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Feasibility of a single-species quota system for management of the Malaysian multispecies purse-seine fishery

Ledhyane Ika Harlyan

Faculty of Fisheries and Marine Science, Brawijaya University, Jl. Veteran, Malang, 65145 Indonesia;

Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan; ledhyane@ub.ac.id

Takashi Matsuishi

Faculty of Fisheries Sciences, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan;

Global Institution for Collaborative Research and Education, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan; catm@fish.hokudai.ac.jp

Mohammad Faisal Md Saleh

Marine Fishery Resources Development and Management Department, Southeast Asian Fisheries Development Center (MFRDMD/SEAFDEC), Chendering Fisheries Garden, Kuala Terengganu 21080, Malaysia; mohd_faisal@seafdec.org.my

Corresponding author: Takashi Matsuishi (email: catm@fish.hokudai.ac.jp).

Tel.: +81 138 40 8857; Fax: +81 20 4623 0037

Abstract

Malaysian fisheries employ multiple measures to improve management; however, not all measures are well-suited to the multispecies characteristic of the fisheries. As part of a pilot project, an individual quota system was recently introduced for the purse-seine fishery off the East Coast of Peninsular Malaysia (ECPM), but no assessment of this particular measure nor the feasibly of its implementation has been confirmed. Therefore, this study analysed patterns of purse-seine fishing spatially and temporally, by collecting catch composition data per landing and its fishing ground within three period fishery surveys during August 2017 – September 2018 at six different landing sites along the ECPM coastline. Similarity and cluster analysis were taken by examining species composition and diversity, to determine the feasibility of implementing a single-species quota system in this multispecies fishery. Some overlapped of indices results and minor difference in catch composition were found due to changes in spatial and temporal fishing activities. However, no specific spatial or temporal patterns were discernible as structuring the fishing grounds that were used by purse-seiners in ECPM areas. The absence of patterns, using the available data, might be attributable to huge species aggregations and widely distributed and homogenously-mixed fish stocks. Thus, it is likely impractical to manage species individually in such a multispecies fishery.

Keywords

fisheries management, mixed-stock fishery, spatial and temporal distribution, species aggregation, species composition, species diversity

1 Introduction

Fisheries management during the last couple of decades has shown considerable improvement in retaining levels of fishing pressure that allow stocks to maintain productivity (Nakatsuka et al., 2017; Sissenwine et al., 2014). Various types of management measures exist as technical controls and input or output controls (Selig et al., 2017). Employing multiple management measures is a useful way to preserve stocks, and especially for small-scale fisheries it is an important means to help resilience of the fishing community in terms of economic and environmental shocks, which may otherwise act as drivers of overfishing (Purcell et al., 2013; Salas et al., 2007). However, recent years, there has been increasing recognition of overfishing and overcapacity in Southeast

Asian fisheries which may critically threaten sustainable management (Amornpiyakrit & Siriraksophon, 2016; FAO, 2004; SEAFDEC, 2017). Southeast Asian fisheries are typically multispecies, multi-gear fisheries that exploit characteristically heterogeneous fishery systems (Najmudeen & Sathiadhas, 2008), which are relatively complicated to manage (Kato, 2008; Pascoe & Greboval, 2003). The increasing consumer demand for fish encourages the regional fishers with well-equipped fleets to continuously compete for fish, which often results in overfishing and possible resource depletion (Amornpiyakrit & Siriraksophon, 2016; Purcell & Pomeroy, 2015). In some cases, reliable data can be difficult to obtain in countries where the region's fisheries are characterised as multispecies, and this makes it difficult to analyse stock assessments for the sake of sustainable fisheries (Kato, 2008).

Malaysia was the first country in the Association of Southeast Asian Nations (ASEAN) to develop a plan of action for the management of fishing capacity, as a model for ASEAN member states (Department of Fisheries Malaysia, 2015a). The implementation of multiple management measures has led to valuable progress for Malaysian fisheries. Input controls to limit fishing effort were established and are now combined with technical controls for the sake of marine-resource conservation and rehabilitation (Department of Fisheries Malaysia, 2015b).

The implementation of output control through an individual quota system (IQS) also was planned (Department of Fisheries Malaysia, 2008). A feasibility study of the IQS for the purse-seine fishery in the East Coast of Peninsular Malaysia (ECPM) has been initiated; however, no assessment of the measure and feasibility of its implementation has yet been confirmed (Department of Fisheries Malaysia, 2015a). The IQS is set for the total catch, since data collected are not categorized by species (Jamaludin et al., 2017) as a consequence of the multispecies characteristic of the fisheries (Kato, 2008).

To set up a single-species quota system, single-species catch data are required (Yuniarta et al., 2017). Uncertainties about obtaining single-species data, however, have caused delay in implementing a single-species quota system throughout Malaysian fisheries (Department of Fisheries Malaysia, 2013). Therefore, there is a definite need to confirm whether implementation of an IQS complies with the current measures applied in Malaysian fisheries.

The purse-seine fishery has long played an important role and contributed a large portion to marine production in Malaysia (Department of Fisheries Malaysia, 2015a). From 2002 to 2016 the landings of the purse-seine fishery contributed between 21.8% and 29.4% of the country's total marine production, positioning purse seines as the second-highest contributing gear after trawl nets. Consequently, it is imperative that managers should be provided with the results of a feasibility study, to use as a reference on the applicability of the IQS, a part of the national fisheries plans, before its general implementation. Therefore, the present study investigated the assemblage patterns of purse seine fishery catches to determine whether to apply single-species or mixed-species fishery management for Malaysian fishery.

2 Methods

2.1 Study area and fishing fleet

To confirm conditions for implementing a single-species IQS in Malaysia's purse-seine fishery, two important factors referring to patterns of spatial and temporal distribution were analysed, namely fishing grounds and fishing seasons. A list of purse seiners was obtained from the Department of Fisheries of Malaysia website, which is regularly updated. The list reported 3,642 licensed vessels in 2016, with 41.34% operating in the ECPM; the rest of the vessels were distributed off the West Coast of Peninsular Malaysia (30.31%), the states of Sabah (24.61%) and Sarawak (3.35%), and the three federal territories (0.39%). The total fleet of purse seiners was dominated by vessel sizes of >70

GRT (66.94%) and 40−69.9 GRT (25.21%). The list also indicated that the largest of the purse seiners were used more in the ECPM area than in any of the other areas.

The Peninsular Malaysia is surrounded by sea on two sides, Strait of Malacca and South China Sea, the coastline of the eastern part (ECPM) is along the South China Sea belonging to four states (Kelantan, Terengganu, Pahang and Johor). In this study, three periods of the field surveys, July – September 2017, June – July 2018, and September – November 2018 that completed at six fishing landing centres in those states taken as the research sites (Table 1). Fishing in Malaysian waters is generally conducted throughout the year, although fewer vessels operate during the monsoon season between November and January (Islam et al., 2014). In the ECPM during post-monsoon season the catches are dominated by appearance of smaller fish group (Isa, Arshad, & Basir, 1999) which might not reflect the actual catches. Therefore, for this work, field surveys were conducted only in high fishing season during July to September.

The fishing activities are managed by zonation, categorised into five zones based on the distance of the fishing grounds from the coastline (Table 2). This study excluded consideration of the tuna fisheries, which are positioned farthest from the coastline. The purse-seine fishery is a part of commercial fisheries in which vessels are larger than 40 GRT and fish in coastal areas of the Indian Ocean; all purse-seine vessels are operated in zones C and C2. Zone C is located 12–30 nm from the coastline, and zone C2 lies between 30 nm from the coastline and the boundary of the exclusive economic zone.

Zone-C vessels and zone-C2 vessels hold separate licenses; licenced vessels can fish in the zone specified and, in all zones, offshore of that zone, but not in zones closer to shore. Therefore, zone-C vessels can operate in zones C, C2 and C3, but zone-C2 vessels can operate only in zones C2 and C3.

2.2. Data source

The data for this study was obtained by face-to-face interviews with enumerators and fishers, using a structured questionnaire. Prior to field data collection, intense discussions were conducted with SEAFDEC/MFRDMD [Marine Fishery Resources Development and Management Department] and the Department of Fisheries of the relevant state at each sampling site, so as to improve the questionnaire and gather baseline information on fishery operations.

The questionnaire covered information about fishery activities including composition of the landings and the associated fishing grounds data (Supporting Information 1). The composition of the landings data was collected from fishery logbook which submitted to fishery local authorities. To attain the data on fishing grounds, a process of participatory mapping was applied to assist the respondents in identifying and marking their fishing grounds.

Sample respondents were randomly selected from among available fishers at the landing sites. Interviews were conducted in the early morning, as most purse-seine landings are obtained before noon. A total of 137 respondents were interviewed, comprising owners of purse seiners sized 14.48–26.46 m length, 4.50–8.70 m width, 1.20–3.94 m depth, and 28.64–229.71 GRT; and the number of daytrips was 1−25 days/month.

2.3 Data analysis

As mentioned, the field surveys were conducted in three different survey periods. Each set of surveys was performed at six different landing sites along the ECPM coastline. Collected data comprised species information by landing site, period of the landing, fishing grounds, vessel zone, and amount of the landing; the data were input and classified based on that information. The data were then organised as pivot tables to facilitate the analyses.

Finally, to broadly describe information about the structured patterns of the areas fished by purse-seiners, four analyses were conducted to delineate the possible structure of the fishing grounds, as described in the following sections.

2.3.1 Species diversity

Two indices were used to describe species diversity in each fishing ground, the Shannon–Wiener index of diversity (S-W index, *H'*) and Menhinick's richness index (*S*) (Boyle et al., 2016; Zhu et al., 2011), using the following equations:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad \text{…………………………. (1)}$$

$$S = \frac{s-1}{\ln n} \quad \text{……………………………………… (2)}$$

where p_i is the fraction of the caught species; i represents species 1, 2, 3,..*s*. In this study, *n* is the weight of all caught individuals.

The value of *H'* represents the number of equally common species that would generate the same heterogeneity. The value of *S* represents the relative richness of species in a community (Lipps et al., 2014; Peet, 1974).

2.3.2 Spatial and temporal analysis

To investigate patterns in the purse-seine fishery by zones and seasons, spatial and temporal analyses were conducted. The spatial analysis attempted to portray the distribution of purse-seine vessels by zone, in zones C and C2. A 'zone distribution' map was created using QGIS software (QGIS Development Team, 2009), to show the distribution of both zone-C and zone-C2 vessels during the different periods of the surveys.

Analysis of variance using distance matrices for partitioning distance matrices among sources of variation was used by permutation test with pseudo-*F* ratios, namely the Adonis function in the vegan package (Oksanen et al., 2018). This is analogous to a multivariate ANOVA based on dissimilarities. Significance tests were applied using *F*-tests based on sequential sums of squares from permutations of the data. In this study, for both the spatial and temporal analyses, the Adonis function was chosen to analyse whether there were any significant effects of vessel zone distribution, period of survey distribution, or the interaction between these factors.

Analysis of similarity (ANOSIM) provides a way to statistically test for significant differences between two or more groups of sampling units; this operates directly on a dissimilarity matrix. Thus, if two groups are different in their species composition, the compositional dissimilarities between the groups must be greater than the dissimilarities within the groups. The ANOSIM statistic *R* compares the means of ranked dissimilarities between groups and within groups. Hence, this analysis was applied to examine significant differences between zones.

Temporal analysis was applied to portray the plot distribution of the periods of the surveys. A 'period of survey distribution' map was likewise created with QGIS software (QGIS Development Team, 2009). ANOSIM was also applied for the temporal analysis (Oksanen et al., 2018) to examine whether there were any significant differences in the three periods of the surveys.

2.3.3 Cluster analysis

To group the fishing areas, ward hierarchical clustering with bootstrapped *p*-values was conducted using R Package cluster analysis (Maechler et al., 2018; R Core Team, 2018). Cluster analysis can group observations into clusters based on the observed values of several variables. In this study, 137 fishing-ground locations were considered as observations, while the 26 species landed and their catch weights reflected the variables and their values, respectively. The purpose of this cluster analysis was to maximise the similarity among individuals within each cluster while maximising the dissimilarity among group clusters that were initially unknown. Hierarchical cluster analysis is used to discover relatively homogenous clusters based on dissimilarity (the Euclidean distance) between variables. With this method, each data point is first considered as an individual cluster, then similar clusters are merged with other clusters until a single cluster is formed containing all observations. A dendrogram was generated to show the hierarchal relationship between the clusters. Euclidean distances were computed from raw data (Roy et al., 2015); the Euclidean distance between two n-dimensional vectors x and y was calculated as:

$$d_{x,y} = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \qquad (3)$$

where i is the number of variables (Himmelstein, Bi, Clark, Bai & Kohtz, 2010).

As mentioned, 137 fishing grounds were clustered by species composition, with a total 26 species, through Euclidean distances. The dendrogram depicts two values given in different colours: red defines the approximated unbiased *p*-value (AU value), which is the approximately unbiased *p*-value computed by multi-scale bootstrap resampling, which has better approximation than the bootstrap probability (BP) values, presented in green, computed by normal bootstrap resampling. For a cluster with AU $p > 0.95$, the hypothesis that 'the cluster does not exist' is rejected with a significance level of 5%; in other words, the highlighted clusters may exist not only because of sampling error but might be stably observed if the number of observations is increased (Suzuki & Shimodaira, 2017).

After clustering, to determine the localisation of the potential fishing areas, the clusters of fishing grounds along with the species composition were plotted by their latitudes and longitudes.

3 Results

3.1 Species composition

In total, 26 species were found in the catches during the surveys, of which 11 species groups were tabulated (Figure 1). These 11 species groups comprised 98.42% of the total weight over the samples (490574.8 kg). The composition was dominated by longtail tuna *Thunnus tonggol* (Bleeker) (13%) and kawakawa *Euthynnus affinis* (Cantor) (10%), with smaller portions for the other species groups. The largest percentages of the aggregated species groups were mackerel scads *Decapterus* spp. (34%), 'trash fish' (20%) and 'mixed fishes' (4%). Trash fish are low-value species, while the mixed fishes were mostly small-sized of *Sardinella* spp., *Decapterus* spp., and others.

Aggregation of catch categories based on genus also occurred for some dominant species composing nearly 65% of the landings, except *T. tonggol* (13%), *E. affinis* (10%), bigeye scad *Selar crumenophthalmus* (Bloch) (5%), Indian mackerel *Rastrelliger kanagurta* (Cuvier) (3%), yellowtail scad *Atule mate* (Cuvier) (2%) and yellowstripe scad *Selaroides leptolepis* (Cuvier) (2%) together comprised 35% of the weight of the landings.

3.2 Species diversity

Based on surveys in three time periods, 137 sites were recognised along with their species composition (a total of 26 species) and were compiled in a map (Figure 2). Various species were captured at each of the fishing grounds, and the species were widely distributed.

Two indices (species diversity and species richness) were used to describe the composition of the species available to purse-seiners in the ECPM. The index of species diversity revealed that diversity also varied in each fishing ground, in three different ranges, between 0–1.8 (Figure 3). Similarly, the index of species richness showed the number of species in each fishing ground, in three different ranges, between of 1 – 9 (Figure 3). There were some overlaps between fishing-ground areas having low and high species diversity, which also occurred for species richness. No structured pattern in either species diversity or species richness was found (Figures 3).

3.3 Spatial and temporal analysis

The results of the spatial and temporal ANOVA showed that both factors and their interaction had a significant effect in structuring the species composition of each site ($p \leq 0.05$). Both factors exerted a more-significant effect than their interaction. The strength of each factor was explained by the percentage of the factor towards the sums of squares, which resulted in 5.9% for the factor 'zone,' 2% for the factor 'period of survey,' and 1.4% for their interaction (Table 3).

The map of vessel zone distribution (Figure 4) clearly shows that vessels with either a zone-C or zone-C2 license were diversely distributed. Some vessels from southern areas are revealed to have also fished in central or even northern areas of the ECPM; however, few zone-C vessels appeared to have proceeded to fish in the C2 zone. Most zone-C2 vessels remained in the designated area, however a few went on to fish in zone C, which is prohibited. The map depicting distribution of the periods of the surveys (Figure 4) also shows some points of overlap and aggregation of the different periods of the surveys in the northern part of the ECPM.

The results of ANOSIM showed that there is a difference in catch composition by weight for both the zone-C and zone-C2 fishing ground ($p \leq 0.001$; $R = 0.2203$) and survey period ($p \leq 0.001$; R = 0.106), indicating that the weight of individual catch between these two factors were significantly different, though may not their species composition. The R values indicated that the zone factor and survey period factor had little effect on catch composition.

3.4 Cluster analysis

Figures 5 and 6 illustrate the results of the cluster analysis intended to identify structure in the pattern of the fishing grounds in the multispecies purse-seine fishery in the ECPM. The clusters involve different numbers of fishing grounds, which depended on the similarity distances for each species. Each cluster also shows the various species' distributions.

Two dominant clusters (VII and II) are widely spread across the ECPM (Figure 6). Cluster VII has the largest number of fishing grounds (98 sites). Cluster II is spread across 10 sites, while clusters V and VI depict more-specific distribution areas; cluster V is distributed more in the southern part, and cluster VI mostly in the northern part of the ECPM. Cluster V and cluster VI consist of 9 and 10 sites, respectively. The other small portions are clusters I, III and IV, and comprise only two sites.

The potential fishing area is pointed as at 103°36°–104°19° E, 3°36°–5°57° N (Figure 6). In these areas, the species composition of the clustered groups revealed that almost all species were diversely distributed in all groups (Figure 7); however, the specific distributions forming clusters V and VI might reveal a structured pattern of the fishing grounds in the ECPM. When comparing the composition of clusters V and VI, *T. tonggol* was found in cluster VI in a large percentage (>50%), but in small portions in the other groups. By preserving *T. tonggol*, in the same time, some species will be directly protected from fisheries (since those species are counted with *T. tonggol* as 11% of cumulative catch weight; Figure 7), such as *Decapterus* spp., *E. affinis*, *R. kanagurta*, leiognathids (ponyfishes), and *S. crumenophtalmus*.

4 Discussion

Malaysia has long implemented management measures for its multispecies fisheries. Output control has largely not been applied because of the impracticality, with many species involved; rather, guidelines have focused on a combination of input controls and technical measures (Cochrane, 2002). This combination might be the best option for the management of a multispecies fishery when it is otherwise not possible to restrict fleets in reducing their landings or possible catches of valuable stocks of certain species (Kvamsdal et al., 2016; Pascoe & Greboval, 2003). Therefore, to reduce landings directly (Petter Johnsen & Eliasen, 2011) and to protect stocks (Marchal et al., 2016), output control measures can be combined with input control and technical controls (Selig et al., 2017).

In the present study, species diversity and species richness were applied to illustrate the species composition for purse-seiners in the ECPM. The overlapped results of these indices between fishing-ground areas having low and high species diversity provide information about the factor that may produce difference in species diversity level within an area. Collecting species assemblage data in nearly adjacent spots at different time may cause the overlapped result variation due to natural and/or other changes (Pyron, 2010), like changes in fishing activity spatially and temporally.

Analyses of spatial and temporal distributions were performed to examine the feasibility of a single-species IQS for the Malaysian multispecies purse-seine fishery. Previous research has explored the spatial structure of demersal fish assemblages in Southeast Asia, with implications for fisheries management (Garces et al., 2006). However, to our knowledge, no previous study has reported on the spatial and temporal distribution of some pelagic fishes caught in Malaysia's multispecies fisheries, and the specific implications to management.

The catch composition documented in annual fisheries statistics for the ECPM show that some species recorded as the largest portion of the landings, such as mixed fishes and trash fish, are actually aggregated groups of species. Formerly, there was no requirement to record all species separately; additionally, there might have been a lack of technical support in making species identifications. Overall, this situation has failed to provide individual biological data and fisheries information even for dominant species.

The spatial and temporal analyses showed that all seasons in the ECPM generated a similar species distribution. No clear shifts in structure occurred, possibly owing to the presence of fishes that have a high growth rate, mature at an early age, and spawn year round (Abdussamad et al., 2010; Smith-Vaniz, 1984; Zheng & Walters, 1988). Moreover, the lack of a temporal pattern could be the consequence of spawning periods (Sanvicente-Anorve et al., 1998), as many small-pelagic tropical fishes, such as scads (*Decapterus* spp., *Selar* spp, *Atule* spp.) (Zheng & Walters , 1988; Qiu, Lin & Wang, 2010; Devaraj and Martosubroto, 1997) and mackerels (*Rastrelliger* spp.), have broad spawning periods that synchronise with successive cohorts (Peck, Huebert, & Llopiz, 2012; Devaraj and Martosubroto, 1997), resulting in high abundances. Migration might also reflect an individual's spatial preference (Humston et al., 2000); no spatial pattern can indicate that the residing species might undertake neither migration nor continuous migration.

The spatial analysis highlighted dissimilarity of the species composition between captures by zone-C and zone-C2 vessels, which might be owing to incomparable widths of the fishing areas for both vessel types. Zone-C vessels can proceed into zone C2, but not *vice versa*. However, zone-C vessels are more limited in their capacity, as they have smaller fish holds and take along less supplies, such as fuel, food and ice as compared with zone-C2 vessels. Moreover, zone-C2 vessels have better capability to land rich and important transboundary fish resources, such as neritic tunas (i.e., *T. tonggol* and *E. affinis*). These neritic fish were mostly caught by zone-C2 vessels, as these two tunas are widely distributed in the Pacific further away from the ECPM coastline (Siriraksophon, 2017).

Peninsular Malaysia is estimated as one of the areas in the world with the highest species richness (Parravicini et al., 2013) and species diversity (Jenkins & van Houtan, 2016). However, in this study, it was challenging to structure the patterns of the fishing grounds based on the diversity indices, since adjacent fishing grounds could not provide similarity to each other or comparable values of the indices. Also, neighbouring and overlapping fishing grounds did not perfectly reflect the species composition and distribution. Cluster analysis is one way to reveal any structure among fishing grounds, and so reveal clear patterns for certain species.

The cluster analysis clearly revealed *T. tonggol* to be a species with structured pattern in the ECPM. This species has a slower growth rate as compared with the other pelagic species in the ECPM; it grows relatively slowly, lives longer, and is more vulnerable to overexploitation by fisheries (Collette et al., 2011; Griffiths et al., 2009). Therefore, regional tuna statistics for Southeast Asia recognised the importance of managing neritic tunas as an important and rich transboundary fishery resource by establishing the Regional Plan of Action on Sustainable Utilization of Neritic Tuna in the ASEAN Region to ensure its sustainable use (SEAFDEC, 2017).

The dissimilarity of species composition between and within fishing grounds demonstrated that species composition between fishing ground is more diverse than that of within fishing ground which indicates fishermen might easily set their gear and locate their fishing areas to avoid certain over-quota species. This result might be affiliated for *T. tonggol*, the habitat of this species needs to be better delineated, since the species might be localised in the central to northern areas of the ECPM ($102^{o}22^{o}$–$104^{o}22^{o}$ E, $5^{o}7^{o}$–$6^{o}42^{o}$ N).

Nevertheless, some studies have found that stocks of highly mobile pelagic species may not respond positively to discrete spatial fishing closures since these often involve only a small part of the species' habitat. Effective protection should consider fishing closures in larger areas, proportional to the habitat range of the targeted individuals (Grüss et al., 2011; Santana-Garcon et al., 2014). Further consideration for closure management to benefit *T. tonggol*, a transboundary species, will require more information on its seasonal migration and age structure. Therefore, it is fair to suggest that reliable species-specific information is critically needed before implementing an IQS for tunas, for example, separate from quotas for other species through the single-species management approach.

The results of the landing composition to species diversity in the ECPM might not clearly reflect genuine conditions since some were actually species groups. This situation also reveals the potential uncertainty in annual data, when differences occur between reported fisheries statistics and actual landing data. Inaccuracy in species separation will cause misreporting, thereby leading to unreliable stock estimations (Yuniarta et al., 2017). A large proportion of species aggregations in the fishery was recorded in the entire landing composition, which might lead to difficulties in defining the particular habitat for each species (Roberts et al., 2005). However, to the best of our knowledge, no previous catch analysis has reported on the species composition of trash fish and mixed fishes, and the findings here might benefit how to make adjustments in compiling annual fisheries statistics.

Subsequent to recognising the multispecies characteristic of a fishery, caution needs to be exercised before taking a single-species approach to management. Catch categories that reflect huge species aggregations are not able to provide species-separated data which is required to conduct single-species approach. Moreover, no specific pattern was found to localise the species spatially and temporally in the ECPM, since a multispecies fishery is subject to widely distributed and homogenously mixed fish stocks, which in practise allows non-selective exploitation. However, in fact, application single-species approach for management of the multispecies purse-seine fishery in Malaysia is still demanded to protect certain severe species due to over-fishing (Marchal et al., 2016; Selig et al., 2017).

Therefore, regarding those situations, a tactical short-term approach to management may be a good option in the context of the limited data on separate species. A feedback harvest control rule (HCR) that applied for single-species management has been successfully validated to be applied for fisheries which only mixed-species data available. This feedback HCR presents an initial stage to sustainably managing multispecies fisheries while challenging with data-limited conditions (Goethel et al., 2019; Harlyan, Wu, Kinashi, Kaewnern, & Matsuishi, 2019).

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Tables

Table 1. Research sites. LKIM is Fisheries development authority of Malaysia (Lembaga Kemajuan Ikan Malaysia). QL is the one of private jetty located in Endau.

No	Research site	State	District
1	LKIM Tok Bali	Kelantan	Pasir puteh
2	LKIM Pulau Kambing	Terengganu	Kuala terengganu
3	LKIM Kuala besut	Terengganu	Besut
4	LKIM Kuantan	Pahang	Kuantan
5	LKIM Endau	Johor	Endau
6	QL	Johor	Endau

Table 2. Fishing zonation in Malaysian fisheries

Category	**Zone A (No-take zone)**	**Zone B**	**Zone C**	**Zone C2**	**Zone C3**
Purpose	Marine Park (Only artisanal fisheries allowed)	Commercial fisheries (Trawlers and Purse seiners)	Commercial fisheries (Trawlers and Purse seiners	Commercial fisheries (Trawlers and Purse seiners	Commercial fisheries (Tuna long liners and tuna purse seiners
Ownership	Must be on board (one person owns one vessel)	Does not have to be in the vessel	Does not have to be in the vessel	Does not have to be in the vessel	Does not have to be in the vessel
Vessel size	<40 GRT	<40 GRT	40–<70 GRT	$\geq$70 GRT	$\geq$70 GRT
Fishing area (distance from shore)	0-5 nm	5-12 nm	12-30 nm	30 nm – EEZ Boundary	High seas

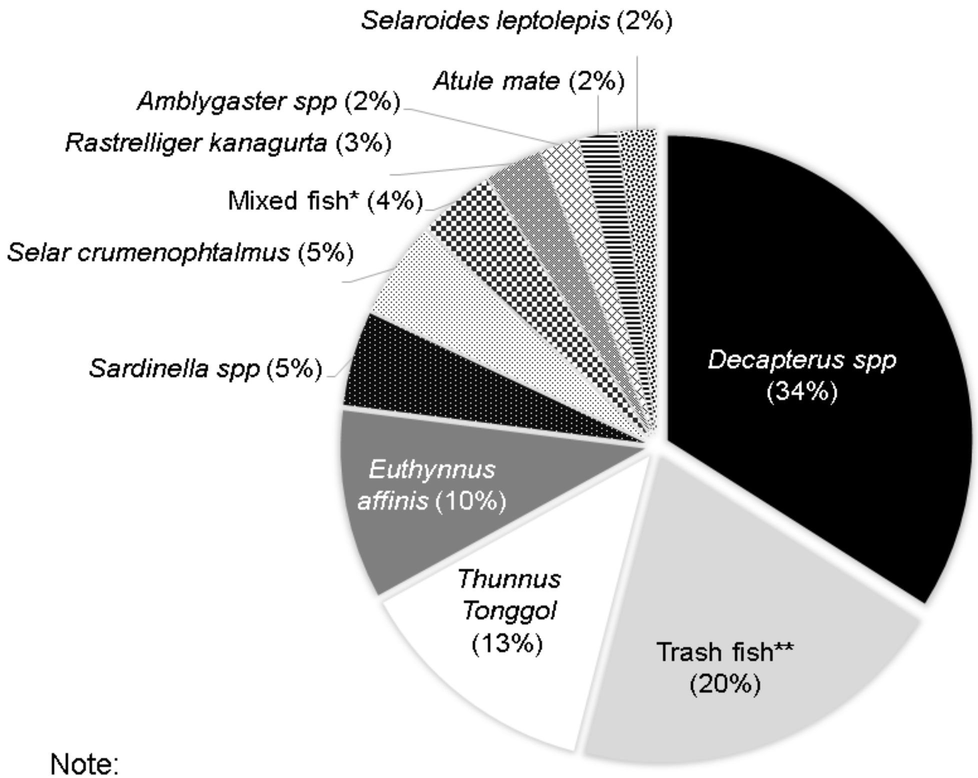
Table 3. The ANOVA results of the zone and period of survey. The zone factor is for vessel zone distribution (C-zone and C2-zone vessels), while the survey factor is for the period of survey distribution

	Sum of Squares	df	Mean Square	*F*	R^2	Sig. (>*F*)
Zone	2.807	1	2.81	8.74	0.059	<0.001***
Survey	0.960	1	0.96	2.99	0.020	<0.001***
Zone * Survey	0.672	1	0.67	2.09	0.014	0.0230*
Residuals	42.696	133	0.32		0.905	
Total	47.136	136			1	

Significance: 0 '***' ; 0.001 '**' ; 0.01 '*'

Figures

Figure 1. Landing composition in the purse-seine fishery, based on survey data for 2017 and 2018



Note:
*Mixed fish: small-sized of *Sardinella* spp., *Decapterus* spp., etc. for processed products (snacks)
**Trash fish : low-value fish

Figure 2. The multispecies condition of the purse-seine fishery off the East Coast of Peninsular Malaysia. The circle diameters are proportional to the yield of individuals caught

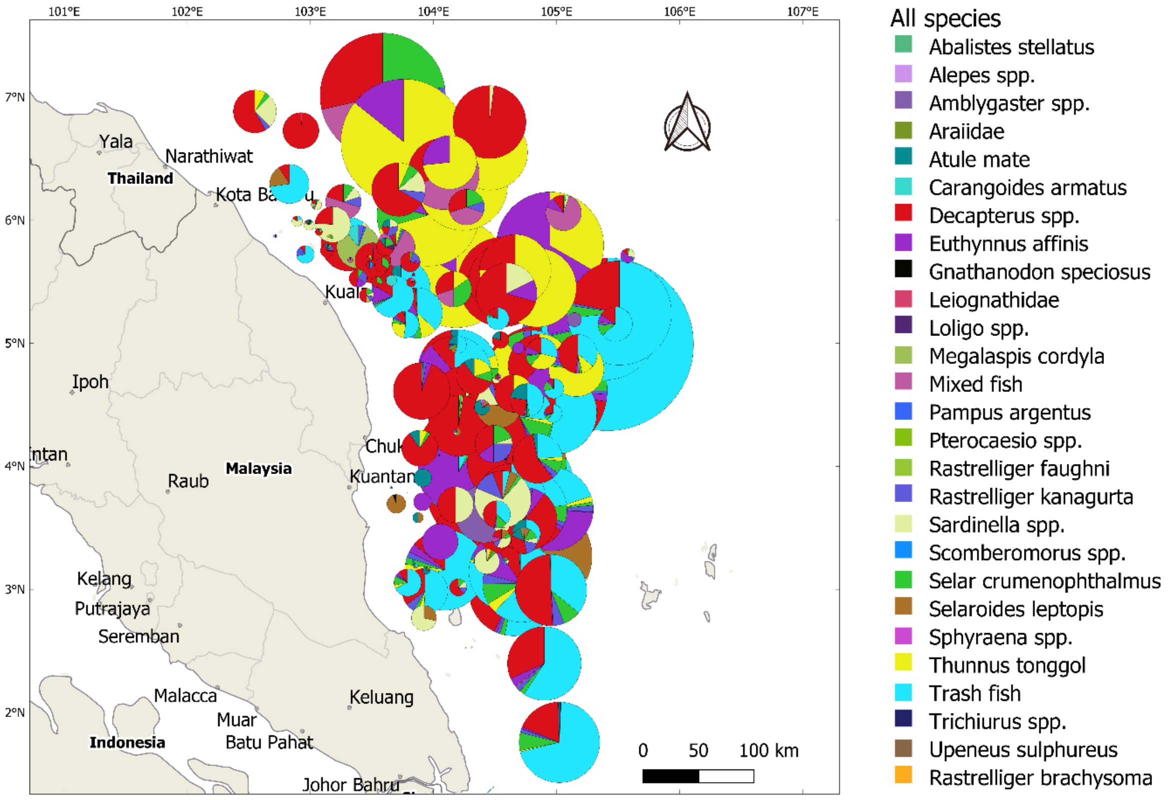


Figure 3. Species richness *and diversity* in the purse-seine fishery off the East Coast of Peninsular Malaysia. Darker colour represents higher species richness

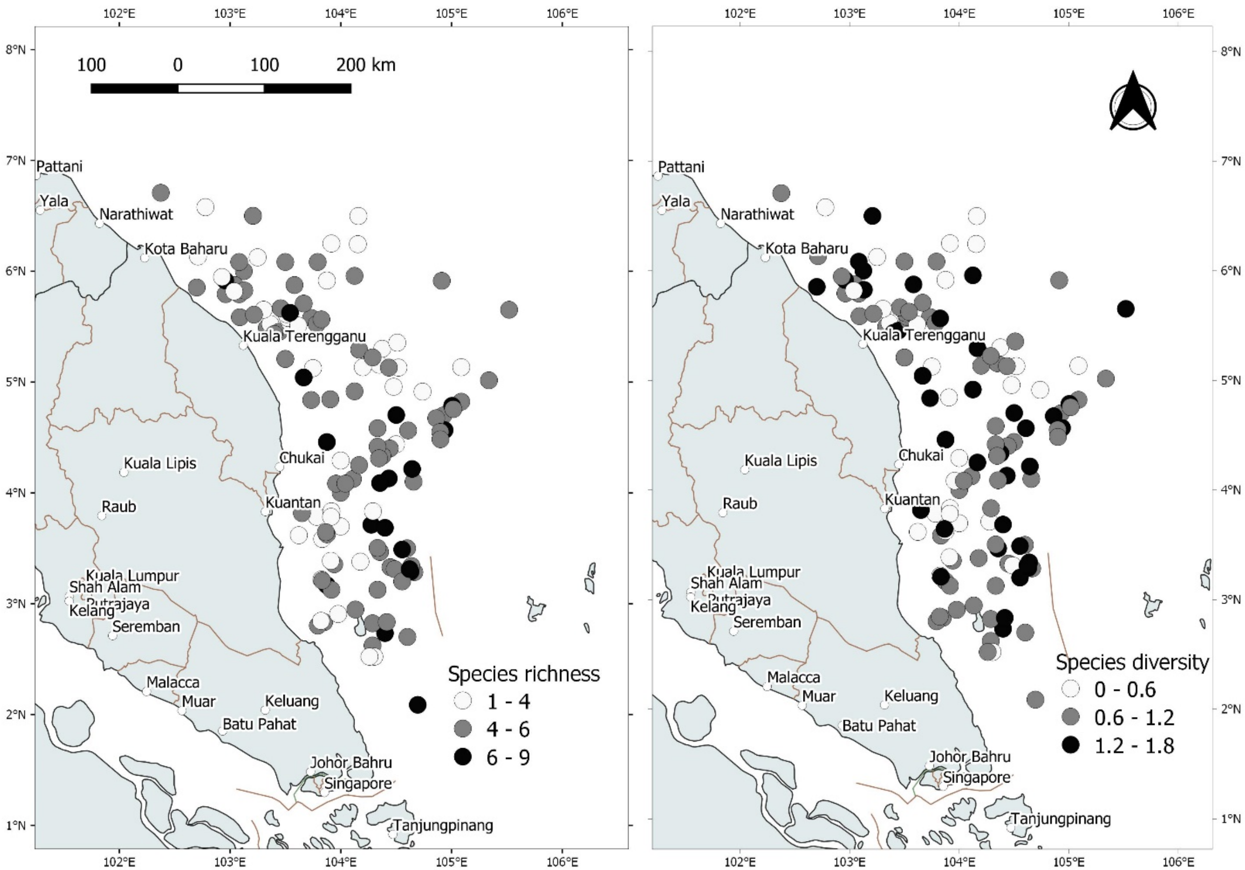


Figure 4. Vessel zone and period survey distribution map. The solid line in the vessel zone distribution marks 30 nm from the coastline, to indicate the border between zones C and C2; zone C lies at 12–30 nm from the coast, and zone C2 is between 30 nm and the exclusive economic zone. Vessels can proceed to fish in zones further from the coast, but not *vice versa.*

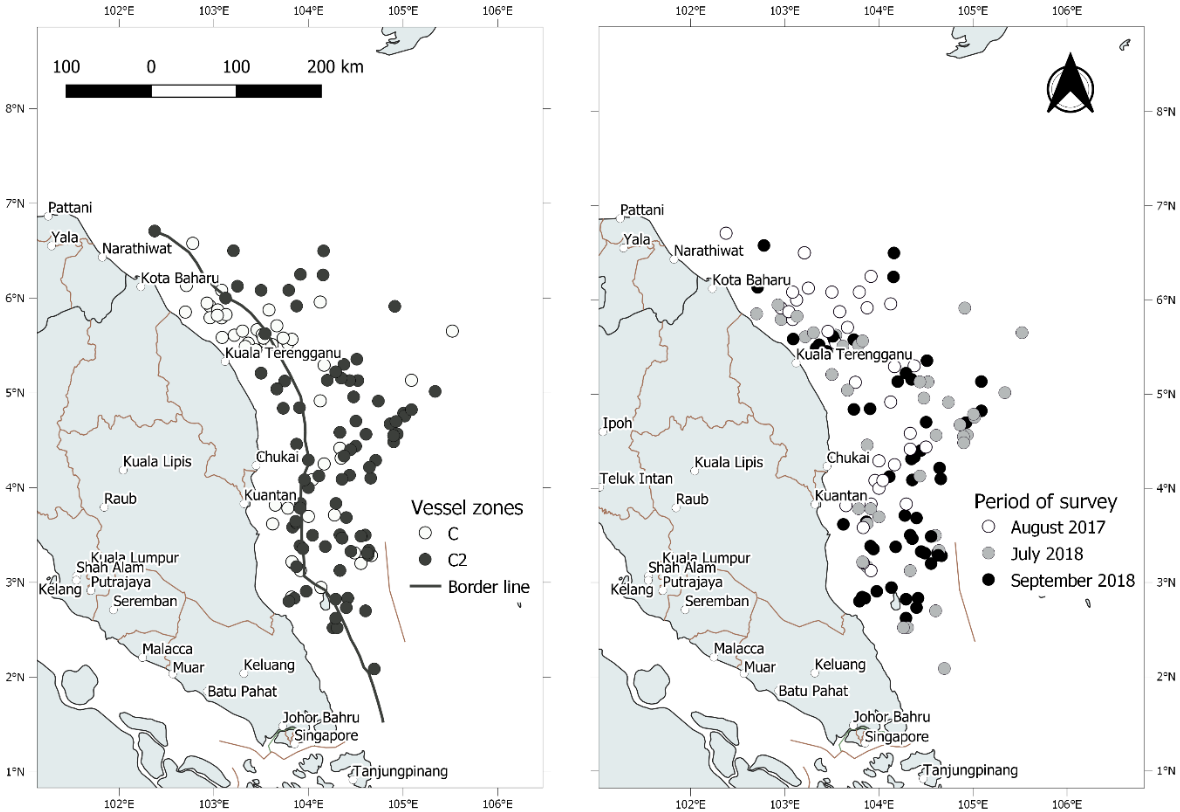


Figure 5. Dendrogram of the clustered groups. Red represents values of approximated unbiased ρ value (AU values), and green represents values of bootstrap probability (BP values). Red rectangles indicate clusters with AU values of >0.95

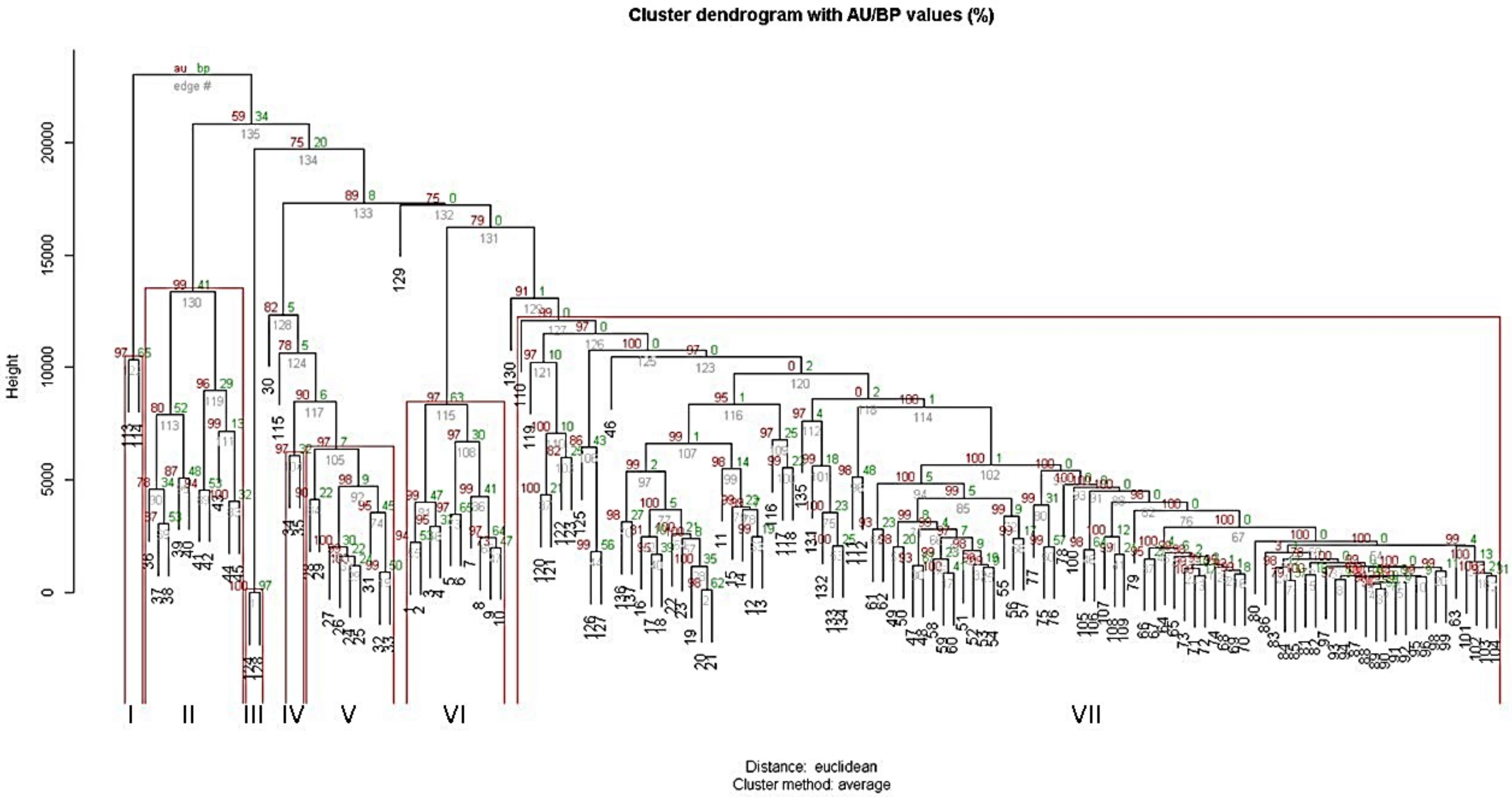


Figure 6. Clustered fishing grounds in the purse-seine fishery off the East Coast of Peninsular Malaysia

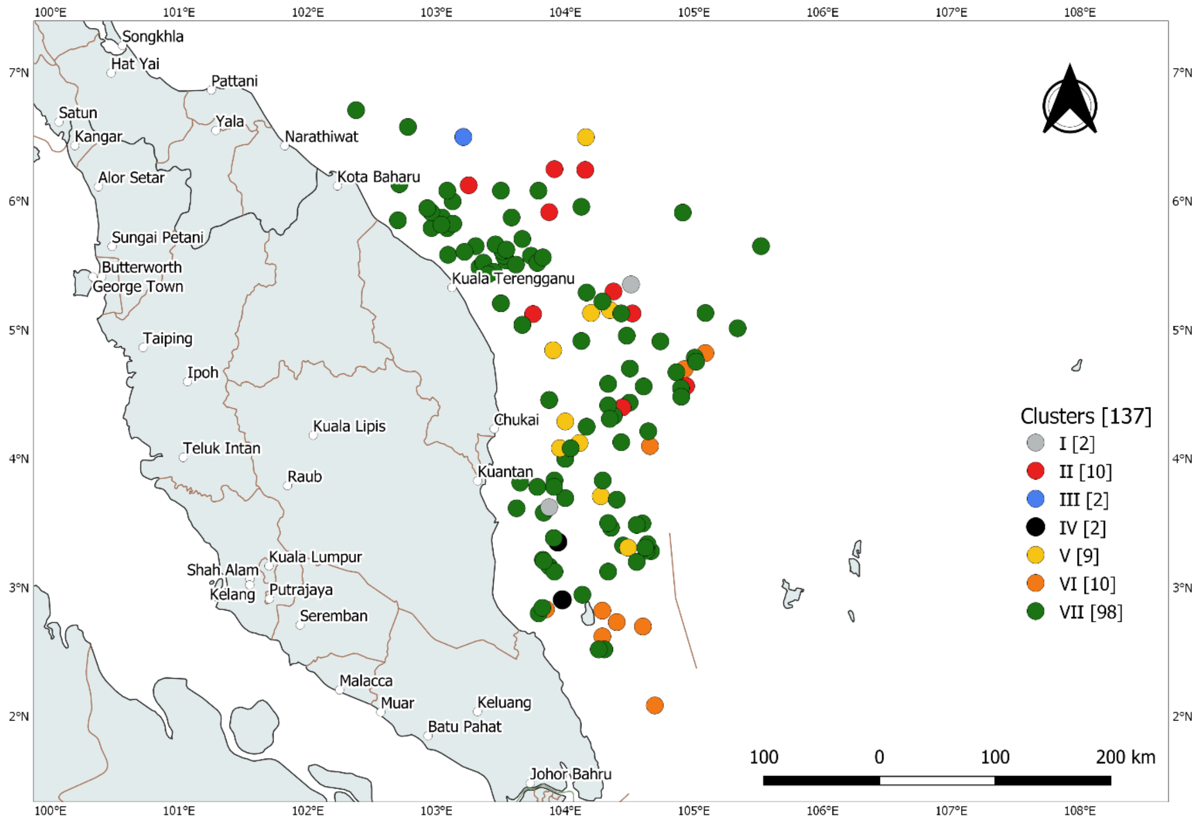
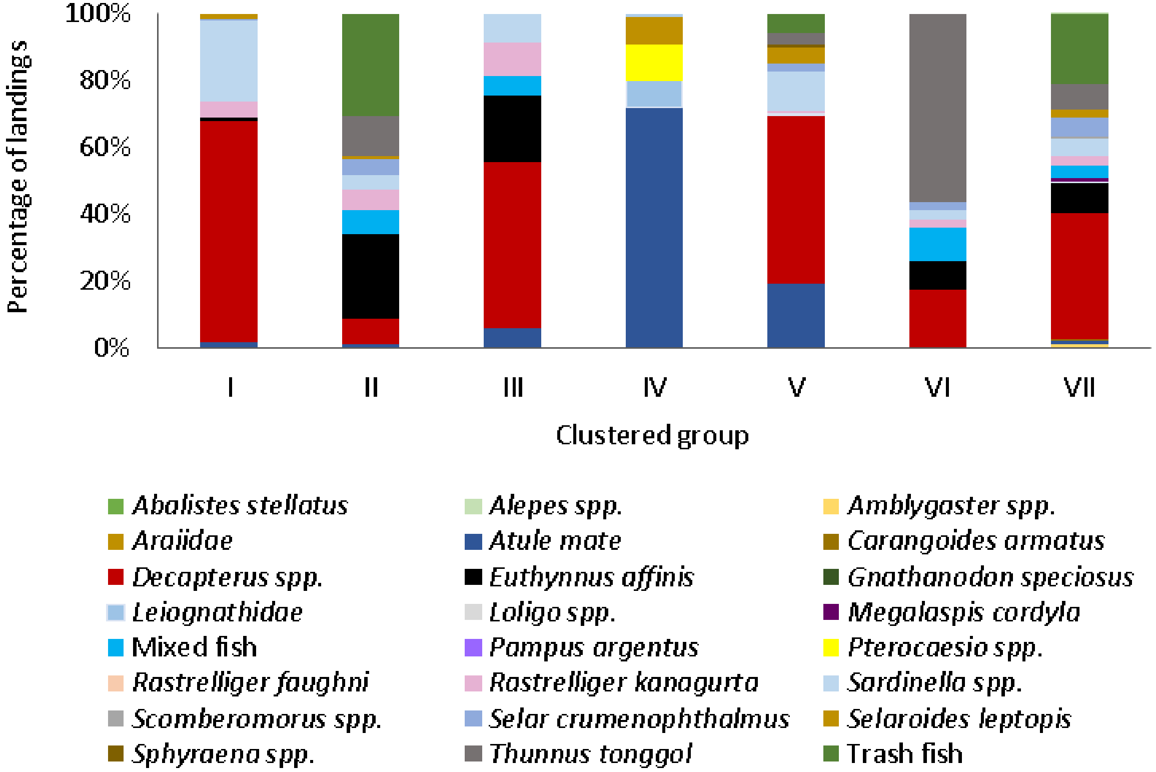


Figure 7. Species composition of clustered groups



Supporting information

Supp 1. This form was used to collect information about fishery activities, including composition of the landings, the associated fishing grounds and fishing operations.

Fishery survey form

Date:	**Vessel**	**Vessel dimension**	**Fishing operation**	**Dimension of gear**
SurveyID:	Name	Length: m	$\sum$ haul/day:	Length: m
DataID:	GT	Width: m	$\sum$ trip/month:	Depth: m / feet
	Owner	Depth: m	Duration: days	Mesh size: inch
State	**Fishing Location**	**Landing**	**Crews**	**Code**
District	- Latitude	Total: kg	$\sum$ crew: persons	A/B/C/C2
Port	- Longitude		$\sum$ foreign crew: persons	

No	Species	Quantity (kg)	Price (RM/kg)	Length (cm)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

No	Species	Quantity (kg)	Price (RM/kg)	Length (cm)
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				