093/jpe/rtq008.

[18] IME, *Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.105/MENLHK/SETJEN/KUM.1/12/2018 concerning procedures for implementation, supporting activities, providing incentives, as well as fostering and controlling forest*. 2018.

[19] L. E. Urrego, E. C. Molina, and J. A. Suárez, "Environmental and anthropogenic influences on the distribution, structure, and floristic composition of mangrove forests of the Gulf of Urabá (Colombian Caribbean)," *Aquat. Bot.*, vol. 114, pp. 42–49, Feb. 2014, doi: 10.1016/j.aquabot.2013.12.006.

[20] A. Rahadian, B. Prasetyo, Y. Setiawan,) Dan, and K. Wikantika, "Tinjauan historis data dan informasi luas mangrove Indonesia," Kecamatan Coblong, 2019.

[21] Y. Oktorini, E. Prianto, V. V. Darlis, R. Rahmatdillah, M. Miswadi, and R. Jhonnerie, "Mangrove Riau: sebaran dan status perubahan," *Din. Lingkung. Indones.*, vol. 9, no. 1, p. 50, Jan. 2022, doi: 10.31258/dli.9.1.p.50-57.

[22] M. Ilman, P. Dargusch, P. Dart, and Onrizal, "A historical analysis of the drivers of loss and degradation of Indonesia's mangroves," *Land use policy*, vol. 54, pp. 448–459, Jul. 2016, doi: 10.1016/j.landusepol.2016.03.010.

[23] Sosia, P. Yudasakti, T. Rahmadhani, and M. Nainggolan, *Mangrove Siak & Kepulauan Meranti*. Environmental & Regulatory Compliance Division Safety, Health & Environment Department ENERGI, 2014.

[24] Miswadi, R. Firdaus, and R. Jhonnerie, "Mangrove wood utilization by the indigenous people of liong river, Bengkalis island. Indonesian Journal of Maritime Dynamics," *Indones. J. Marit. Dyn.*, pp. 35–39, 2017.

[25] A. M. Ellison, A. J. Felson, and D. A. Friess, "Mangrove Rehabilitation and Restoration as Experimental Adaptive Management," *Front. Mar. Sci.*, vol. 7, May 2020, doi: 10.3389/fmars.2020.00327.

[26] A. Bergamasco, H. Q. Nguyen, G. Caruso, Q. Xing, and E. Carol, "Advances in water quality monitoring and assessment in marine and coastal regions," *Water (Switzerland)*, vol. 13, no. 14. MDPI AG, Jul. 02, 2021. doi: 10.3390/w13141926.

[27] S. S. Shih, "Spatial habitat suitability models of mangroves with Kandelia obovata," *Forests*, vol. 11, no. 4, Apr. 2020, doi: 10.3390/F11040477.

[28] S. Sreelekshmi, S. B. Nandan, S. V. Kaimal, C. K. Radhakrishnan, and V. R. Suresh, "Mangrove species diversity, stand structure and zonation pattern in relation to environmental factors — A case study at Sundarban delta, east coast of India," *Reg. Stud. Mar. Sci.*, vol. 35, Mar. 2020, doi: 10.1016/j.rsma.2020.101111.

[29] F. Samara, N. Solovieva, T. Ghalayini, Z. A. Nasrallah, and M. Saburova, "Assessment of the environmental status of the mangrove ecosystem in the United Arab Emirates," *Water (Switzerland)*, vol. 12, no. 6, 2020, doi: 10.3390/w12061623.

[30] V. Seygita, Sulistiono, C. Kusmana, and G. Yulianto, "Water quality, plankton community, and pollution index in the spawning habitat of longtail shad (Tenualosa macrura) in the waters of Bengkalis, Meranti Island and Siak Regencies, Riau Province," in *IOP Conference Series: Earth and Environmental Science*, May 2021, vol. 744, no. 1. doi: 10.1088/1755-1315/744/1/012074.

[31] C. E. Moore, K. Meacham-Hensold, P. Lemonnier, R. A. Slattery, C. Benjamin, C. J. Bernacchi, T. Lawson, and A. P. Cavanagh, "The effect of increasing temperature on crop photosynthesis: From enzymes to ecosystems," *J. Exp. Bot.*, vol. 72, no. 8, pp. 2822–2844, Apr. 2021, doi: 10.1093/jxb/erab090.

[32] S. S. Myers, M. R. Smith, S. Guth, C. D. Golden, B. Vaitla, N. D. Mueller, A. D. Dangour, and P. Huybers, "Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition," *Annu. Rev. Public Heal.*, vol. 38, pp. 259–77, 2017, doi: 10.1146/annurev-publhealth.

[33] A. R. Sánchez, J. E. M. Pineda, X. M. Casas, and J. H. M. Calderón, "Influence of edaphic salinity on leaf morphoanatomical functional traits on juvenile and adult trees of red mangrove (Rhizophora mangle): Implications with relation to climate change," *Forests*, vol. 12, no. 11, Nov. 2021, doi: 10.3390/f12111586.

[34] M. Moslehi, T. Pypker, A. Bijani, A. Ahmadi, and M. H. S. Hallaj, "Effect of salinity on the vegetative characteristics, biomass and chemical content of red mangrove seedlings in the south of Iran," *Sci. For. Sci.*, vol. 49, no. 132, 2021, doi: 10.18671/scifor.v49n132.16.

[35] S. K. Agarwal and A. Mitra, "Salinity: A Primary Growth Driver of Mangrove Flora," *Curr Trends For. Res*, p. 114, 2018, doi: 10.29011/CTFR-114.

[36] M. H. Panh and M. S. J.F, "Managing mangroves and coastal land cover in the Mekong Delta.," *Ocean Coast. Manag.*, vol. 219, 2022.

[37] C. Lønborg, M. Müller, E. C. V. Butler, S. Jiang, S. K. Ooi, D. H. Trinh, P. Y. Wong, S. M. Ali, C. Cui, W. B. Siong, E. S. Yando, D. A. Friess, J. A. Rosentreter, B. D. Eyre, and P. Martin, "Nutrient cycling in tropical and temperate coastal waters: Is latitude making a difference?," *Estuarine, Coastal and Shelf Science*, vol. 262. Academic Press, Nov. 05, 2021. doi: 10.1016/j.ecss.2021.107571.

[38] S. Kesavan, K. A. M. Xavier, G. Deshmukhe, A. K. Jaiswar, S. Bhusan, and S. P. Sukla, "Anthropogenic pressure on mangrove ecosystems: Quantification and source identification of surficial and trapped debris," *Sci. Total Environ.*, vol. 794, Nov. 2021, doi: 10.1016/j.scitotenv.2021.148677.

[39] C. K.-C. Ng and R. C. Ong, "A review of anthropogenic interaction and impact characteristics of the Sundaic mangroves in Southeast Asia," *Estuar. Coast. Shelf Sci.*, vol. 267, 2022.

[40] O. Celis-Hernandez, M. P. Giron-Garcia, J. F. Ontiveros-Cuadras, J. C. Canales-Delgadillo, R. Y. Pérez-Ceballos, R. D. Ward, O. Acevedo-Gonzales, J. S. Armstrong-Altrin, and M. Merino-Ibarra, "Environmental risk of trace elements in mangrove ecosystems: An assessment of natural vs oil and urban inputs," *Sci. Total Environ.*, vol. 730, Aug. 2020, doi: 10.1016/j.scitotenv.2020.138643.

[41] O. Celis-Hernandez, M. Villoslada-Peciña, R. D.Ward, Bergamoc, R. Perez-Ceballos, and M. P. Girón-García, "Impacts of environmental pollution on mangrove phenology: Combining remotely sensed data and generalized additive models," *Sci. Total Environ.*, vol. 810, 2022.

[42] S. Eddy, N. Milantara, S. D. Sasmito, T. Kajita, and M. Basyuni, "Anthropogenic drivers of mangrove loss and associated carbon emissions in South Sumatra, Indonesia," *Forests*, vol. 12, no. 2, pp. 1–14, Feb. 2021, doi: 10.3390/f12020187.

[43] B. C. Sekadende, A. Michael, S. C. Painter, S. Shayo, M. Noyon, and M. S. Kyewalyanga, "Spatial variation in the phytoplankton community of the Pemba Channel, Tanzania, during the south-east monsoon," *Ocean Coast. Manag.*, vol. 212, Oct. 2021, doi: 10.1016/j.ocecoaman.2021.105799.

[44] Y. Gao, L. Sun, C. Wu, Y. Chen, H. Xu, C. Chen, and G. Lin, "Inter-annual and seasonal variations of phytoplankton community and its relation to water pollution in Futian Mangrove of Shenzhen, China," *Cont. Shelf Res.*, vol. 166, pp. 138–147, Aug. 2018, doi: 10.1016/j.csr.2018.07.010.

[45] W. Wang, Z. Yan, S. You, Y. Zhang, L. Chen, and G. Lin, "Mangroves: Obligate or facultative halophytes? A review," *Trees - Structure and Function*, vol. 25, no. 6. Springer Verlag, pp. 953–963, 2011. doi: 10.1007/s00468-011-0570-x.

[46] K. Havens, "Climate Change: Effects on Salinity in Florida's Estuaries and Responses of Oysters, Seagrass, and Other Animal and Plant Life 1." [Online]. Available: http://edis.ifas.ufl.edu.

[47] M. K. Smith and P. Zwollo, "Transient increase in abundance of B lineage but not myeloid-lineage cells in anterior kidney of sockeye salmon during return migration to the natal grounds," *Fish Shellfish Immunol.*, vol. 107, pp. 395–402, Dec. 2020, doi: 10.1016/j.fsi.2020.09.022.

[48] L. J. Melnyk, J. Lin, D. H. Kusnierz, K. Pugh, J. T. Durant, R. J. Suarez-Soto, R. Venkatapathy, D. Sundaravadivelu, A. Morris, J. M. Lazorchak, G. Perlman, and M. A. Stover, "Risks from mercury in anadromous fish collected from Penobscot River, Maine," *Sci. Total Environ.*, vol. 781, Aug. 2021, doi: 10.1016/j.scitotenv.2021.146691.

[49] E. Duval, Ø. Skaala, M. Quintela, G. Dahle, A. Delaval, V. Wennevik, K. A. Glover, and M. M. Hansen, "Long-term monitoring of a brown trout (Salmo trutta) population reveals kin-associated migration patterns and contributions by resident trout to the anadromous run," *BMC Ecol. Evol.*, vol. 21, no. 1, Dec. 2021, doi: 10.1186/s12862-021-01876-9.

[50] M. A. R. Hossain, I. Das, L. Genevier, S. Hazra, M. Rahman, M. Barange, and J. A. Fernandes, "Biology and fisheries of Hilsa shad in Bay of Bengal," *Sci. Total Environ.*, vol. 651, pp. 1720–1734, Feb. 2019, doi: 10.1016/j.scitotenv.2018.10.034.

[51] D. T. Brewer, S. J. M. Blaber, G. Fry, G. S. Merta, and D. Efizon, "Sawdust ingestion by the tropical shad (Tenualosa macrura, Teleostei: Clupeidae): Implications for conservation and fisheries," *Biol. Conserv.*, vol. 97, no. 2, pp. 239–249, 2001, doi: 10.1016/S0006-3207(00)00117-8.

[52] L. Meilana, A. A. Hakim, and Q. Fang, "Nursery habitat of three species of juvenile Asian horseshoe crabs in Teritip Beach, East Kalimantan, Indonesia: Characterization and implication," *Glob. Ecol. Conserv.*, vol. 26, Apr. 2021, doi: 10.1016/j.gecco.2021.e01453.

[53] L. D. Vorsatz, P. Pattrick, and F. Porri, "Ecological scaling in mangroves: The role of microhabitats for the distribution of larval assemblages," *Estuar. Coast. Shelf Sci.*, vol. 253, May 2021, doi: 10.1016/j.ecss.2021.107318.

[54] A. C. Enchelmaier, E. A. Babcock, and N. Hammerschlag, "Survey of fishes within a restored mangrove habitat of a subtropical bay," *Estuar. Coast. Shelf Sci.*, vol. 244, Oct. 2020, doi: 10.1016/j.ecss.2018.11.009.

[55] P. R. Marlianingrum, T. Kusumastanto, L. Adrianto, and A. Fahrudin, "Valuing habitat quality for managing mangrove ecosystem services in coastal Tangerang District, Indonesia," *Mar. Policy*, vol. 133, no. 60, p. 104747, 2021, doi: 10.1016/j.marpol.2021.104747.

[56] A. Himes-Cornell, S. O. Grose, and L. Pendleton, "Mangrove ecosystem service values and methodological approaches to valuation: Where do we stand?," *Front. Mar. Sci.*, vol. 5, no. OCT, Oct. 2018, doi: 10.3389/fmars.2018.00376.

[57] A. Rizal, H. Herawati, and A. Sahidin, "Economic Value Estimation of Mangrove Ecosystems in Indonesia," *Biodivers. Int. J.*, vol. 2, no. 1, Feb. 2018, doi: 10.15406/bij.2018.02.00051.

[58] M. Carrasquilla-Henao, N. Ban, M. Rueda, and F. Juanes, "The mangrove-fishery relationship: A local ecological knowledge perspective," *Mar. Policy*, vol. 108, no. March, 2019, doi: 10.1016/j.marpol.2019.103656.

[59] V. M. Muro-Torres, F. Amezcua, M. Soto-Jiménez, E. F. Balart, E. Serviere-Zaragoza, L. Green, and J. Rajnohova, "Primary sources and food web structure of a tropical wetland with high density of mangrove forest," *Water (Switzerland)*, vol. 12, no. 11, pp. 1–18, 2020, doi: 10.3390/w12113105.

[60] M. I. Alam, M. U. Ahmed, S. Yeasmin, A. O. Debrot, M. N. Ahsan, and M. C. J. Verdegem, "Effect of mixed leaf litter of four mangrove species on shrimp post larvae (Penaeus monodon, Fabricius, 1798) performance in tank and mesocosm conditions in Bangladesh," *Aquaculture*, vol. 551, no. January, p. 737968, 2022, doi: 10.1016/j.aquaculture.2022.737968.

[61] R. Seary, T. Spencer, M. Bithell, and C. McOwen, "Measuring mangrove-fishery benefits in the Peam Krasaop Fishing Community, Cambodia," *Estuar. Coast. Shelf Sci.*, vol. 248, no. December 2019, p. 106918, 2021, doi: 10.1016/j.ecss.2020.106918.

[62] A. O. Debrot, A. Plas, H. Boesono, K. Prihantoko, M. J. Baptist, A. J. Murk, and F. H. Tonneijck, "Early increases in artisanal shore-based fisheries in a Nature-based Solutions mangrove rehabilitation project on the north coast of Java," *Estuar. Coast. Shelf Sci.*, vol. 267, no. January, p. 107761, 2022, doi: 10.1016/j.ecss.2022.107761.

[63] B. Tarimo, M. Winder, M. S. P. Mtolera, C. A. Muhando, and M. Gullström, "Seasonal distribution of fish larvae in mangrove-seagrass seascapes of Zanzibar (Tanzania)," *Sci. Rep.*, vol. 12, no. 1, pp. 1–13, 2022, doi: 10.1038/s41598-022-07931-9.

[64] Y. A. Nugraha, Sulistiono, H. A. Susanto, C. P. H. Simanjuntak, and D. M. Wildan, "Mangrove ecosystem related to fisheries productivity in the coastal area of Karawang Regency, West Java, Indonesia," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 800, no. 1, 2021, doi: 10.1088/1755-1315/800/1/012016.

[65] M. Ulfa, K. Ikejima, E. Poedjirahajoe, L. R. W. Faida, and M. M. Harahap, "Effects of mangrove rehabilitation on density of Scylla spp. (mud crabs) in Kuala Langsa, Aceh, Indonesia," *Reg. Stud. Mar. Sci.*, vol. 24, pp. 296–302, 2018, doi: 10.1016/j.rsma.2018.09.005.