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Untangling the Complexity of Small-Scale Fisheries: Building an Understanding of Grouper-Snapper Fisheries Dynamics in Saleh Bay, West Nusa Tenggara, Indonesia

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Abstract: Small-scale tropical fisheries are complex systems that utilize multiple fishing gears to target various species. In this study, we investigated small-scale reef and demersal fisheries in Saleh Bay, Indonesia, using catch and effort data from 2016 to 2019, where 57.7 percent of the catch was grouper (serranids) and snapper (lutjanids). Despite the complexity (75 documented species and eight fishing methods), this fishery is characterized by the catches of four dominant species: leopard coral grouper (*Plectropomus leopardus*), orange-spotted-grouper (*Epinephelus coioides*), spotted coral grouper (*P. maculatus*), and malabar blood snapper (*Lutjanus malabaricus*). The species caught varied among fishing methods. Over 90% of the catch was attributed to three primary fishing methods: bottom longline, speargun, and handline. Multivariate analyses found that fishing depth, season, and/or year significantly influenced the catch composition for each of these fishing methods. Fishing activities exhibit a temporal pattern influenced by monsoonal seasons. Results also suggest that fishers employ specialized fishing tactics by targeting high-value species to maximize their profits. This study recommends a management strategy of focusing on monitoring and managing the three main fishing gears and four important species during their peak seasons to reduce some of the complexity and management costs.

Keywords: fishing fleet characteristics; fishing seasonality; fishing tactics; fish landing monitoring

Key Contribution: This study demonstrates an approach to understanding the complexity and fishing dynamics of small-scale fisheries to provide key recommendations for their management.

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1. Introduction

Small-scale fisheries (SSF) play an important role in global fisheries, contributing approximately half of fish catches and providing labor opportunities to more than 90 percent (35 million) of people employed in the capture fisheries sector worldwide [1]. These fisheries are also estimated to provide more than US$61 billion to the annual labor-buffer function, a mechanism to sustain coastal community livelihoods where people can move in and out of fishing activities, depending on other job opportunities [2]. Globally, approximately 90% of the estimated 4.56 million fishing vessels are considered to be small-scale [1], with approximately 90–95% of their catches destined for human consumption [3].

Indonesia is one of the main contributors to production in capture fisheries and aquaculture, contributing 26.5% and 45% to the global production of grouper and snapper from capture fisheries, respectively [4,5]. The contribution of grouper capture fisheries to the total Indonesian marine capture fisheries production (6.23 million tons) has increased from 0.54% in 2008 to 1.62% in 2017. Indonesia, together with the Taiwan region and mainland China, also dominated global grouper aquaculture production, with Indonesia contributing 11%, the Taiwan region contributing 17%, and mainland China contributing 65%. The total value of grouper exports (fresh, chilled, and frozen) from Indonesia in 2016 was an estimated US$32.81 million [6] and the export value of Indonesian snapper reached US$13 million in 2018 [4].

Groupers are one of the most highly targeted and commercially important species groups for coastal communities [7] and are targeted by SSF using multiple fishing gears. This puts intense pressure on grouper stocks, particularly in Eastern Indonesia [8,9]. A study by Halim et al. (2020) [8] estimated the length-based spawning potential ratio (LB-SPR) for leopard coral grouper (*Plectropomus leopardus*) stocks in Saleh Bay, West Nusa Tenggara and found the SPR was <0.25. A comprehensive study by Dimarchopoulou et al. [10] of 16 deep sea demersal species (including groupers and snappers) in four Indonesian Fisheries Management Areas also reported the potential overexploitation of five grouper and snapper species, i.e., banded grouper (*Epinephelus amblycephalus*), malabar blood snapper (*Lutjanus malabaricus*), emperor red snapper (*L. sebae*), brownstripe red snapper (*L. vitta*), and pinjalo (*Pinjalo pinjalo*), with very low SPRs ranging from 0.03 to 0.16. Furthermore, Halim et al. [8] found that several grouper (*Plectropomus leopardus*, *Variola albimarginata*, *P. maculatus*, and *Epinephelus areolatus*) and snapper (*Lutjanus gibbus* and *L. boutton*) species in Saleh Bay and the Timor Sea were harvested below their size at maturity. In addition, the high dependence of grouper export markets on wild catch sources has increased pressure on grouper stocks and resulted in the degradation of their habitats (e.g., coral reefs) [9,11,12].

Small-scale fisheries exhibit a diverse array of characteristics, which differ both within and across countries and regions [13–18]. In addition, the definition of SSF extends beyond the technical characteristics of the fishing boat or fishing gear and also includes management and socioeconomic aspects such as the value chain and gender, depending on the national or regional laws and policies [18]. This makes it exceedingly challenging to establish a universally applicable definition on a global scale [14]. As part of building effective management strategies for SSFs, fisheries scientists and managers need to understand the dynamics of these fisheries [19]. A wide range of behavioral and fleet dynamics theories and studies, including their empirical applications in fisheries, has been discussed comprehensively by van Putten et al. [20]. They state that fishing dynamics (or fleet dynamics) are related to changes in fishing effort (fishing capacity, intensity, and allocation) due to decisions made by fishers that directly impact fish stocks.

Studies on fishing dynamics also cover the broader context and dimensions of a fishery, such as fleet and gear characteristics (e.g., [21,22]), spatio-temporal catch and effort patterns (e.g., [23,24]), fishing tactics and behaviors (e.g., [25,26]), socio-ecological systems (e.g., [27–29]), and governance (e.g., [30]). A wide range of approaches have been used to characterize the dynamics of fisheries, ranging from simple descriptive statistical analyses to sophisticated computer modeling. Thus, acquiring information on the technical characteristics of fishing fleets (such as boat size and engine power) and fishing effort (including fishing gear, trip hours, and number of crew) in SSF is crucial. This knowledge forms the foundation for understanding the dynamics of SSF and serves as a fundamental basis for designing effective management strategies.

One key subject of the human dimension of fisheries is fishing behavior, i.e., the tactics, strategies, and decision-making of fishers, which is often less considered in the decision-making process during fisheries management planning [31,32]. Fishers employ their strategies based on their competition (or cooperation) for available natural resources and the market [32,33]. The selection of fishing strategies by fishers is influenced by multiple factors, including fisher knowledge, e.g., spatial and temporal distribution of target species, seasonal patterns of fishing, weather, and technology, e.g., fishing gear, boat power, and capacity [34]. Salas and Gaertner [32] suggest that there are two major groups of fishers based on the strategy they employ in fishing: specialists and generalists. Specialists generally focus on specific species, fishing grounds, and fishing methods. Specialists also take advantage of technological developments to maximize their catch of high-value fish. In contrast, generalists are more flexible in their fishing patterns, switching target species and fishing methods, and some may even temporarily switch to livelihoods unrelated to fishing. The lack of understanding and consideration of the complex dynamics of fishing is one of the main causes of management failures in many fisheries [32,34].

A fishing tactic refers to the approach employed by fishers to distribute their fishing effort as an adaptive response to changes in resource abundance, environmental conditions, and market or regulatory constraints [32,35]. Fishing tactics encompass the practices adopted at the level of the fishing operation. In the context of mixed fisheries, fishing tactics are characterized by a combination of the target species, fishing methods, and the selection of fishing grounds during specific times of the year [35]. In addition, the term fishing tactics is often used to articulate the fishing intention concerning the target species, fishing ground, and fishing method [26,36].

West Nusa Tenggara (WNT) is one of the eight archipelagic provinces in Indonesia that has high potential fisheries resources from its 29,159 km^2 of marine waters, which cover 59% of the province area. According to the national fisheries production statistics of Indonesia [37], marine capture fisheries production of WNT in 2021 reached 240,536 tons, which is 3.3% of the national production. Saleh Bay is located on Sumbawa Island, WNT (Figure 1) and is flanked by the regencies of Sumbawa and Dompu and has a population of ~67,000, of which 3800 are fishers, distributed across various fish resources [38]. Saleh Bay is also fished by nearly 2000 fishers from outside the bay (mainly from Medang Island and from the north-west coast of Sumbawa), making a total of 5800 fishers who fish in Saleh Bay [38]. With an area of 2087 km^2, Saleh Bay is home to a range of productive fisheries resources, such as pelagic, demersal, and reef fish, including groupers and snappers. It also has a diversity of habitats, including small islands and multiple coastal ecosystems such as coral reefs, seagrass, and mangroves that provide important habitats. According to annual provincial and regency statistic reports, the combined grouper and snapper production from the Sumbawa and Dompu regencies in 2018 was 8938 tons, accounting for approximately 10.2% of the total capture fisheries production from both regencies and 4.4% of the provincial production. Hence, Saleh Bay is an important fisheries area that significantly contributes to the total reef fisheries production for WNT Province and Indonesia's Fisheries Management Area (FMA) 713.

Specific regulations have been in place for managing grouper and snapper fisheries in Saleh Bay since 2018. These regulations include (i) establishing a minimum legal size of catches by regulating hook and mesh sizes of fishing gears, (ii) reducing destructive fishing practices, and (iii) enhancing the efficacy of no-take area management of existing marine protected area [39]. Continuous catch monitoring has been undertaken to assess the impact of these management measures on enhancing the stock condition of the 12 main grouper and snapper species. However, the management measures have not been able to improve the stock condition of some of these species [11]. This is partly due to the ineffective enforcement of minimum legal-size regulation and the prohibition of fishing in the MPA no-take areas [40]. Thus, the current study improves our understanding of the fishing dynamics and behavior to inform more effective management strategies for grouper and snapper fisheries in Saleh Bay by identifying (i) the technical and operational characteristics of the fishing fleets targeting groupers and snappers, (ii) key species of groupers and snappers targeted by fishers, (iii) main fishing methods that contribute significantly to groupers and snappers catches, (iv) temporal trends in catches and fishing effort, and (v) tactics employed by grouper and snapper fishers to allocate their fishing effort.

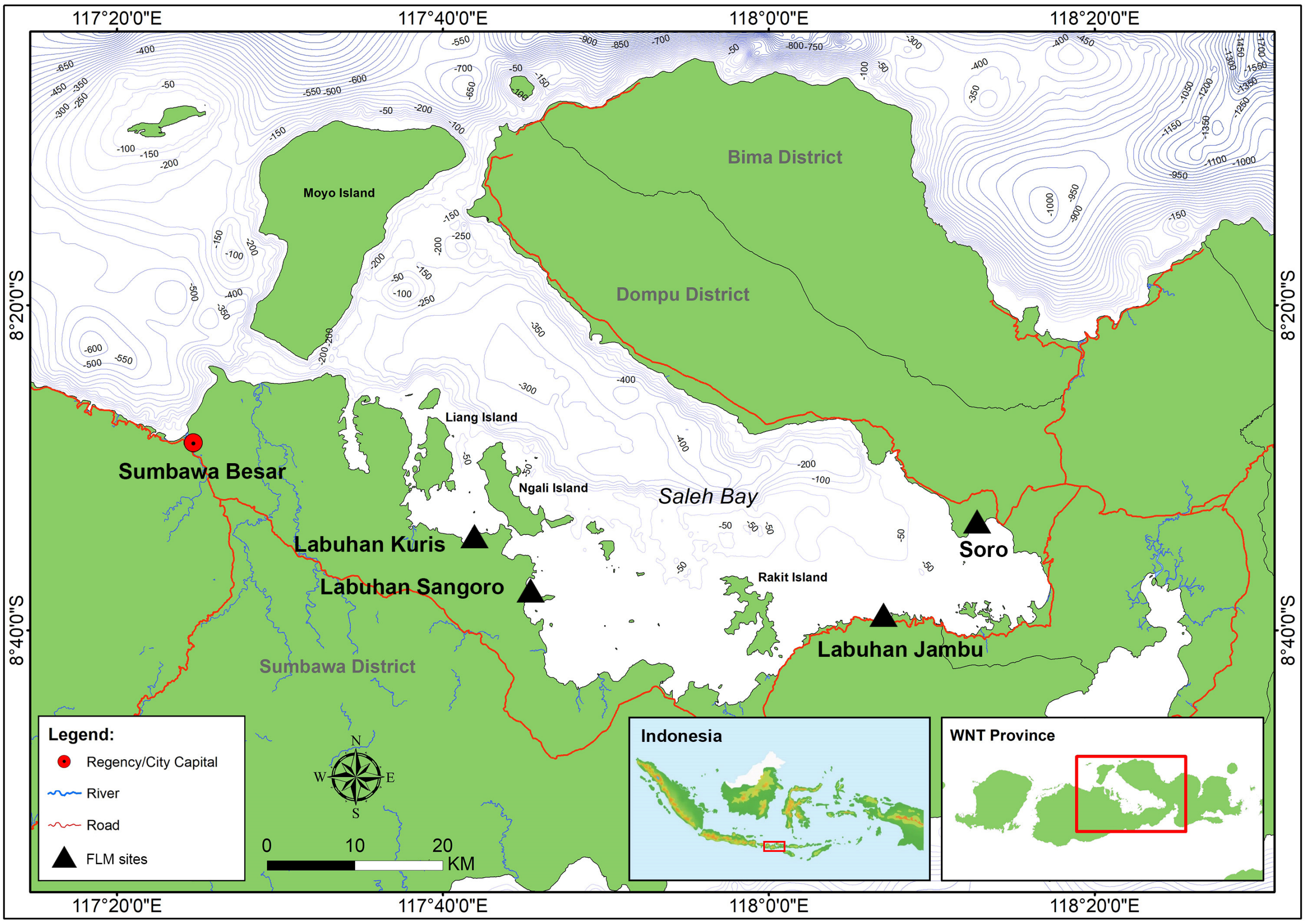

Figure 1. Map of Saleh Bay and four main fish landing monitoring (FLM) sites (triangle) around the bay in Sumbawa, West Nusa Tenggara (WNT), Indonesia. Basemap source: Indonesian Geospatial Information Agency (BIG) and the Wildlife Conservation Society (WCS) Indonesia Program. Red boxes in insets show location of Saleh Bay in Indonesia and WNT province.

2. Materials and Methods

This study characterizes fishing operations of the nearshore reef and demersal fisheries in Saleh Bay, WNT Province based on monthly catch and fishing effort data collected from April 2016 to December 2019. Further analyses were conducted to determine how the composition of the landings differs between methods and if they change with depth and over time. Finally, the drivers of variation in CPUE for key grouper and snapper species are investigated.

2.1. Data Sources

2.1.1. Climate Data

The monsoonal season in Saleh Bay can be categorized into four distinct seasons: the North-western monsoonal season (December–February), Transition I (March–May), South-eastern monsoonal season (June–August), and Transition II (September–November) [41]. The North-western monsoonal season (hereafter 'NW') is characterized by high rainfall and relatively low wind speeds coming from the northwest. In contrast, the South-eastern monsoonal season (hereafter 'SE') experiences very low rainfall and high wind speeds originating from the southeast. Transition season I marks the shift from the NW to SE monsoon, featuring lower average monthly rainfall and higher wind speeds than the NW monsoon. On the other hand, Transition II, the time between the NW and SE seasons, exhibits relatively similar levels of rainfall and wind speeds as Transition I.

Monthly total rainfall (mm) and average windspeed (m/s) data of Sumbawa Besar City from April 2016 to December 2019 were downloaded from the Indonesia Meteorological, Climatological, and Geophysical Agency (BMKG)'s online database [42].

2.1.2. Fisheries Catch and Effort Data

The catch and effort data are derived from the WNT government's fish landing monitoring (FLM) database, covering the period from April 2016 (when the FLM was initiated) to December 2019. The FLM gathers a comprehensive set of data encompassing details about the fishing fleet, including fisher profiles, boat characteristics, and fishing gear. It also captures information on the fishing effort allocation, such as the time spent at sea for each trip, fishing depth, number of crew, and associated fishing costs. Furthermore, the FLM records data related to landings, covering the total catch, numbers, weights, and lengths of each reef-associated and demersal fish species, along with the corresponding fish prices (Table 1). Other groups, such as Muliidae and Priacanthidae, were not identified during the FLM but were counted and weighed to calculate the total catch.

Table 1. List of data collected, data description, and data collection method by the Wildlife Conservation Society Indonesia Program's fish landing monitoring in Saleh Bay from April 2016 to November 2019. Data collection methods include interviews with fishers (interview), direct measurement (d.m.), and direct observation (d.o.).

Data Group	Data	Description	Data Collection Method
Fisher profile	Village	Name of village	interview
	Home port	Name of fishing port	interview
	Landing port	Name of fishing port	interview
	Fisher name	-	interview
	Fish collector	Name of fish collector	interview
	Boat name	-	interview
Boat characteristic	Engine category	(inboard, outboard, no-engine)	interview
	Engine power	horsepower (HP)	interview
	Number of boat crew	-	interview
	Boat tonnage	Gross tonnage (GT)	interview
	Boat length	meter	d.o./interview
Fishing effort	Date of fishing	-	d.o.
	Time of fishing	-	d.o.
	Date of landing	-	d.o.
	Time of landing	-	d.o.
	Main fishing gear	-	d.o.
	Secondary fishing gear	-	d.o./interview
	Additional gear	(e.g., lamp, FAD)	d.o./interview
	Fishing depth	meter	interview
Catch	Family	-	d.m.
	Species	-	d.m.
	Common name	Local common name	d.m.
	Price per kg	IDR (Indonesian Rupiah)	d.o./interview
	Total catch (kg)	kilogram (kg)	d.m.
	Total catch (number)	number of individuals	d.m.
	Fish total length (TL)	centimeter (cm)	d.m.
	Storage	fresh, frozen	d.o./interview

The FLM was carried out at four main fish landing sites around Saleh Bay, namely Labuhan Kuris, Labuhan Sanggoro, Labuhan Jambu, and Soro (Figure 1), and landing data were collected for 7 to 15 days in each month through direct observation of fish landing activities, direct measurements of the catch, and interviews with fishers after their fishing trip. A total of 4046 fishing trips in Saleh Bay from April 2016 to December 2019 were documented during the FLM, which made it possible to evaluate trends in a nominal catch and fishing effort, as well as changes in target species based on catch composition.

2.2. Characterizing Fishing Operations

Fishing operations in the study area were characterized by applying descriptive statistics to FLM data collected from April 2016 to December 2019. The analysis focused on the following variables: (i) Boat and fishing methods, (ii) catch-per-unit-effort (CPUE) expressed in number of fish of each species per trip hour, (iii) catch composition based on the proportion by weight of grouper species in the catch and proportion of high-value species in the total catch, and (iv) depth of the fishing ground. Depths were grouped into four depth categories: 0–13 m; 14–30 m; 31–40 m; and >40 m to allow patterns in catch composition and fishing effort to be investigated for each method. Temporal changes in fishing operations were evaluated by examining how catch, fishing effort, and catch composition varied among seasons (NW, Transition 1, SE, and Transition II) for each of the main methods over four years.

2.3. Statistical Analyses

2.3.1. Catch Composition and Diversity of Targeted Groupers and Snappers Species

As preliminary investigations showed that small-scale fishers in Saleh Bay employed multiple types of fishing gear and targeted a wide range of reef and demersal fish species, initial statistical analyses focused on determining the catch composition of different fishing methods and investigating how it varied among methods. Given that substantial differences were detected among methods (see Section 3), subsequent analyses were conducted using the data for the three most frequently used methods, i.e., bottom longline, speargun, and handline, individually, to determine whether catch composition was influenced by fishing depth, season, and/or year.

Firstly, a data matrix was constructed for the CPUE of the 75 species landed in each of the 3140 fishing trips conducted using five of the eight methods documented in Saleh Bay: bottom longline, speargun, handline, troll line, and drop line. That matrix was then subjected to the DIVERSE routine in PRIMER v7 [43] to calculate the number of species, total CPUE, and Shannon diversity. The data for each of these three univariate variables were examined separately to determine whether transformations were required to meet the assumptions of homogenous dispersion among a priori groups. This was achieved by calculating the extent of the linear relationship (slope) between the $\log_e$ (mean) and $\log_e$ (standard deviation) of each variable among all groups and comparing them to the criteria in Clarke et al. [44]. These analyses demonstrated that no transformations were required. The data for each variable were used to construct a separate Euclidean distance matrix and subjected to a one-way permutational analysis of variance (PERMANOVA [45]) test. These analyses aimed to determine whether the values for each variable differed among fishing methods (five levels: bottom longline, speargun, handline, troll line, and drop line). The null hypothesis of no significant differences among a priori groups was rejected if the significance level (p) was <0.05, and the relative influence of each term in the model was quantified using the percentage contribution of the mean squares of that term to the total mean squares [46]. If a significant difference was detected, pairwise PERMANOVA was used to determine those pairwise combinations responsible for the differences supported by means plots with 95% confidence limits.

As, on average, <2 species were landed on an individual fishing trip, samples collected using the same method may differ markedly, and this variability prevents effective multivariate analyses by masking subtle but "true" trends in catch composition. As such, trips were randomly sorted into groups of between 2 and 6 for each of the fishing methods, depending on the total number of trips for that fishing method [47,48]. This mirrors the statistical approach often used in multivariate analyses of fish dietary data as many species consume, at any one point in time, a limited range of prey [47]. Samples within each group were averaged to create a new suite of replicates, which were, in turn, used to construct a

Bray–Curtis resemblance matrix and subjected to the same one-way PERMANOVA test described above. A one-way Analysis of Similarities test (ANOSIM [49]) was used to interpret the relative size of the fishing method factor using the size of the universally scaled *R*-statistic, which ranges from ~0 to 1 [44]. Trends in species composition were explored visually using both Canonical Analysis of Principal coordinates (CAP [45]) and Bootstrapped metric Multidimensional Scaling (Bootstrapped mMDS) [43]. Superimposed onto the CAP are vectors for species whose CPUE changes in a linear direction (Pearson correlation > 0.3) relative to the CAP axes. The averages of repeated bootstrap samples (bootstrapped averages) for each fishing method were used to construct an mMDS ordination plot. Superimposed on the plot was a point representing the group average (i.e., the average of the bootstrapped averages) and the associated, smoothed, and marginally bias-corrected 95% bootstrap region, in which 95% of the bootstrapped averages fall.

Similarity Percentages (SIMPER [43]) and shade plots [50] were used to elucidate the species that were responsible for the differences in species compositions among fishing methods. SIMPER used the replicate level data and identified those species that typified the landings in one method and those that were responsible for distinguishing between each pair of methods. A shade plot, derived from the data averaged across replicates for each fishing method, was constructed and used to visualize trends in CPUE. This plot is a simple visualization of the frequency matrix, where a white space for a species demonstrates that it was not landed. At the same time, the depth of shading from grey to black is linearly proportional to the abundance of that species [50]. Note that as many of the species recorded made a very minor contribution, only those contributing at least 1% to the total CPUE in any single fishing method were included on the plots. Species (y-axis) and fishing methods (x-axis) were arranged in an optimal order, based on seriation.

In addition, differences in the total length of the four main species caught in the five main methods (*E. coioides*, *P. malabaricus*, *P. leopardus* and *L. malabaricus*) were investigated using non-parametric Kruskal–Wallis tests. When significant differences were found in lengths among methods, the Mann–Whitney U test was used to determine how lengths differed among the methods.

2.3.2. Seasonal Trends in Catch and Effort

A similar suite of multivariate techniques was then employed to investigate how catch composition for the three most-utilized fishing methods, i.e., bottom longlines, speargun, and hand lines, varied with depth and over time. The data from individual trips within each fishing and method combination were averaged to create a new suite of replicates, this time ensuring that the internal group structure was maintained, i.e., each group of replicates contained trips from the same depth category, season, and sometimes also year. Data for bottom longlines and hand lines were subjected to two-way PERMANOVA (depth category and season), and for spearguns, three-way PERMANOVA (depth category, season, and year). These factors were chosen to ensure there was sufficient data across all levels of the factors to ensure robust analyses. As described above for the fishing-method-only analyses, pairwise PERMANOVA and ANOSIM tests were also employed. Finally, the data were visualized using bootstrapped mMDS plots (significant main effects), centroid non-metric multidimensional scaling (centroid nMDS plots; significant interactions), and shade plots of the species that contributed at least 1% to the total CPUE in any depth category, season, and/or year combination. Centroid nMDS plots were constructed by outputting a distance among the centroid matrix for the significant interaction term, creating an average in the 'Bray–Curtis space' for each combination of main effects, which, in turn, was used to generate an nMDS ordination plot [47]. Interpretation of the shade plots was informed by SIMPER.

2.3.3. Factors Influencing the CPUE of the Four Main Species

Variation in the CPUE among seasons (year, month, and monsoon), fishing gears, trip hours, fishing depth, boat capacity, and fish price was examined for the four most targeted grouper and snapper species in Saleh Bay, i.e., the leopard coral grouper (*Plectropomus leopardus*), spotted coral grouper (*Plectropomus maculatus*), orange-spotted grouper (*Epinephelus coioides*), and the malabar blood snapper (*Lutjanus malabaricus*). Generalized Linear Models (GLM) and Generalized Additive Models (GAM) were fitted to the catch for targeted species as follows:

1. CPUE ~ Year + Month + Fishing Gear + Trip Hour + Depth + Gross Tonnage + Price . . . fitted with GLM.
2. CPUE ~ Year + Month + Fishing Gear + f (Trip Hour) + f (Depth) + f (Gross Tonnage) + f (Price) . . . fitted with GAM, where f is a smoothing function.

A zero-inflated Poisson (ZIP) model was used as the number of individual fish caught for each species in each fishing trip and contained a substantial number of zero values. Both GLM and GAM analyses were conducted in R software using the basic function and *mgcv* package [51], respectively, and the *pscl* package for the ZIP model [52]. Residuals and the Akaike information criterion (AICs) were used to determine the most parsimonious model (between GLM and GAM [53]) for explaining the variation in CPUE of each of the four species.

3. Results

3.1. Climatic Conditions

The monthly average windspeed between April 2016 and December 2019 in Sumbawa Besar ranged from 1.8 to 3.3 m·s^{-1} and the monthly rainfall from 0 to 435.7 mm (Figure 2a). The average monthly wind speed peaked in August at 2.98 m·s^{-1} (±0.19 SE) and was typically higher in the SE monsoon season (June–August) than at other times of the year (Figure 2b). The highest mean monthly rainfall in Sumbawa Besar occurred in January (355.07 mm ± 77.8 SE) in the NW monsoon, and the lowest rainfall occurred in August (0.93 mm ± 0.93 SE) (Figure 2b).

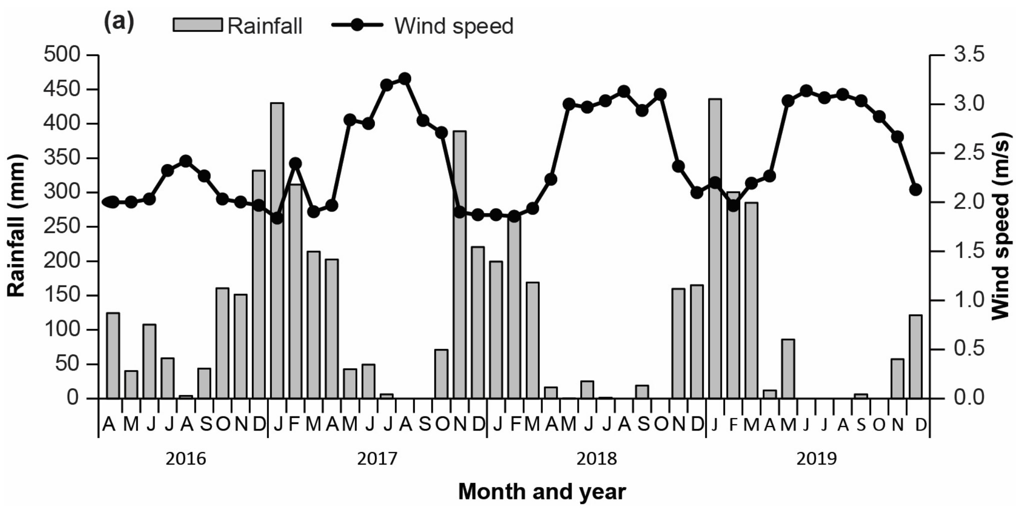

Figure 2. *Cont.*

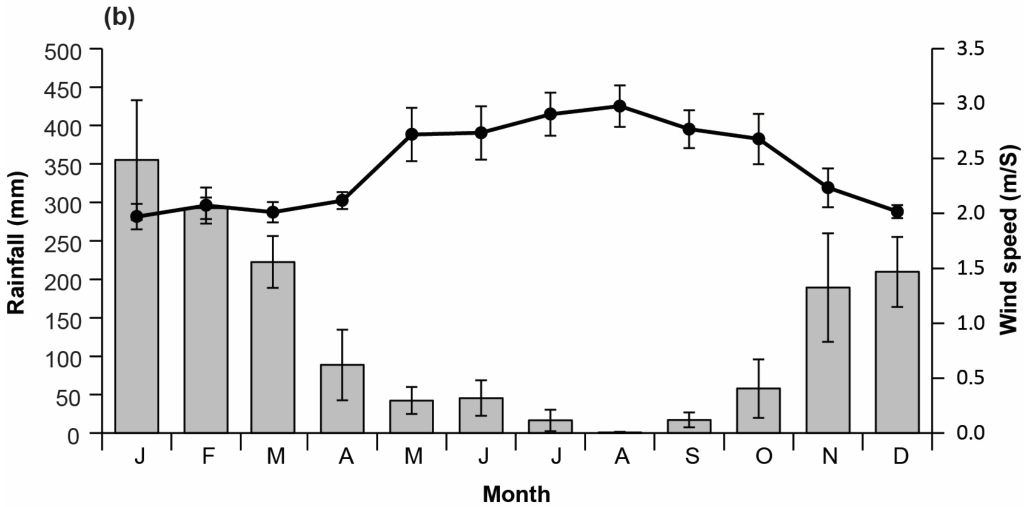

Figure 2. (**a**) Total monthly rainfall (grey bar) and average monthly windspeed (black line) in each month between April 2016 to December 2019 and (**b**) average (±SE) monthly rainfall (grey bar) and monthly windspeed (black line) in Sumbawa Besar, West Nusa Tenggara, Indonesia between January 2009 and December 2019. Data derived from https://dataonline.bmkg.go.id (accessed on 29–31 December 2021).

3.2. Characteristics of Fishing Operations in Saleh Bay

3.2.1. Fishing Boat and Gear Characteristics

A total of 4046 fishing trips were recorded during the FLM program from April 2016 to December 2019 in Saleh Bay (Table 2). Monitoring included fishing activities by small-scale fishers that targeted reef and demersal fish. Fishing boat sizes ranged from 1 to 9 GT with three engine categories: inboard, outboard, and non-motorized. The vast majority of trips (89.1% = 2931 trips) were completed using vessels with an onboard engine, with trips from vessels with outboard engines representing 10.9% (358) of trips and only two trips were conducted on non-motorized fishing boats. The engine power of the fishing vessels varied greatly, ranging from 5 to 66 HP (horsepower). The SSF boats in Saleh Bay originated from 10 fishing villages and landed the majority of their catches at four fish landing sites (Figure 1).

Table 2. Summary of the general characteristics of small-scale fishing fleets in Saleh Bay, West Nusa Tenggara from data collected by survey and interview between April 2016 and December 2019. Data were recorded for a total of 4046 fishing trips. Values are medians, with the range shown in parentheses.

Fishing Method	Boat Size (GT)	No. of Crew	Trip Duration (Hour)	Hook Size	Engine Power (HP)	Engine Category	No. of Trips	% Trips
Bottom longline	5 (2–9)	1 (1–6)	14 (4–63)	8 (4–13)	23 (5–48)	inboard & outboard	1771	43.8
Speargun	2 (1–5)	3 (1–7)	14 (5–89)	n/a	24 (5–30)	non-motorized, inboard & outboard	1261	31.2
Handline	2 (1–9)	2 (1–9)	15 (6–63)	8 (4–13)	24 (5–66)	inboard & outboard	478	11.8
Troll line	2	1	24 (10–72)	4 and 7	16 (5–24)	inboard & outboard	192	4.7
Drop line	2 (2–3)	1 (1–2)	10 (3–35)	9 and 10	24 (15–26)	inboard	179	4.4
Boat liftnet	5 (2–9)	6 (1–9)	27 (27–28)	n/a	30 (16–48)	inboard	108	2.7
Gill net	2 (1–7)	1 (1–3)	17 (5–28)	n/a	24 (13–48)	inboard	42	1.0
Trap	2 (1–3)	1 (1–2)	5 (3–29)	n/a	24 (6–24)	inboard	15	0.4
						Total	4046	

Fishers used eight fishing methods, including active methods, i.e., speargun and troll line, and passive methods, i.e., bottom longline, handline, dropline, liftnet, trap, and set gillnet. Among these, three fishing methods, namely bottom longline (43.8%), speargun (31.2%), and handline (11.8%) were used in 86.8% of fishing trips, while the other five fishing methods each contributed less than 5% to the total fishing trips. Fishing trip duration also greatly varied among all fishing gears, ranging from 3 to 89 h, with median values ranging from 5 (Trap) to 27 h (Boat liftnet) (Table 2). The median duration for the three main methods was 15 h.

3.2.2. Overall Catch Composition

A total of 75 species from 12 major families of reef and demersal fish were landed from the 4046 fishing trips over the four-year FLM. Among these species, 35 were epinephelids and 20 were lutjanids (Supplementary Material Table S1). The species from these two families represented 57.7% of the total catch by weight and 32% by number. Minor contributions were made by species in the Carangidae (0.3%), Lethrinidae (0.2%), and Sphyraenidae (0.2%). Fish species or families that were not identified in the FLM (categorized as others) contributed 41.4% by weight (66.2% by number) to the total catch (Table 3). These included species such as goatfish *Parupeneus barberinus* (Muliidae) or *Priacanthus* spp. (Priacanthidae) [54].

The highest proportion of the catch of epinephelids and lutjanids were taken in bottom longlines (92.8% by weight, 82.7% by number, Table 3). The other gears that caught a significant proportion of these families by weight were troll line (98.7%), dropline (93.4%), set gillnet (53.7%), and trap (100%). Although epinephelids and lutjanids were landed using boat liftnets, these data were omitted from further analysis, as this fishing method is primarily used to target anchovies and other bait fish [55,56].

The proportion of epinephelids and lutjanids varied among fishing methods. For example, speargun, drop line, and troll line caught a much higher proportion (>80%) of epinephelids than lutjanids (Figure 3). In contrast, handlines showed a more balanced proportion of epinephelids (54.2%) and lutjanids (45.8%), while gillnets caught a much greater proportion of lutjanids (78%) than epinephelids (Figure 3).

Table 3. Catch composition (by family) of each fishing gear in Saleh Bay, West Nusa Tenggara, Indonesia from April 2016 to December 2019. Catch is presented in weight (kg), number, and percentage. Families ranked by overall biomass. * Others are catches of other fish families that were not identified in the fish landing monitoring (e.g., Pomacentridae, Pomachantidae).

Family	Fishing Gear/Method									
	Bottom Longline	Speargun	Handline	Troll Line	Drop Line	Set Gillnet	Trap	Boat Liftnet	Total	
Catch by Weight (kg)									(kg)	%
Epinephelidae	4708.3	3144.6	700.4	587.6	415.5	29.9	35.8	56.4	9678.5	40.0
Lutjanidae	2848.3	87.4	592.7	111.1	40.5	106.1	-	488.9	4275.0	17.7
Carangidae	65.0	-	7.2	-	2.1	-	-	-	74.3	0.3
Lethrinidae	32.3	10.1	-	-	14.7	1.3	-	-	58.4	0.2
Sphyraenidae	-	38.0	-	-	-	-	-	-	38.0	0.2
Serranidae	-	14.7	-	-	-	-	-	-	14.7	0.1
Scaridae	1.3	9.0	1.6	-	-	-	-	-	11.9	0.0
Haemulidae	9.0	-	-	-	-	-	-	-	9.0	0.0
Caesionidae	-	6.8	-	-	-	-	-	-	6.8	0.0
Siganidae	-	4.3	-	-	-	-	-	-	4.3	0.0
Nemipteridae	1.9	-	-	-	-	-	-	-	1.9	0.0
Acanthuridae	-	1.1	-	-	-	-	-	-	1.1	0.0
Others *	473.3	6290.4	3123.0	9.3	15.2	116.0	-	-	10,027.2	41.4
Total weight (kg)	8139.4	9606.4	4424.9	708.0	488.0	253.3	35.8	545.3	24,201.1	
% all catch by weight	33.6	39.7	18.3	2.9	2.0	1.0	0.1	2.3		
% of grouper and snapper catch by weight	92.8	33.6	29.2	98.7	93.4	53.7	100.0	100.0		

Table 3. *Cont.*

Family	Fishing Gear/Method								Total	
	Bottom Longline	Speargun	Handline	Troll Line	Drop Line	Set Gillnet	Trap	Boat Liftnet		
Catch by Number									no	%
Epinephelidae	1906	2760	508	377	354	11	37	22	5975	23.9
Lutjanidae	1280	87	306	45	13	52	-	245	2028	8.1
Carangidae	14	-	6	-	1	-	-	-	21	0.1
Lethrinidae	43	24	-	-	6	5	-	-	78	0.3
Sphyraenidae	-	12	-	-	-	-	-	-	12	0.0
Serranidae	-	10	-	-	-	-	-	-	10	0.0
Scaridae	1	19	1	-	-	-	-	-	21	0.1
Haemulidae	3	-	-	-	-	-	-	-	3	0.0
Caesionidae	-	31	-	-	-	-	-	-	31	0.1
Siganidae	-	21	-	-	-	-	-	-	21	0.1
Nemipteridae	8	-	-	-	-	-	-	-	8	0.0
Acanthuridae	-	1	-	-	-	-	-	-	1	0.0
Others *	596	4367	11,811	5	2	26	-	-	16,807	67.2
Total number	3851	7332	12,632	427	376	94	37	267	25,016	
% all catch by number	15	29	50	2	2	0	0	1		
% of grouper and snapper catch by number	82.7	38.8	6.4	98.8	97.6	67.0	100.0	100.0		

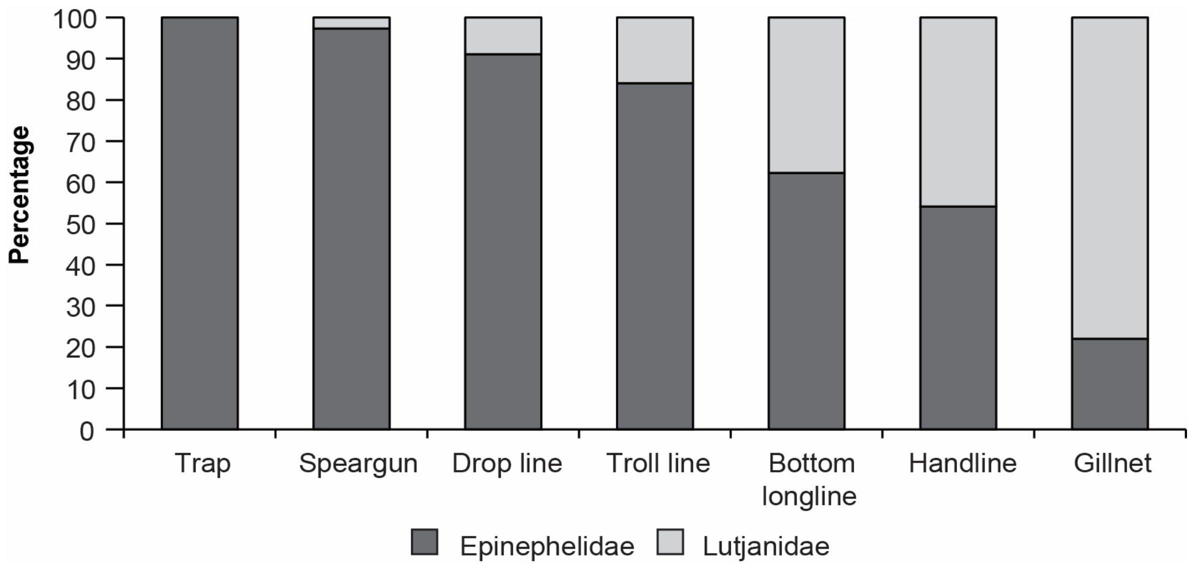

Figure 3. Percentage composition (based on weight) of epinephelids (grouper) and lutjanids (snapper) catches in different fishing methods from the fish landing monitoring program in Saleh Bay, West Nusa Tenggara, Indonesia.

3.3. Variation in Catches among Fishing Methods

One-way univariate PERMANOVA showed that the number of species differed significantly among the five main fishing methods (p = 0.001), and between all pairwise comparisons (all p = 0.001), except handline vs. drop line (p = 0.399). The greatest mean number of species landed was recorded from spearguns (1.95), followed by troll lines (1.65) and bottom longlines (1.48), and then for handlines and drop lines (~1.28; Figure 4a). Significant differences among methods were also detected for the mean of total CPUE (p = 0.001) and all CPUE pairwise comparisons were significant (p = 0.001–0.027), except handline vs. drop line (p = 0.350). The largest differences occurred between bottom longline (0.42 h^{-1}) and both speargun (0.21 h^{-1}) and troll line (0.18 h^{-1}), with intermediate values for drop line (0.29 h^{-1}) and handline (0.26 h^{-1}; Figure 4b). Values for Shannon diversity also differed among methods (p = 0.001) and between pairwise comparisons (all p = 0.001), except handline vs. drop line (p = 0.321). The pattern of diversity followed that of the number of species: mean diversity was greatest for spearguns (0.49), followed by troll lines (0.37) and bottom longlines (0.25) and lowest in drop and hand lines (0.17 and 0.15, respectively; Figure 4c).

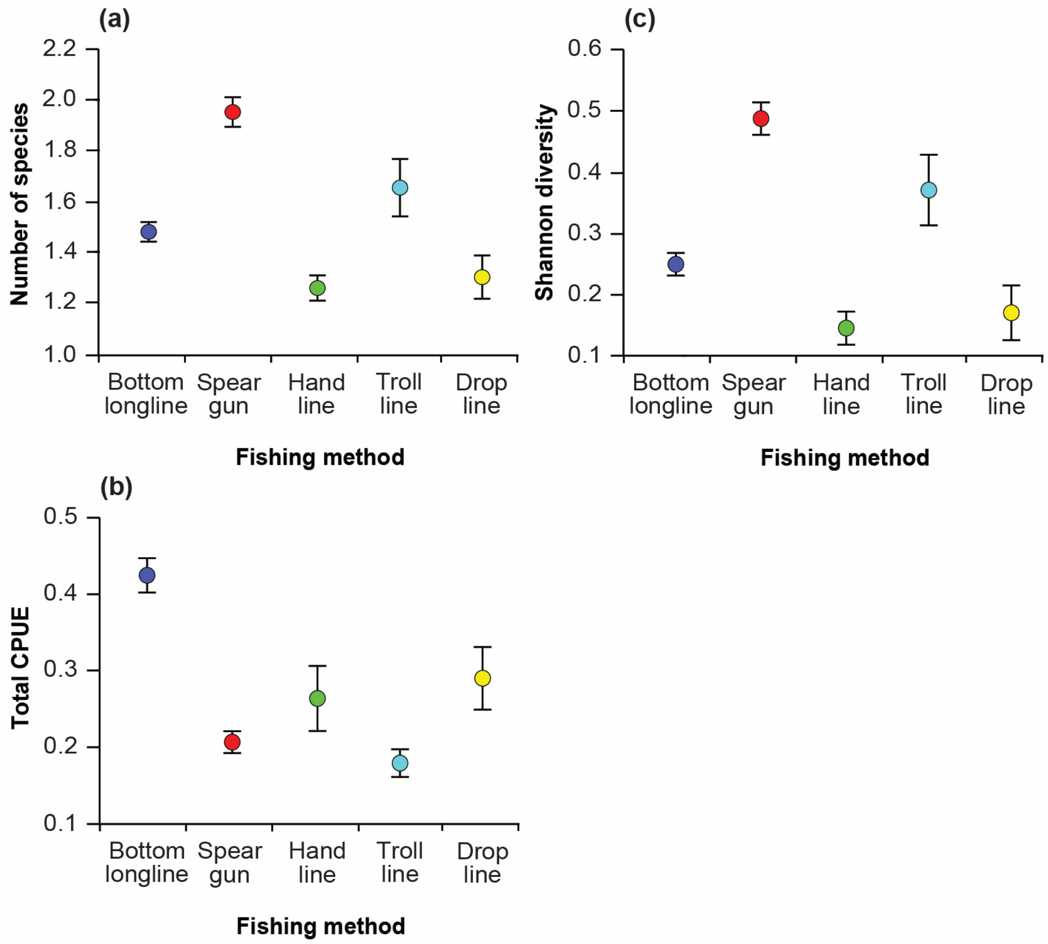

Figure 4. Mean (±95% confidence limits) for (**a**) number of species, (**b**) total catch per unit effort (h^{-1}), and (**c**) Shannon diversity of the five main fishing methods used in Saleh Bay, West Nusa Tenggara, Indonesia.

PERMANOVA found that the composition of the landings from the five main fishing methods differed significantly overall (p = 0.001) and between each pairwise comparison (p = 0.001; Figure 5). ANOSIM indicated that the extent of this difference was moderate (Global R = 0.638). Although 75 species were landed, 22 species contributed ≥1% of the total CPUE for a particular fishing method and the majority of the catch comprised four main species; *P. leopardus*, *P. maculatus*, *E. coioides*, and *L. malabaricus*, which, together with *E. fuscoguttatus* and *E. epistictus*, were as shown as vectors on the canonical analysis of principle coordinates analysis (CAP) plot (Figure 5a). Among the pairwise comparisons, the most distinct were between bottom longlines, located on the top left of the mMDS ordination plots, and drop line, speargun, and troll line on the right (t values = 12.12–14.77; Figure 5b). This was due to far larger CPUEs of *L. malabaricus* and *E. coioides* in the bottom longline and SIMPER identifying these species as typifying the catch from this method (Figures 5a and 6). The composition of landings from spearguns were the next most distinct (t values 8.05–9.62) due to relatively high catches of *E. fuscoguttatus* and catches of *P. leopardus* and *P. maculatus* that were greater than that in the bottom longlines but less than that in drop lines and troll lines. The CPUEs of the latter two species were greater in drop lines and troll lines than in handlines, with the reverse being true for *L. malabaricus* (Figures 5a and 6). Finally, drop lines and troll lines were the least different (t value = 5.63) with catches from both methods being dominated by *P*. *maculatus* and *P. leopardus*, but with the CPUE of *P*. *maculatus* being greater in drop lines and *P. leopardus* greater in troll lines.

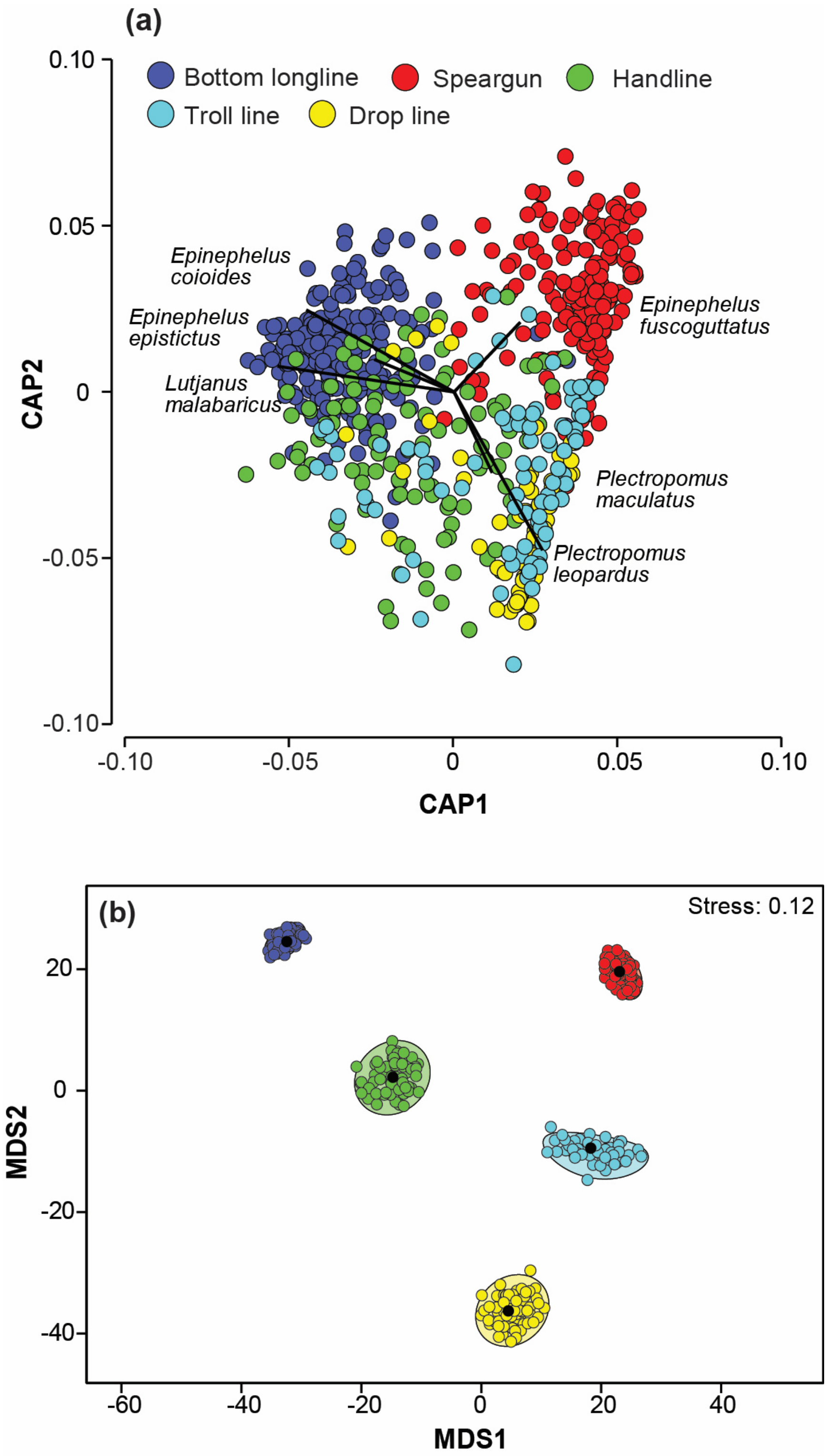

Figure 5. (**a**) Canonical analysis of principal coordinates plot illustrating differences in the catch

composition of the five main fishing methods used in Saleh Bay, West Nusa Tenggara, Indonesia. Vectors provided for species whose CPUE changes in a linear direction (Pearson correlation > 0.3) relative to the CAP axes. (**b**) Two-dimensional mMDS ordination plot constructed from bootstrap averages for fishing method calculated from a Bray–Curtis resemblance matrix of the CPUE of each fish species in each new replicate sample. Group averages (black symbols) and approximate 95% region estimates fitted to the bootstrap averages are provided.

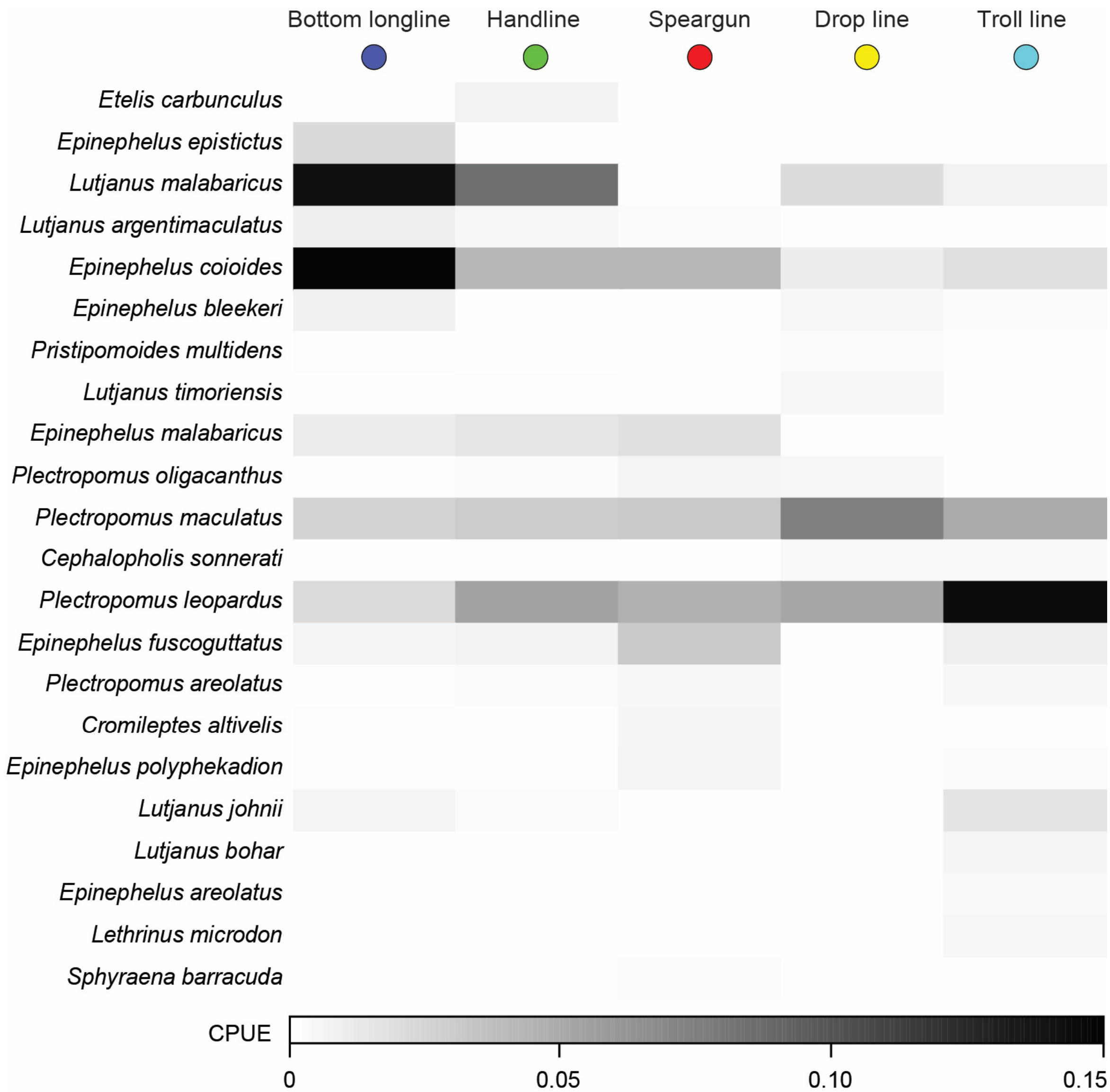

Figure 6. Shade plot of the mean catch per unit effort (no. h^{-1}) of species representing ≥1% of the total catch for a particular fishing method for each of the five main fishing gears in Saleh Bay, West Nusa Tenggara, Indonesia.

The non-parametric Kruskal–Wallis test demonstrated there were significant differences in the mean total length for each of the four main species (*E. coioides*, *P. maculatus*, *P. leopardus*, and *L. malabaricus*) among the five main fishing methods (p = 0.001; Figure 7). The mean lengths in speargun catches were typically shorter than in other methods for each of the species. The mean length of *E. coioides* was significantly smaller for spearguns (46.0 cm) than the mean lengths for other methods (53.3 cm in dropline to 60.4 cm in bottom longline; Figure 7a). Similarly, significant differences in the mean length of *P. maculatus* were observed among fishing methods, with the shortest fish being caught by spearguns (38.5 cm) and handline (41.1 cm) compared to the other methods (52.2 to 53.4 cm; Figure 7b). Significant differences in the mean length of catch are also evident for *P. leopardus* among fishing methods, with the shortest mean length for spearguns (38.2 cm) and the longest in troll lines (46.8 cm; Figure 7c). For *L. malabaricus*, the mean length of fish caught in spearguns was typically shorter (45 cm) than fish caught by other methods (52.2 to 55.8 cm; Figure 7d).

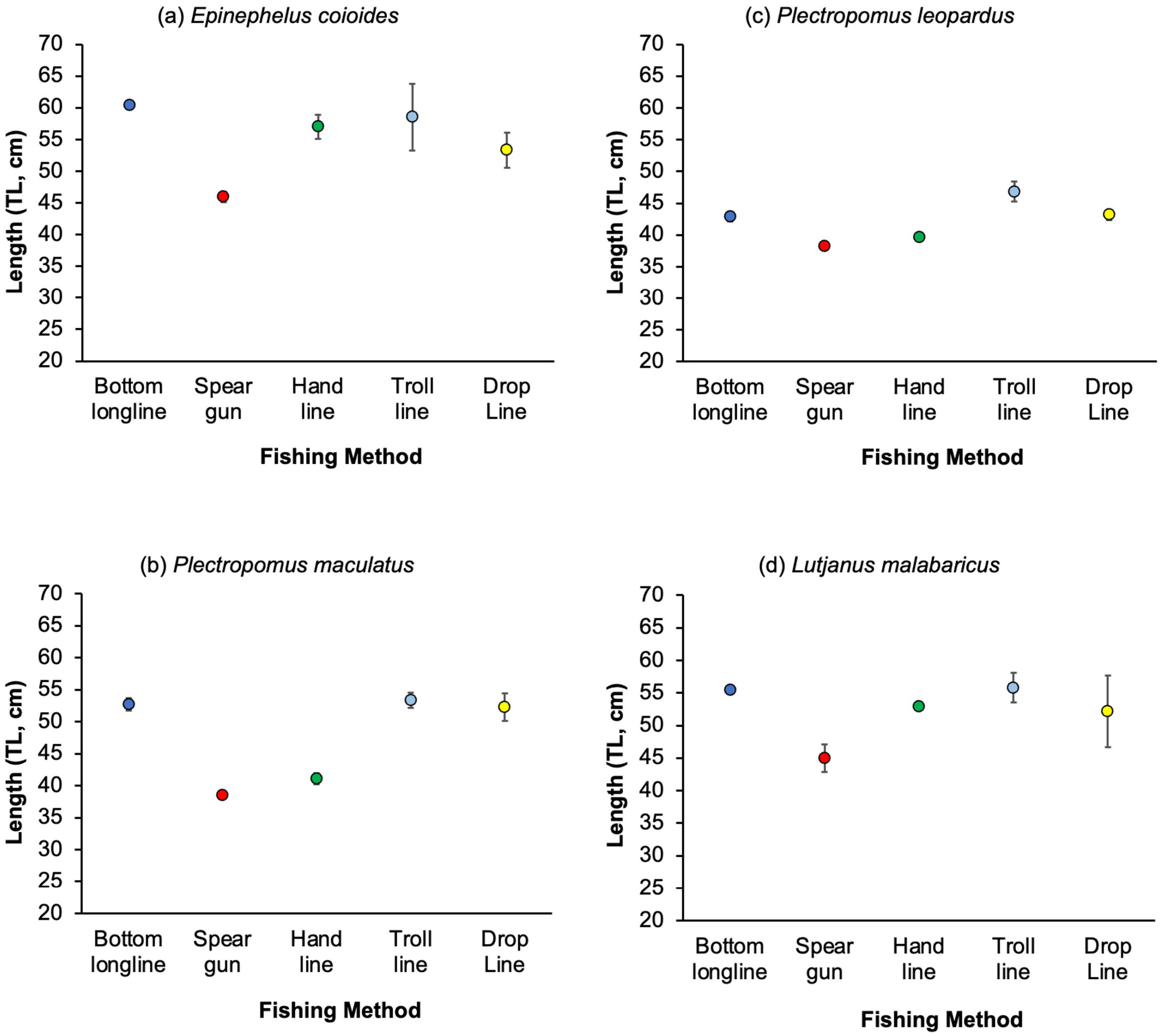

Figure 7. Mean total length (TL, in cm) of individuals (±95% confidence limits) of (**a**) *Epinephelus coioides*, (**b**) *Plectropomus maculatus*, (**c**) *Plectropomus leopardus*, and (**d**) *Lutjanus malabaricus* caught in each of the five main fishing methods used in Saleh Bay, West Nusa Tenggara, Indonesia.

3.4. Variation in Catch Composition among Depths, Seasons, and/or Years

3.4.1. Bottom Longline

The composition of fish landed from bottom longlines differed significantly with depth category (14–30 m, 31–40, and >40 m) and monsoonal season with the interaction between these factors also being significant (all $p = 0.001$). Depth was the most influential factor representing 59% of the total mean squares, followed by season with 22% and their interaction with 13%. Each of the pairwise comparisons between depths was significantly different (p = 0.001–0.017), with the points representing the bootstrapped averages for each depth category forming discrete groups on the left (14–30 m), in the center (31–40 m), and to the right (>40 m) of the mMDS ordination (Figure 8a). Two species, *E. coioides* and *L. malabaricus*, dominated the landings and were the typifying species in each depth category, but slightly more of the former species were landed from waters > 40 m deep and slightly fewer of the latter species were landed from waters between 31 and 40 m deep (Figure 9). Significantly different landings were recorded from the four monsoonal seasons with all pairwise comparisons being significant (p = 0.001–0.049) and forming discrete groups on the mMDS ordination (Figure 8b). Once again *E. coioides* and *L. malabaricus* were identified as typifying the landings in all seasons, and the differences in relative abundance being responsible for the differences together with species such as *P. maculatus* being most caught in the SE monsooon and *Epinephelus epistictus* in Transition I (Figure 9). The significant depth category $\times$ season interaction is a result of distinct seasonal variations that vary across different depths (Figure 8c), for example, *E. malabaricus* was mainly landed during the NW monsoon and Transition I but only from the deeper two depth categories (Figure 9).

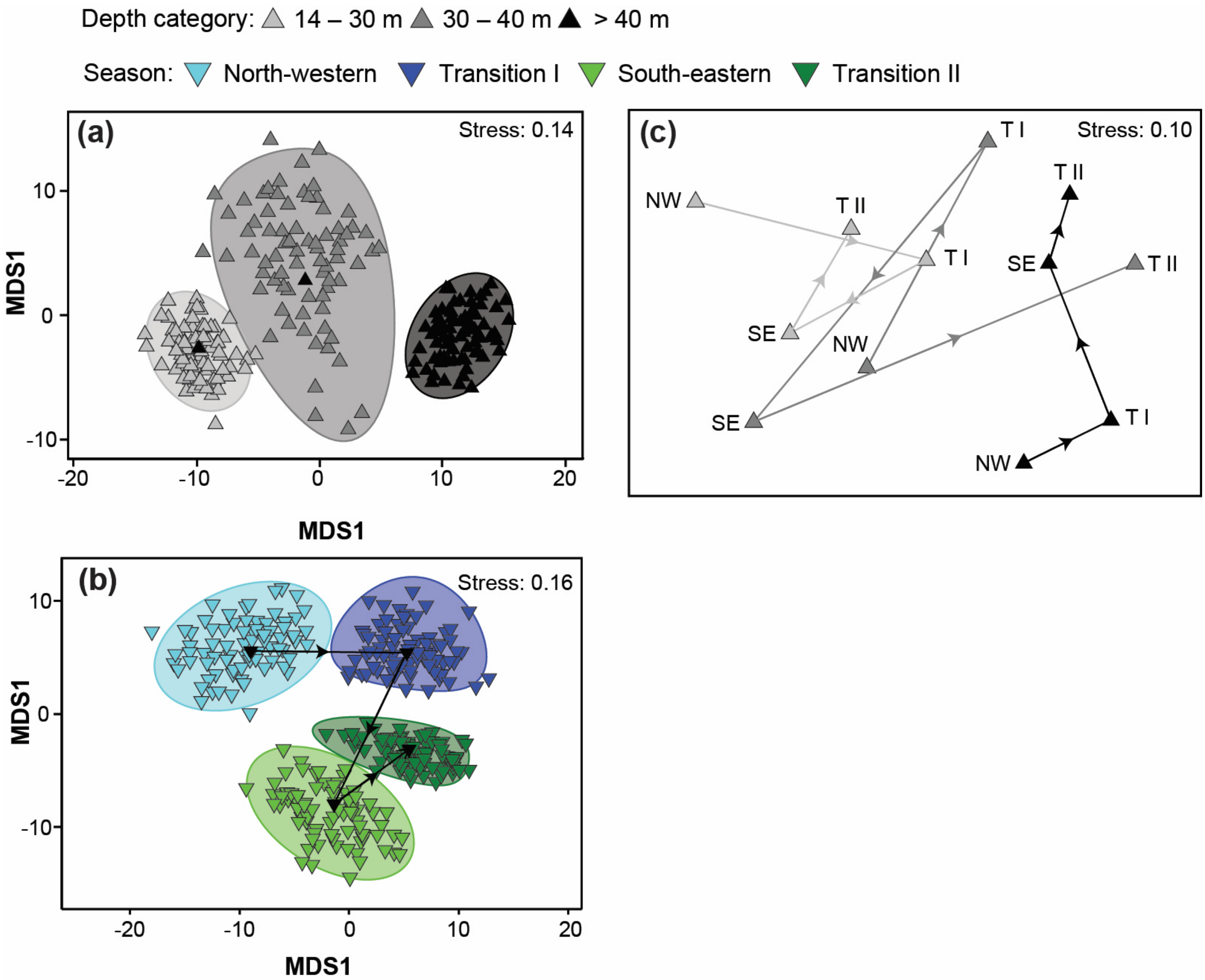

Figure 8. Two-dimensional mMDS ordination plots constructed from bootstrap averages for each (**a**) depth category and (**b**) monsoonal season calculated from a Bray–Curtis resemblance matrix of the CPUE of each fish species in each new replicate sample of bottom longlines. Group averages (black symbols) and approximate 95% region estimates fitted to the bootstrap averages are provided. (**c**) Centroid nMDS ordination plot derived from a distance among centroid matrix for each depth category and monsoonal season combination. Arrows denote direction of seasonal cycling.

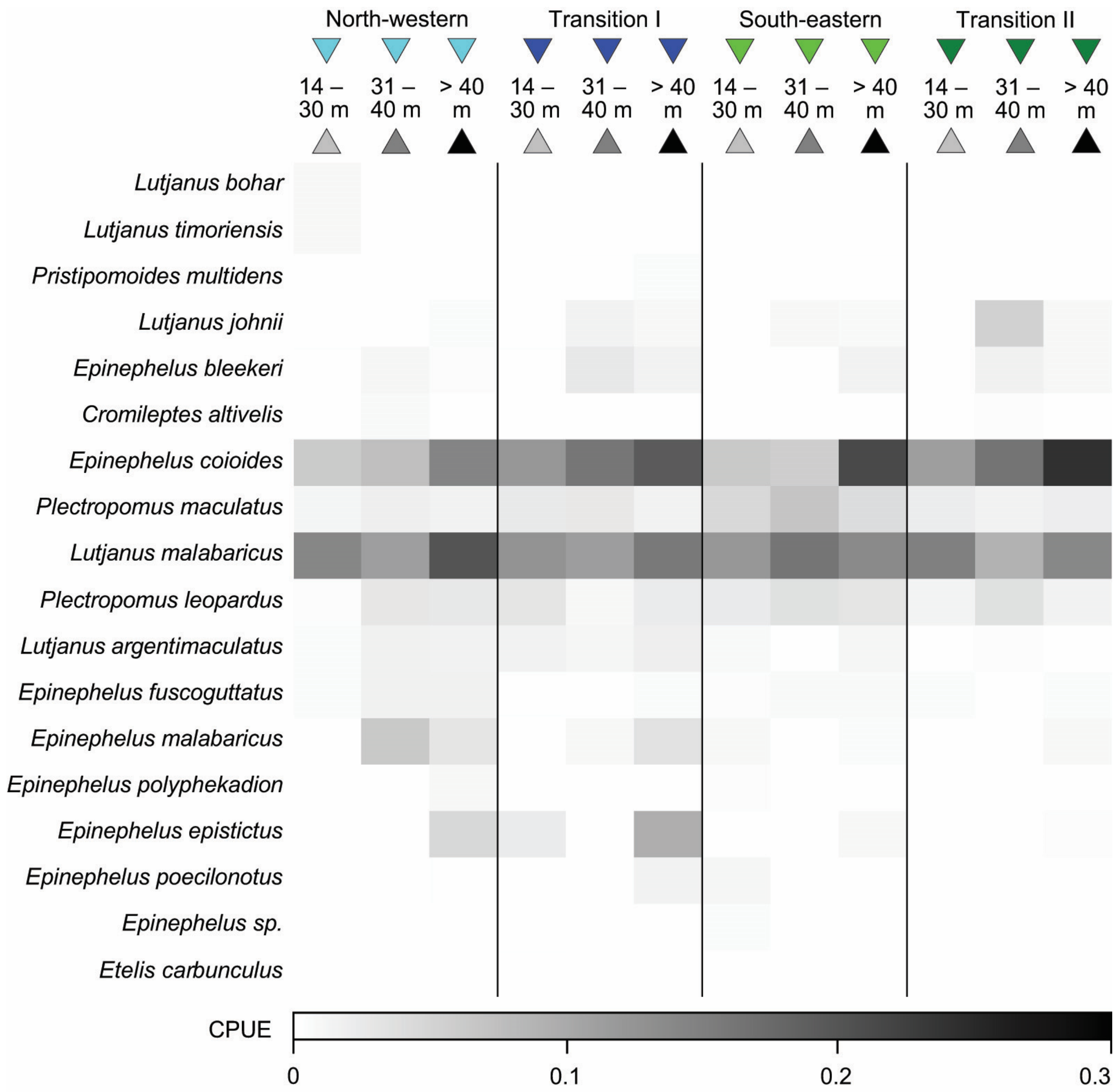

Figure 9. Shade plot of the mean catch per unit effort (no. h^{-1}) of species representing $\geq$1% of the total catch for bottom longline in each depth category and each monsoonal season in Saleh Bay, West Nusa Tenggara, Indonesia.

3.4.2. Speargun

Landings from speargun differed significantly among the two depth categories where sufficient data were available for analysis (<13 m and 13–30 m), year, season, and all three two-way interactions (p = 0.001–0.005), but not the three-way interaction (p = 0.087). Depth and year explained the greatest proportion of the total mean squares (30 and 22%, respectively), with all other factors each accounting for < 10% of the total mean squares. The bootstrapped averages of the two depth categories were widely separated on the ordination plot (Figure 10a). A wide range of species represented $\geq$ 1% of the landings with *P. maculatus*, *P. leopardus*, *E. fuscoguttatus*, *E. coioides*, and *E. malabaricus* being the most numerous and consistent (Figure 11). The first four of these species typified the landing from each depth category; however, shifts in their abundances were responsible for differences between depths. For example, greater CPUEs of *E. coioides* were landed from shallower waters and *P. leopardus* and *E. fuscoguttatus* from deeper waters.

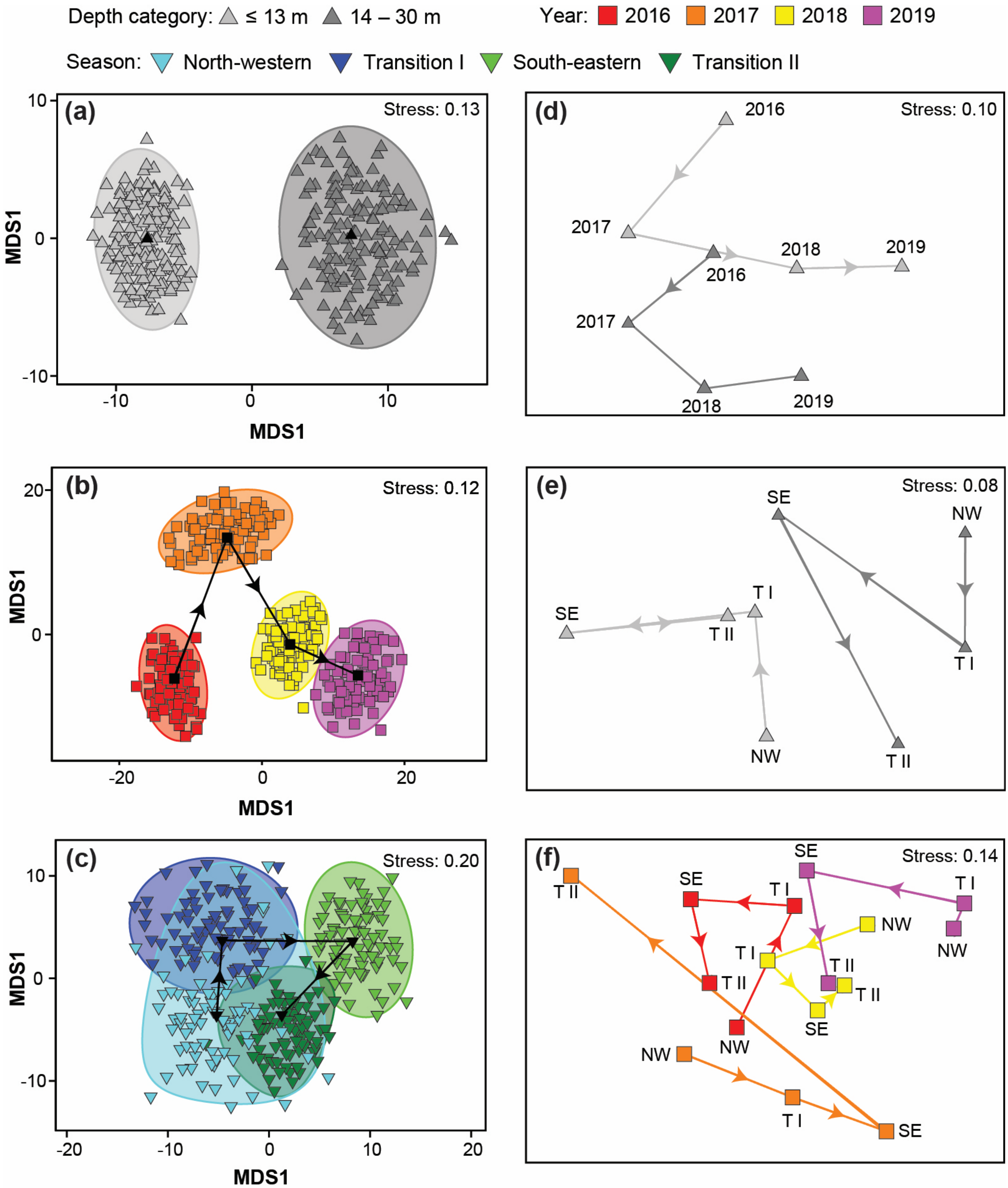

Figure 10. Two-dimensional mMDS ordination plots constructed from bootstrap averages for each (**a**) depth category, (**b**) year, and (**c**) monsoonal season calculated from a Bray–Curtis resemblance matrix of the CPUE of each fish species in each new replicate sample of spearguns. Group averages (black symbols) and approximate 95% region estimates fitted to the bootstrap averages are provided. Centroid nMDS ordination plots derived from a distance among centroid matrix for each (**d**) year and depth category, (**e**) monsoonal season and depth category, and (**f**) year and monsoonal season combination. Arrows denote direction of seasonal cycling.

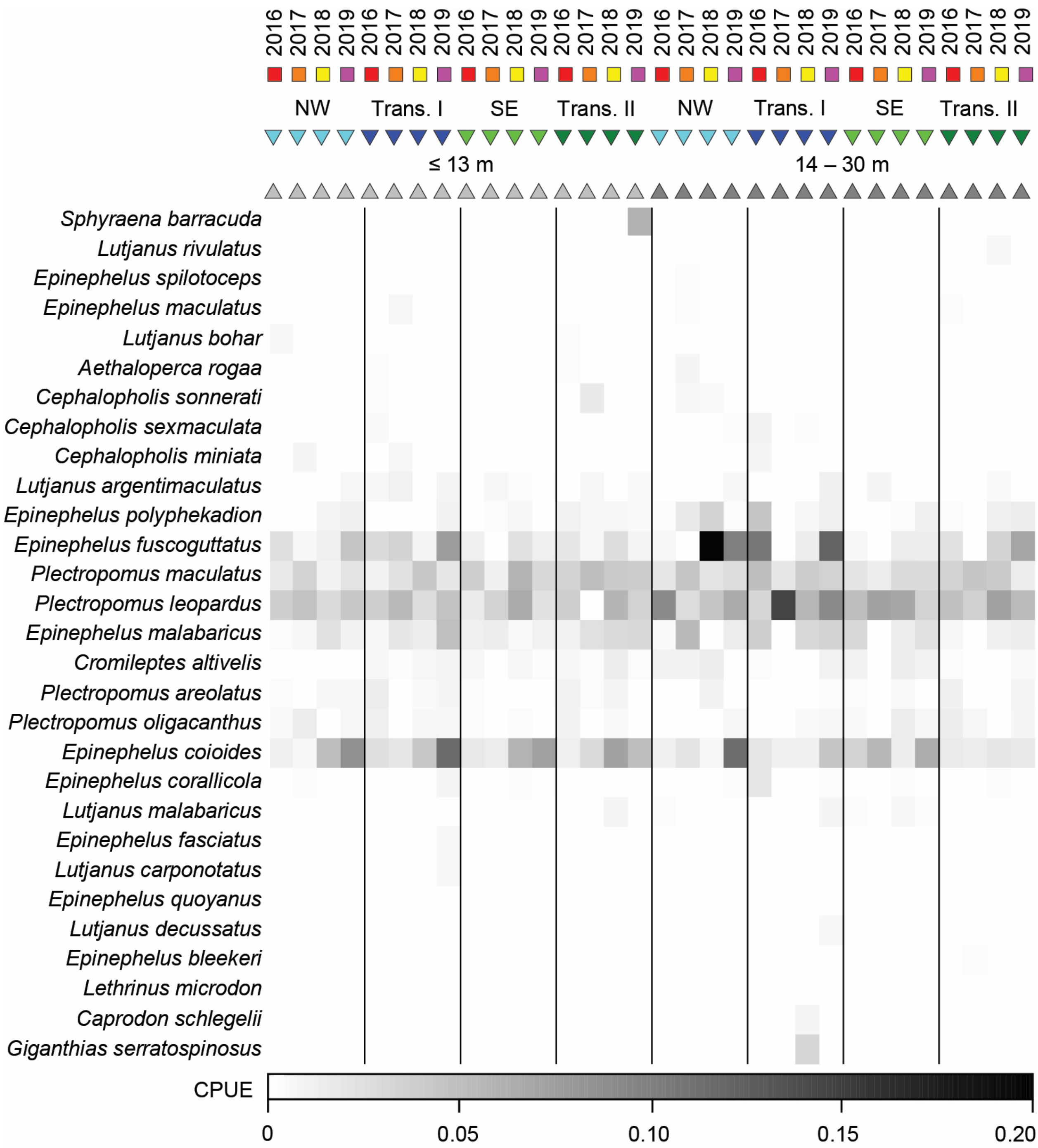

Figure 11. Shade plot of the mean catch per unit effort (no. h^{-1}) of species representing $\geq$1% of the total catch for spearguns in each depth category, monsoonal season and year in Saleh Bay, West Nusa Tenggara, Indonesia.

Each of the pairwise comparisons of species composition for year differed significantly (p = 0.001–0.01) and each year formed a distinct group on the mMDS plot (Figure 10b). In contrast, the only significant pairwise comparisons between season were those involving the SE monsoon (p = 0.012–0.014 vs. 0.078–0.0359). This is illustrated on the mMDS plot where the bootstrapped averages representing the NW monsoon overlap with those of Transitions I and II (Figure 10c). Landings from spearguns in all years and seasons were typified by *P. leopardus*, *P. maculatus*, and *E. coioides*, with differences largely due to minor differences in the CPUEs (Figure 11).

3.4.3. Handline

Handline landings differed significantly among seasons (p = 0.001; 37% mean squares) and the interaction between depth and season was significant (p = 0.005; 32% mean squares), but landings did not differ significantly between depths (p = 0.467; 14.4% mean square). Only three of the six pairwise comparisons between seasons were significant, i.e., NW vs. SE and Transition I and Transition I vs. Transition II (Figure 12). The interaction was caused by inconsistent seasonal differences among the two depths. The composition of handline landings in the SE monsoon differed significantly from all other seasons in the shallower waters, but in the deeper waters, only pairwise comparisons involving the NW monsoon were significant. A small suite of species dominated the handline landings, i.e., *E. coiodes*, *P. maculatus*, *P. leopardus*, and *L. malabaricus* and the distinctness of the SE and NW monsoons in the two waters depths, respectively, was due to lower landings during these seasons (Figure 13).

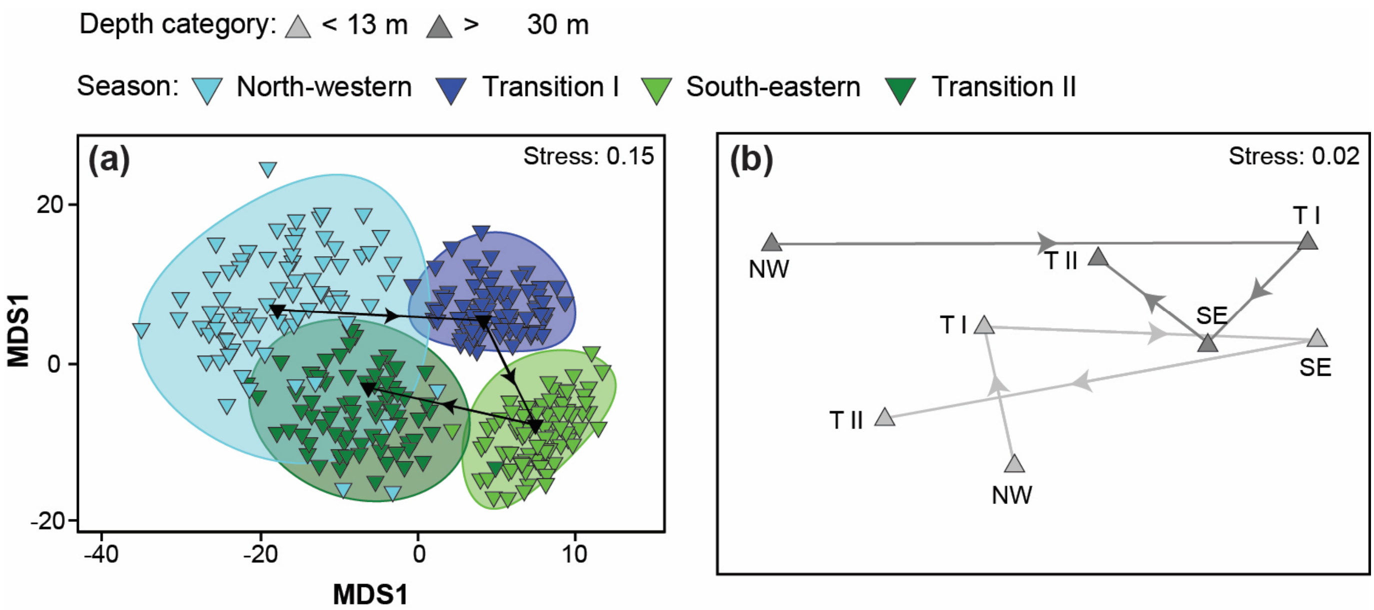

Figure 12. (**a**) Two-dimensional mMDS ordination plot constructed from bootstrap averages for each monsoonal season calculated from a Bray–Curtis resemblance matrix of the CPUE of each fish species in each new replicate sample of handlines. Group averages (black symbols) and approximate 95% region estimates fitted to the bootstrap averages are provided. (**b**) Centroid nMDS ordination plot derived from a distance among centroid matrix for each monsoonal season and depth category combination. Arrows denote direction of seasonal cycling.

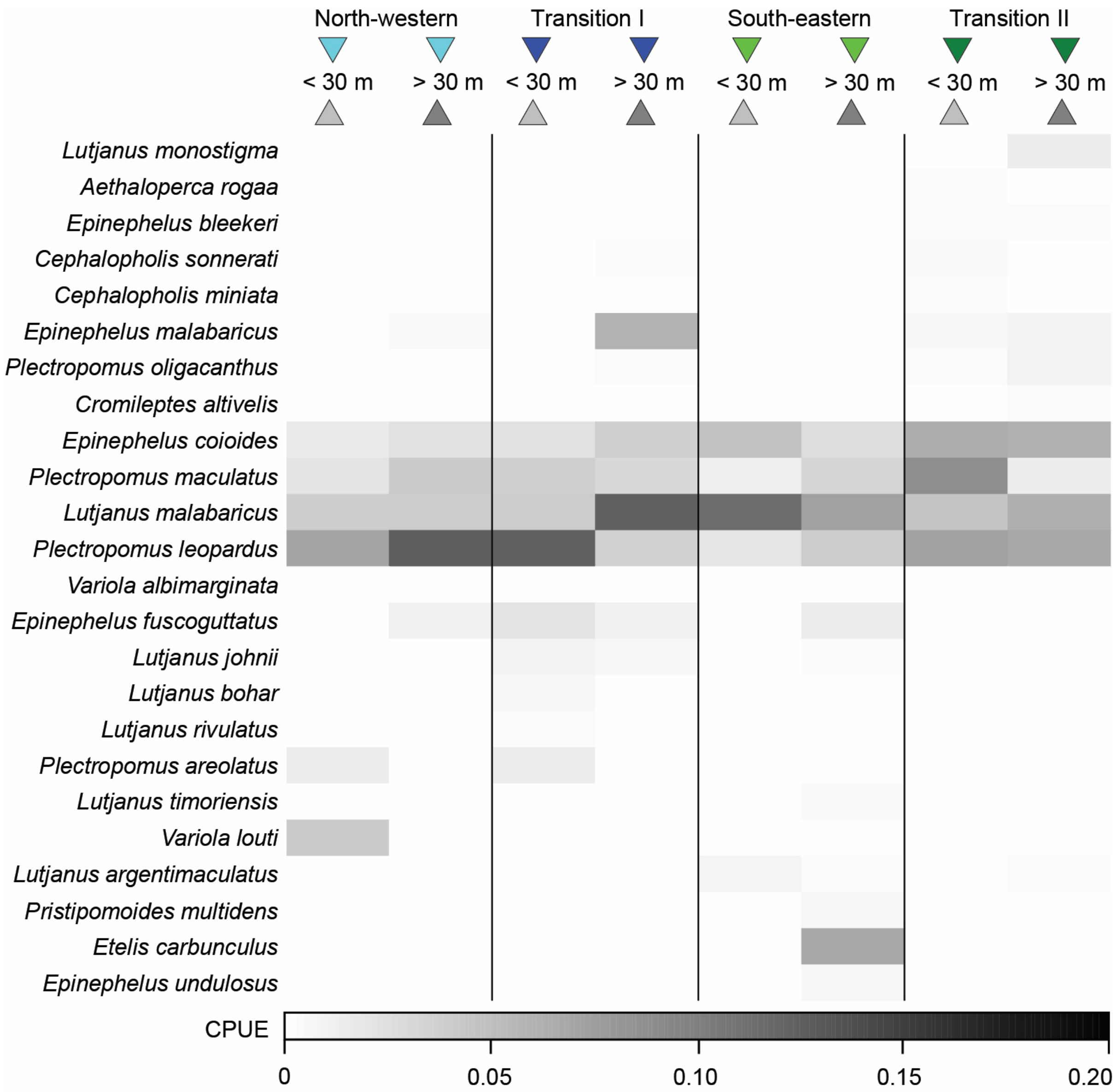

Figure 13. Shade plot of the mean catch per unit effort (no. h^{-1}) of species representing $\geq$1% of the total catch for handlines in the two depth categories and in each of four monsoonal in Saleh Bay, West Nusa Tenggara, Indonesia.

3.5. Factors Influencing the CPUE of the Four Main Species

The results of model testing using both GLM and GAM indicate that the GAM provides a better model fit. This is evidenced by the smaller Akaike Information Criterion (AIC) values (Supplementary Material Table S2). GAM analysis indicated that there was a relationship between the CPUE of *P. leopardus* with year (p = 0.0028–0.0001), trip hour (p = 0.0012), and price (p < 0.0001). GAM analysis showed a significantly higher CPUE of *P. leopardus* in 2016 than in 2018–2019 and showed a significantly higher CPUE in spearguns than other methods (p = 0.001). Other factors, such as month, fishing depth, and boat capacity, did not have a significant relationship with *P. leopardus* CPUE in the GAM analysis (Supplementary Material Table S2).

For *P. maculatus*, fishing methods were significant in the GAM analysis, with lower CPUEs in the bottom longline and handline than other methods (p = 0.0001–0.0063). The trip hour also showed a significant relationship with the CPUE of *P. maculatus* (p = 0.0136). The year was significant in *E. coioides* (p = 0.0202–0.0329) with higher CPUE in 2016. CPUE of *E. coioides* also showed a relationship with trip hour ($p = 0.0467$). For *L. malabaricus*, GAM analysis showed a significantly lower CPUE in 2016 ($p < 0.0001$) than in 2017–2019. In addition, price showed a significant relationship ($p < 0.0001$) with the CPUE of *L. malabaricus*, where CPUE was higher at higher prices.

4. Discussion

Our analysis of the landings over four years in Saleh Bay (2016–2019) found a total of 75 species caught by eight fishing methods. The high variation in the technical characteristics of fishing fleets (e.g., fishing gear, vessel size, and engine type) and fishing effort allocation (e.g., number of crew, trip duration) clearly demonstrates the complex and diverse nature of the fisheries in Saleh Bay. Although eight fishing methods were recorded, almost 90% of the fishing trip data came from only three methods: bottom longline, speargun, and handline.

Of the 12 fish families identified as the target catch of these fisheries, almost 60% of the total catch (in weight) was epinephelids (grouper) and lutjanids (snapper). While the FLM focused on fisheries that target reef fish and nearshore demersal species, many other species are caught by fishers in Saleh Bay, such as pelagic fish (e.g., *Euthynnus* spp., *Katsuwonus* spp., *Decapterus* spp.), sea cucumbers (*Holothuria* spp.), and jellyfish (see [57–59]), which are beyond the scope of the FLM. This suggests even more complex fisheries in the area. Furthermore, our focus on five fishing methods (bottom longline, speargun, handline, troll line, and drop line) identified that the grouper and snapper catch was dominated by four species, i.e., *Plectropomus leopardus* (leopard coral grouper), *Plectropomus maculatus* (spotted coral grouper), *Epinephelus coioides* (orange-spotted-grouper), and *Lutjanus malabaricus* (malabar blood snapper).

In addition to the technical variation among fishing methods and the species they catch, the complexity of these fisheries was further explored with multivariate analyses to investigate the significance of depth, season, and/or year in influencing the catch composition (by CPUE). Further analysis of the individual CPUEs for the four main species using the general additive model (GAM) and the general linear model (GLM) showed that GAMs provided a better fit to the data and that factors such as fishing gear, price, and fishing ground influenced CPUE, although this influence varied among the four species. These further analyses explored particular patterns within the complexity of the grouper fisheries in Saleh Bay (see Section 4.4 below).

4.1. Fishing Fleet Characteristics

The technical characteristics of the fishing fleets operating in Saleh Bay targeting grouper and snapper vary widely. The size of the vessels used is below 10 gross tonnes (GT), with a range between 1 and 9 GT or with a median between 2 and 5 GT. Furthermore, other fishing fleet characteristics, such as the number of crew, fishing duration, and engine capacity, also vary greatly. This significant variation was observed even within the same type of fishing method. For example, speargun fishers employ three different types of vessels equipped with non-motorized, outboard, and inboard engines and engage in fishing activities individually or in groups, with crews comprising up to seven members.

The substantial variability in fishing fleet technical characteristics in Saleh Bay is a typical feature of a small-scale fishery (SSF) according to the FAO definition [14]. This complexity contributes to the significant challenges in managing SSF. For example, standardizing fishing efforts and allocating a selectivity curve for assessing fish stocks exploited by SSF is equally complex [60]. Moreover, ensuring compliance with regulations like the total allowable catch, reducing fishing effort, or gear restrictions is exceptionally challenging in Saleh Bay [40]. The management authority for SSF needs to understand the dynamics and characteristics of the fishery to be managed, such as the overall number and characteristics of the operating fishing fleets and their catches, in formulating policy and making management decisions [40].

4.2. Variation of Catches among Fishing Methods

The catch composition of epinephelids and lutjanids varied among the five main fishing methods employed by fishers in Saleh Bay, indicating a degree of selectivity of fishing methods. For instance, troll and drop lines tended to catch more epinephelids than lutjanids. Determining the underlying cause of this pattern is, nevertheless, challenging. Fishing methods categorized as 'hook and line fishing' (including handline, troll line, drop line, and bottom longline) use baits for fishing, including fresh bait such as threadfin bream (*Nemipterus* spp.), quaker fish (*Malacanthus* spp.), and mackerel scad (*Decapterus* spp.), and artificial lures [61]. In addition to using fresh bait, troll lines in Saleh Bay also employ artificial lures (made of plastic that resembles a fish), which accounts for a very high proportion of epinephelid catches. It is not known whether epinephelids and lutjanids exhibit preferences for particular bait and lure.

Further analysis of the five main fishing methods (bottom longline, speargun, handline, drop line, and troll line) revealed that bottom longlines yielded the highest CPUE. This is likely due to the nature of bottom longlines, which can deploy 100–250 hooks in a single setting [61]. This number is much greater than the single line and hook used in handlines or troll lines. Spearguns typically had one of the lowest CPUEs among the fishing methods due to the nature of speargun fishing—fishers actively chase fish while freediving and so fish in shallower depths than other fishing methods (i.e., bottom longline and handline).

Although spearguns had the lowest CPUE, they had the highest diversity, while the lowest diversity was in bottom longlines. This suggests that speargun fishers have a level of opportunism in selecting their catch and that bottom longlines are more selective in the species they catch. These differences are primarily attributed to the distinct methods and characteristics of the gear used. Bottom longlines are typically set on the seabed at uniform depths and employ the same bait, resulting in relatively uniform catches. On the other hand, speargun fishing occurs at varying depths, can target a more complex habitat (e.g., coral reef), and is more opportunistic, depending on the species fishers encounter, leading to a more diverse catch.

Furthermore, the PERMANOVA analyses of the species composition among the five fishing methods identified significant differences ($p = 0.001$), with the largest differences between the bottom longlines and spearguns, with some overlap between the other methods, indicating that all five fishing methods catch some common species. This can be attributed to at least two factors, the overlap in fishing grounds for the different methods (as indicated by [61]) and the use of the same type of bait and lure in bottom longline, handline, and troll line. Competition among fishing methods, as evidenced by the overlap in species composition across these methods, is a common characteristic in small-scale, multi-gear, and multi-species fisheries. For example, a study of the catch composition of four fishing gears (cast net, beach seine, gillnet, and longline) in the Bonny River, Nigeria, showed competition over some dominant species in the family Mugilidae (mullet) [62]. In addition, the study by Humphries et al. [63] in West Lombok, Indonesia also showed that handlines and spearguns competed in targeting some key reef fish species such as the siganids *Acanthurus mata* and *Naso caeruleacauda* and the scarid *Scarus goban*.

4.3. Fishing Tactics

Despite the diverse features of fishing fleets and the species they target, we can still identify a consistent pattern in how fishers in Saleh Bay allocate their effort. Even though the catch varies greatly and species composition differs significantly among fishing methods, further analyses revealed that at least five major fishing methods consistently caught four main species: *P. leopardus*, *P. maculatus*, *E. coioides*, and *L. malabaricus*. This also confirms that the four species are the main target of grouper-snapper fishers in Saleh Bay.

The presence of competition among fishing methods in capturing the four primary species suggests a specific fishing tactic employed by grouper-snapper fishers in Saleh Bay. The above-mentioned four main targeted species are well known for their high value, especially in the export market [64]. The main export markets from Indonesia for groupers are Hong Kong and the Taiwan region [64] and the for red snapper are the USA, the Taiwan region, Singapore, and Australia, especially from WNT Province through Bali [65]. This suggests the fishers in Saleh Bay employ a specialized fishing tactic by targeting high-value species to maximize their revenue. GAM analyses suggest a relationship between the CPUE of *P. leopardus* and *L. malabaricus* with prices, which may be a profit-maximizing tactic of fishers. We suspect that the three primary fishing methods have significant roles in determining the pattern of CPUE for the two species since they are responsible for the high catch rate of these two species as identified from the multivariate analyses. When selling prices are high, they appear to target *P. leopardus* and *L. malabaricus* by adjusting their fishing efforts, such as allocating them to specific fishing grounds or depths.

This adaptive strategy aligns with practices in other small-scale fisheries, e.g., lobster, octopus, snapper, and grouper fisheries in San Felipe, Yucatan, Mexico. In these fisheries, fishers adjust their fishing operation over time in response to various factors, such as resource availability, species prices, and regulatory management [66]. The adaptation strategies in small-scale fisheries, particularly for grouper and snapper, can be attributed to the continuous expansion of global exports from tropical countries. This growth has led to increased demand for a broader variety of species, sizes, and age groups sourced from both small-scale and industrial fisheries, which led to a growing number of species being overfished [67,68].

4.4. Variation in Catch Composition among Depths, Season, and/or Years

The species composition of catches in the three main fishing methods (bottom longline, speargun, and handline) showed significant variations across different monsoonal seasons and/or years. There were also significant differences in catch composition at various depths, except for handlines. Additionally, the interaction between depth and season contributed to the variation in catch composition. Each fishing method exhibited a distinct set of dominant species in their catch composition. For example, bottom longline catches were characterized by *E. coioides* and *L. malabaricus*, while speargun catches had a wider variety of species, but with a notably smaller proportion of *L. malabaricus* than bottom longlines and handlines.

Catch composition is largely influenced by the abundance and distribution of the targeted fish, which fluctuate in response to environmental conditions. These conditions are affected by the seasonal changes in monsoonal rainfall and wind direction, and the varying habitat characteristics at different depths (e.g., [69–72]). In addition, seasonal migrations also occur in fish, such as migrating from nursery areas to deeper water areas or for spawning purposes [73]. For example, a study in the Great Barrier Reef revealed a seasonal vertical and horizontal migration pattern in *P. leopardus* [74]. This behavior is influenced by variations in water temperature, where fish move to deeper waters during the daytime in summer, and aligns with their spawning season. During the spawning season, they exhibit localized movements within the reef areas that offer ample access to food, shelter, and potential mates [74].

Fishing effort allocation is also influenced by weather conditions (e.g., wind and precipitation) caused by the monsoonal season. Hence, to maintain their revenue, fishers must adapt to this seasonal condition by adjusting their fishing effort, such as altering fishing grounds or targeting other abundant species in a particular season [66]. In addition, changing fishing gear and the target species to adjust to the seasonal pattern of fish distribution is also a common practice in Indonesia. For instance, a study in East Java [75], Indonesia, revealed a shift in fishing gear usage by small-scale fishers where they transitioned from gillnets and traps, targeting demersal fish such as grouper, snapper, and golden threadfin bream, to fishing gear designed to catch small pelagic species like purse seines. This adaptation was driven by changes in the abundance of target fish influenced by seasonal and climatic factors. In a study of lobster fishers in southern Java, fishers transitioned to using alternative fishing gear, such as traps, gillnets, and longlines, to catch various fish species, including snapper, silver pomfret (*Pampus argenteus*), and sharks during the off-season for lobsters [76]. Supply chain, market demand (e.g., export market for high-value species), and trader–fisher relationships may influence catch and fishing effort allocation (e.g., [77]). However, it was beyond the scope of the current study to investigate these factors.

The four primary target species for snapper-grouper fishers in Saleh Bay are caught year-round using three main fishing methods. The catch rates of *P. maculatus* remained relatively consistent throughout the year and did not display a discernible seasonal pattern. In contrast, *P. leopardus*, *E. coioides*, and *L. malabaricus* exhibit specific seasonal patterns. For example, the peak catch rate of *P. leopardus* is observed from December to May (during the NW monsoon and Transition I), while catches of *L. malabaricus* were highest from December to February (during the NW season) and then again from June to August (during the SE monsoon). The relatively lower average windspeeds from December to May make very favorable conditions for fishing and are thought to influence this pattern. Efendi et al. [78] suggests that the main fishing season for grouper in Saleh Bay peaks in April, similar to our findings. Similarly, the monthly grouper export volume from Indonesia also peaks in April [64], suggesting a similar pattern of grouper catch and fishing effort in other places in Indonesia. Furthermore, a study by Mustaruddin and Astarini [79] in Bangka Island, Indonesia, found that the highest grouper catches also occurred from April to September. Seasonal patterns in grouper and snapper fishing are also reported from other countries. For example, Mavruk et al. [80] reported that fishing pressure from grouper fisheries is significantly higher from March to May and September to November in the north-eastern Mediterranean. In addition, the harvest rate of red snapper (*Lutjanus campechanus*) by anglers in the Gulf of Mexico peaks in May, June, and October [81].

4.5. Managing Complexity in Saleh Bay

The fish landing monitoring program in Saleh Bay has been run and financially supported by non-government institutions and other parties since 2016, enabling it to be carried out continuously for more than five years. Since limited budget and human resources are common issues in local governments, it is necessary to assist the WNT provincial government by designing a cost and time-effective catch monitoring and evaluation program. In addition to the other management measures suggested by the management strategy evaluation of fisheries in Saleh Bay [40], the findings from the current study can be used to design the grouper and snapper fisheries catch monitoring and evaluation program in Saleh Bay.

The complexity of the fisheries and the diversity of target species in Saleh Bay makes monitoring and data recording challenging. However, the results from this study suggest that monitoring and enforcement can still be optimized by focusing on three fishing methods (bottom longline, speargun, and handline) during peak fishing months of the four main species (*P. leopardus*, *P. maculatus*, *E. coioides*, and *L. malabaricus*). These species are also part of a group of twelve grouper-snapper species subject to annual monitoring since 2018 to assess the impact of the fisheries action plan in Saleh Bay [11]. The monitoring results have revealed that three of the four species (*P. leopardus*, *E. coioides*, and *L. malabarcius*) are overfished, as indicated by the low spawning potential ratio (SPR) values (SPR < 0.3) and the ratio of fishing mortality to natural mortality (*F/M*) higher than 1 [11]. This study suggests that catch monitoring for spearguns can be prioritized from December to May, as these months yield higher catches of *E. coioides* and *P. leopardus*. Likewise, for handlines, prioritized monitoring is recommended from December to August, aligning with the peak fishing season for *P. leopardus* and *L. malabaricus*. Meanwhile, continuous monitoring for bottom longline is necessary throughout the year to track the catch of *E. coioides* and *L. malabaricus* (Table 4).

Table 4. Recommended priority months and monsoonal seasons (grey shade) for monitoring the catches of the three main fishing methods in Saleh Bay.

Methods	Seasons											
	NW			Trans. I			SE			Trans. II		
	Months											
	D	J	F	M	A	M	J	J	A	S	O	N
Bottom longline												
E coioides				■	■	■				■	■	■
L. malabaricus	■	■	■				■	■	■			
Speargun												
E coioides	■	■	■	■	■	■						
P. leopardus				■	■	■						
L. malabaricus	■	■	■	■	■	■						
Handline												
P. leopardus	■	■	■									
L. malabaricus				■	■	■	■	■	■			

Multivariate analyses revealed that spearguns yielded a substantial catch of *E. fuscoguttatus*. This is noteworthy, as this species is very depleted in Saleh Bay, as evidenced by very low SPR (0.06 in 2019) and very high fishing mortality with F/M = 2.20, which is far below its biological target reference point of 0.3 (i.e., it is severely depleted and overfished) [11]. The peak fishing season for *E. fuscoguttatus* with spearguns is from December to May, which may also be a priority time for monitoring spearguns catches (Table 4). Furthermore, the GAM analyses show that the CPUE of *P. leopardus* is significantly influenced by method, with greater CPUE obtained using spearguns. In addition, the average sizes of fish caught by spearguns were generally smaller than those from the other main methods, which can lead to negative consequences for the reproductive ability of the targeted fish stocks. Thus, continued monitoring and enforcement of speargun fishing will help to maintain the stock condition for the above two species.

Fishing monitoring and enforcement in Saleh Bay should also include local fish collectors to ensure their compliance with regulations [40]. With the growing export markets for grouper and snappers globally [67], mechanisms to ensure compliance with regulations along the trade chain become increasingly important. These mechanisms could include greater enforcement, developing incentives for fishers, and greater education/communication about the status of the fisheries and the need for regulations to ensure fishery sustainability. Incentives for fishers who comply with regulations can include assistance in different aspects of their operations, such as banking services for obtaining loans, training in post-harvest handling and financial management, ice production facilities, and the provision of marine safety technology (e.g., life jacket, GPS, radio communication equipment) [13]. Additionally, fisheries monitoring in Saleh Bay should not solely concentrate on recording catch and fishing effort; rather, conducting biological studies related to the life-history traits of targeted species is also recommended to reduce uncertainties in stock assessments (e.g., see [40]).

5. Conclusions

Overfishing in tropical SSF has been a global issue in recent decades. However, most tropical countries face similar challenges (e.g., data-poor and limited management capacity) in managing small-scale fisheries to overcome the issue. Fishing is also a complex economic activity in which fishers seek to maximize their revenue by applying a certain tactic or adapting to changes in the abundance and distribution of target fish due to the influence of various factors. Therefore, understanding the dynamics and complexity of small-scale fisheries in tropical countries is needed to design fisheries management, especially those employing multi-gear and targeting multi-species. The results of this study provide an understanding of the fishing dynamics of the small-scale grouper-snapper fisheries (using Saleh Bay as a case study), which can be used as a reference for fisheries managers in designing effective monitoring, enforcement, and management evaluation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes9010002/s1, Table S1: List of fish family and species, including catch in weight (kg) and number from the fish landing monitoring in Saleh Bay, West Nusa Tenggara 2016–2019; Table S2: Model Selection and Results of Generalized Additive Modeling (GAM).

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