Purse seine fishery management in Malaysia
: an output control for sustainable fisheries

（マレーシアにおけるまき網漁業管理: 持続可能な漁業のための産出量規制）

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2019 年

ABSTRACT

I. Introduction

Southeast Asia (SEA) region is a promising region to provide a continuously increasing capture fishery production. Among SEA countries, Malaysia is the best practice model and a leading country for estimating best management strategies that promote sustainable fisheries practices. Purse seine fishery have played an important role in Malaysian fisheries for small, pelagic, economically important fishes, not only for food consumption, but also for supporting the livelihoods and employment of fishers. Over the past 10 years, purse seine fishing capacity has increased with minor changes in species composition for all species. However, it is still important to examine the sustainability of the Malaysian purse seine fishery as the fishing capacity has progressively increased.

To maintain sustainability, three management measures can be considered: input control, technical control, and output control. The Malaysian Government has conducted input and technical controls, but output control has not been implemented yet, although a pilot project and feasibility study began in the East Coast Peninsular Malaysia (ECPM) in 2015. Prior to starting a quota system, the fishery managers set a total allowable catch (TAC) as an annual catch limit, which is usually based on scientific advice or catch data known as allowable biological catch (ABC). It requires data of each species individually fitted and applied in single-species stock management models. However, most fisheries, including Malaysian fisheries, involve multiple stocks or multiple fleets competing for the same fish resources. Therefore, to implement a quota system in the multispecies purse seine fishery in Malaysia, information of species such as habitat and seasonal life stages is needed. It is critical to confirm whether the purse seine fishery as a multi-species fishery in Malaysia can be easily localized by areas (spatially) or by seasons (temporally) before the implementation of output control.

II. Overview of the purse seine fishery in Malaysia

To confirm the feasibility of output control, concerning on its limitations and requirements, towards Malaysian purse seine fishery, an overview of purse seine fishery in Malaysia was given by clarifying the spatial and temporal patterns of purse seine fishing areas and seasons through species diversity and cluster analysis. The analyses showed no specific seasonal and temporal pattern in the structure of the purse seine fishery fishing grounds in ECPM areas. Huge species aggregations in catch categories lead to incapability of providing species-separated data.

Multispecies fisheries are subjected to widely distributed and homogenously mixed fish stocks which lead to non-selective exploitation. Therefore, realizing the multispecies fishery condition in Malaysian fisheries, it is impractical to manage each species individually using single-species stock assessment in multispecies fisheries. A tactical short-term management approach can be an option to respond to the demands of data-limited management, which might occur in a multispecies fishery.

III. Proposed management measure for purse seine fishery in Malaysia: an output control for sustainable fisheries

A short-term management approach that can deal with multispecies fisheries in ECPM is the feedback harvest control rule (HCR), which has been successfully applied in Japanese fisheries management, called the ABC rule 2-1 in the Japanese TAC system. This feedback HCR was previously validated to be applied in fisheries with a single-species approach. By combining management strategy evaluation with a simulation to generate mixed-species data from a multispecies fishery, the performance of this feedback HCR was evaluated and then compared with its performance using species-specific data. Also, the sensitivity of the feedback HCR's performance over several scenarios of population dynamics was also examined and compared across other modified HCRs.

The results showed that the feedback HCR is appropriate for multispecies fisheries management where only mixed-species data are available but with special monitoring for slow-growing minor species. In other words, the feedback HCR presents an initial step toward sustainably managing multispecies fisheries while contending with data-limited conditions.

IV. Concluding discussion

The Malaysian purse seine fishery management needs to commit to maintaining sustainable fisheries. It can be done by considering establishing input control through a clear and accurate adjustment of fishing capacity; strengthen capacity and capability for regional cooperation, in particular regional coordination meetings and joint surveillance with neighboring countries; and the implementation of output control.

A combination of input and output controls will be the best option for providing sustainable fisheries management for Malaysian fisheries and other multispecies fisheries in the region. The limitation of output control implementation towards multispecies fisheries condition can be solved by conducting the feedback HCR which was validated dealing with data-limited conditions. As a merit, the feedback HCR is designed to attain an optimum catch and biomass along with less catch variation which will simultaneously affect fisheries sustainability.

This research pointedly suggests that data-limited multispecies fisheries can be managed sustainably using multiple management measures, such as a combination of input, output and technical controls. Furthermore, the availability of reliable species-specific data for certain major species and mixed-species data for other species will generate substantial progress for fisheries management in SEA.

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah for giving me strength and opportunity to undertake this doctoral study and to persevere and complete it satisfactorily. الحمد لله ربّ العالمين Without his blessings, I would not have been possible.

In my journey towards this degree, I have found a teacher and a pillar of support, **Prof. MATSUISHI Takashi.** I would like to express my sincere gratitude for his continuous support, his patience, motivation and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. All his advices assisted me to have great living experience in Japan.

I also would like to thank the rest of my thesis committee: **Prof. TAKATSU Tetsuya, Prof. FUJIMORI Yasuzumi** and **Prof. John Bower**, for their valuable insightful suggestions that incented me to improve my thesis from various perspectives. In addition, for the entire staff at **Faculty of Fisheries Sciences, Hokkaido University**, who have always been so helpful and cooperative in giving their support for academic affairs.

A very special gratitude goes out to the Indonesia Endowment Fund for Education **(LPDP)** and the Southeast Asian Fisheries Development Center **(SEAFDEC)** for providing the funding for the work. Also, to **Department of Fisheries Malaysia, Jabatan Perikanan Malaysia**, for giving me great opportunity exploring the Malaysian purse seine fishery and providing me various invaluable supporting documents.

To all my fellows in Matsuishi-Ken, **MATSUDA Ayaka, KURODA Mika, Khuu Thi Phuong Dong, MATSUI Natsuki, MAEDA Saki, YOSHIYAMA Taku, WU Dengke, KINASHI Ryosuke, MUNEHARA Masami, Suppapong Pattarapongpan, TAKANO Keiko, KANNO Hayato, TAGE Kaori, YAMAMOTO Aito and Pran Chavalittumrong,** I thank you for all great times we have had in the last three years.

I take pride in acknowledging my institution**, Faculty of Fisheries and Marine Science Brawijaya University**, to give me an opportunity to pursue my study. Also, for **MEXMA-UB** for encouraging and giving me chance to still contribute in remarkable activities during my study.

My acknowledgement would be incomplete without thanking the biggest source of my strength, my family. To my loves of my life, **Herbhirawa & Dastan**, for their love and care that always brighten my days now and forever. Also, to my parents **Bapak Harsono & Ibu Ellyana, Bapak Sumaryono & Ibu Laila Tsalasih**, **Tante Diyang**, brothers & sisters **Gendhy Dwi Harlyan & Festi Winda Sari**, **Dewi Handzani & Azharul ulum Syabana**, **Gusti Arya Seta & Ratih Fitriyani**, and my relatives for all their prayers at all times.

Ledhyane Ika Harlyan

1. INTRODUCTION

1.1. Characteristics of Southeast Asian (SEA) fisheries

The United Nations' 2030 Agenda for Sustainable Development (2030 Agenda) and its Sustainable Development Goals (SDGs) provide an integrative approach to improve the world to a sustainable and resilient path that leaves none behind, particularly supporting developing countries to achieve their economic interdependencies. Related to fisheries, SDG 14 fully concerns conservation and sustainable use of the oceans, seas and marine resources for sustainable development. SDG 14 and its targets have continued their efforts to regulate harvesting by implementing science-based management plans and ending all destructive fishing practices such as overfishing, illegal, unreported and unregulated (IUU) fishing to restore fish stocks to the levels that can produce the maximum sustainable yield (MSY) as determined by their biological characteristics. Other SDGs that are also relevant with fisheries are as follows: fisheries value chain for supporting the poor livelihoods (SDG 1), fish for combating zero hunger (SDG 2), fisheries for contributing to good health and well-being (SDG 3), fisheries for establishing economic growth (SDG 8), reductions in fishery post-harvest losses (SDG 12), and low environmental climate impact of fisheries and aquaculture compared to other food sources (SDG 13). In the other words, for achieving the 2030 Agenda and its SDGs, the global community needs to promote sustainability in fisheries as a food supply in developing countries as well as it is done in developed countries (FAO 2018).

In 2016, the global fish production peaked at about 171 million tons, with static capture fishery production since the late 1980s and progressive growth of aquaculture to compose about 47% of total production. The stable trend of capture fishery has been mainly due to the declining catches of some regions. According to The State of World Fisheries and Aquaculture 1988 – 2018, in the world's most productive capture fishery areas, the Northern and the Southern Pacific Ocean, capture fishery production has declined, while in other regions, it has remained steady. Only three regions, the Western Central Pacific, the Eastern and the Western Indian Ocean, have had a continuously increasing trend in capture fishery production to compensate for declines in the other regions and to stabilize the world capture fishery productions by composing the highest proportion of biologically sustainable stocks at 72.6% (FAO 2018).

Southeast Asia (SEA) countries have played an important role in the increased fishing capacity in the world through enhancing the numbers of fishers and motorized fishing vessels (SEAFDEC 2015a, 2017, FAO 2018). It is believed that increased fishing capacity might cause increased fishery landings (Sumaila et al. 2016). However, SEA has suffered from the uncontrolled exploitation of resources caused by overcapacity, which in turn has led to illegal fishing and ultimately to resource depletion. Under such conditions, the task of managing fisheries sustainably in SEA has become progressively challenging (Worm et al. 2009, Pomeroy 2012, Amornpiyakrit and Siriraksophon 2016).Therefore, recognizing that overfishing and overcapacity threaten the sustainability of fisheries, regionally, the Southeast Asian Fisheries Development Center (SEAFDEC), as an autonomous inter-governmental body founded in 1967 that supports the sustainability of fisheries and aquaculture in Southeast Asia, had committed to promote better management of fishing capacity (Amornpiyakrit and Siriraksophon 2016) and to strengthen regional cooperation of sustainable fisheries development (Silapajarn et al. 2015).

The growing fishing capacity in SEA together with rapid increases in the number of fishing fleets, have not been matched with the national capacities and regional cooperation to manage fisheries resources sustainably. Limited management action such as control and regulation seem to allow fisheries to operate an “open-access regime”. In such situations, improved licensing schemes and other management measures that effectively limit the entry of fisheries, replacing the current insufficient designed systems are needed (SEAFDEC 2017).

The coastal waters of SEA are the highly productive and biologically diverse, and support many multi-species and multi-gear small-scale fisheries (Pomeroy 2012). The fisheries employ different sizes and types of fishing vessels and gears along with various catching methods for diverse target species. The characteristics of SEA fisheries have caused the fisheries management to somewhat differ from other parts in the world because they are complex with the multiple landing sites and fishers, and some of the fisheries have not been registered yet (FAO 2005, Kato 2008). Moreover, inadequate data collection systems have occurred in some SEA countries (De Young 2006, Kato 2008, Yuniarta et al. 2017) and led to the problems of improving stock assessments and related information relevant for decision makers (Rudd and Branch 2017). Owing to these complications, it is difficult to estimate the future potential fish stock in SEA for its sustainability concerns.

After years of experience dealing with various challenges in capture fisheries management, some SEA countries have set three main sustainable fisheries management objectives: maximizing the catch, minimizing the catch variation and minimizing the depletion of stocks (De Young 2006). Therefore, it is critically needed to initiate estimating the best management strategies for achieving the management objectives while dealing with the fisheries characteristics. A set of management strategies might be attained from best practices among SEA countries.

1.2. Exemplary fisheries management in Malaysia

Among SEA countries, Malaysia has in managed its multispecies fisheries differently. Before the 1980s, Malaysia still had exploitable and largely uncontrolled resources. However, by the mid-1980s, Malaysia attempted to take control of its Exclusive Economic Zone (EEZ) using a full range of management tools. When other countries in the Eastern Indian Ocean region continued an "open access" strategy in managing both coastal and offshore fisheries, Malaysia maintained "limited access" along with a strict licensing policy for its fisheries, fishers, fleets and gears (De Young 2006).

Malaysia has centralized its governance systems comprehensively through both regional and local authority networks for implementing conservation and sustainable resource management policies with multiagency participation. In regard to its law enforcement system, Malaysia has invested more for patrol fleets and conducted fisheries patrols, while other countries have smaller, older and poorly maintained fleets. Malaysia has attempted to gain control of its coastal fisheries through licensing, zoning and data collecting system. Consequently, in the 1990s, Malaysia was a success story in fisheries management among developing countries in Asia. However, it is still necessary to question the future sustainability of Malaysian fisheries. Regardless of this issue, it is still fair to consider Malaysia as the best practice models for estimating best management strategies in SEA (De Young 2006), as Malaysia is also well-known as a leading country for the cluster "Promoting Sustainable Fisheries Practices: Fishing Capacity and Responsible Fisheries Practices" (SEAFDEC 2017).

Small pelagic fishes such as *Decapterus* spp.(Scads), *Rastrelliger* spp. (Indian mackerels) and *Sardinella* spp. (Sardinellas) are economically important species in SEA, not only for food consumption, but also for supporting livelihood and employment of fishers (FAO 2008). Purse seines are a dominant gear used to catch these small pelagic fishes (Kirkley et al. 2003). According to the Annual Fisheries Statistics report years 2002–2016 published by the Department of Fisheries Malaysia (Department of Fisheries Malaysia 2002-2016), the number of fishing vessels operating purse seines has remained stable and composed a small percentage (1.03 – 2.92%) compared to other dominant gears, such as drift gillnets, hook and lines and trawls (Figure 1), but, the purse seine fishery is the second largest after trawl fisheries, and its catches have a consistently increased (Figure 2). Therefore, it is believed that the purse seine fishery might be the most promising fishery for Malaysian fisheries and the livelihoods of their fishers.

A purse seine captures schooling fish trapped inside a purse net while a purse wire at the bottom is pulled and tightened resembling a purse toward a purse seiner vessel. To prevent fish from escaping out of the purse net, the top of net is floated at the surface while the bottom part is equipped by weights. Therefore, a purse seine can catch a very dense fish school in one short haul. It is believed that huge purse seine landings can compensate for the cost of fuel consumption (Suuronen et al. 2012). Technically, there are some important factors affecting purse fishing efficiency, such as net size, number of crew, use of auxiliary instruments, temporal and spatial fish availability and some technical methods to find and to attract fish schools (Pascoe and Greboval 2003). A unit of Malaysian purse seine gear has net sized from 352.33 to 361.63 meters; employs 14 – 19 crew including the captain (Kirkley et al. 2003); has catch rates of 14 mt per haul; and operates mostly during night (Chee 1995). During fishing operations, some fishers use luring lights and fish aggregating devices (FADs) made from coconut leaves and concrete blocks, while other fishers search for fish without lights or FADs (DOF Malaysia 2015, Hassan and Latun 2016, Siriraksophon 2017).

Ecologically, purse seines have a small impact on the sea bed, since the gear is set near the surface (Chuenpagdee et al. 2003, Suuronen et al. 2012). Moreover, the catching performance of the gear is relatively unselective as its catches various species and sizes that could include important non-target species or small-sized target species (Yami 1994, Chumchuen et al. 2016). Regarding fisher's viewpoint, the large purse seine catches might increase their preference of employing this gear, as purse seine is the second most efficient fishing gear contributing to the fish landings after trawls (DOF Malaysia 2015) .

Realizing the potential of their fisheries, the Malaysian Government made a policy to improve the fishing exploitation by increasing the capacity of vessels. The Government issues licenses for vessels larger than 70 gross tonnage (GRT), but at the same time limits the licenses issued to small-sized vessels to balance the effort and fish stock abundance (Jamaludin et al. 2017). According to the Departement of Fisheries Malaysia (2002-2016), the number of purse seine large vessel units has been increased markedly while smaller-sized vessels steadily decreased in number (Figure 3).

Besides the landing trend, the effect of fishing exploitation can be observed from the trend of species composition (Worm et al. 2009). It is documented that the composition of the fish community changed due to fishing impact (Haedrich and Barnes 1997, Jennings et al. 1999). Catch data from the Departement of Fisheries Malaysia (2002-2016) shows that the catch composition graph, which comprises 10 dominant species (82.3% of the total landing of all landed species), changed slightly for all species during 2003 – 2016 (Figure 4).

1.3. General measures of fisheries management

As shown in the section 1.2, the species composition of the purse seine fishery has been relatively stable for years. However, it is still important to question the sustainability of the Malaysian purse seine fishery after the recent increase in fishing capacity (Pascoe and Greboval 2003, Department of Fisheries Malaysia 2015). Therefore, the sustainability of fisheries, especially the purse seine fishery, has been of concern for years. To maintain the sustainability, some predictions of management actions should be taken. Similar to all predictions, they contain uncertainty and should be subject of much elaboration, discussion and conflict (Costanza and Patten 1995). There are three general categories of fishery management measures that can be considered (Cochrane 2002, De Young 2006, FAO 2009, Selig et al. 2017):

1.3.1. Input control

An input control is any measure to limit fishing capacity to control the amount of fish caught, or in the other words, to reduce mortality among all species. It is considered to be easier to implement and less costly to monitor and enforce than other measures. However, it needs administrative and monitoring capacity to decide the amount of effort to assign to each vessel (FAO Fisheries Department 2003). Gear restriction, limited entry (e.g., licensing) and time restriction (e.g., days at sea) are input controls that can be easily used for multiple target species. Particularly, time restriction is thought to protect spawning areas or size classes and to prevent the use of fishing gears on stocks that have high risks or sensitive life histories (Selig et al. 2017). However, biologically this measure could not directly restrict all fleets to target certain stocks (FAO Fisheries Department 2003).

1.3.2. Technical control

A technical control is any measure to reduce fishing mortality or restrict fishing activities on certain times or seasons in certain areas. As a management tool, technical controls can reduce the mortality rate, not only for target species, but also for associated species in their vulnerable life stages. If the stocks are shared by more than one country, the closure must be coordinated (FAO Fisheries Department 2003). This measure works best in fisheries with low-mobility species, steady spawning seasons and locations, and multiple target species (Selig et al. 2017). Therefore, the application of technical control require caution if the stock is mobile, since the fishing impact will be only displaced to other areas and increase mortality of other species or other life stages. Also, it should include the overall effect of closures. Area closures may require a large enforcement effort and can be costly (FAO Fisheries Department 2003).

1.3.3. Output control

An output control or quota system is a measure to limit the amount of fish that can be caught, called total allowable catch (TAC), which is set and shared by fishers through quotas. This system has proved successful in fisheries that have a single target species and relatively low number of fishers as monitoring catch levels is easier under such conditions. Monitoring is the critical factor for implementing output controls (FAO Fisheries Department 2003). In fact, the frequency of output control use is equal for both targeted and multispecies fisheries (Selig et al. 2017). Some studies have highlighted that the use of output control can be ineffective and result in undesirable outcomes, such as high-grading, discarding, etc. (FAO Fisheries Department 2003, Baudron et al. 2010, Selig et al. 2017). However, by combining a quota system and limited entry, TAC has had more success (Selig et al. 2017).

1.4. Purse seine fishery management in Malaysia

Purse seine fishery management measures are based on the existing Fisheries Act 1985 (Act 317). Based on the previous general measures of fisheries management, below are the current management measures being used for purse seine fishery management in Malaysia (DOF Malaysia 2015, Jamaludin et al. 2017):

1.4.1 Input control

Several management measures applied in the core of input control mechanisms as follows:

(1) Zonation

Four fishing zones have been established using a licensing scheme that is designed for specific vessel size, delineated fishing area, purposes and ownership (Figure 5). Zoning is used as a management tool to provide an equitable resource allocation and to diminish conflict between traditional and commercial fishers. Fishers are allowed to fish in areas offshore of the zone they are licensed to fish, but not inshore of that zone.

Zonation details are shown in Table 1. Fishing zonation in Malaysian fisheries clearly displays the design of specific categories in Malaysian fishing zones. Each vessel must register to obtain a license and equipment from the Department of Fisheries (DOF) Malaysia. Also, each fisher must comply with all licensing policies set, and they can be arrested or punished if found guilty. As the purse seine fishery is part of a commercial fishery with vessels larger than 40 GRT and fishing areas in the Indian Ocean, all purse seine vessels operate in Zone C and C2.

(2) Effort limitation

Effort limitation measures applied and regulated in the purse seine fishery in Malaysia are as follows:

a. Closed fishing areas

Commercial fishing vessels including trawlers and purse seiner are prohibited in Malaysian waters less than 5 nm from shore to conserve fishery resources in the zone which is the main nursery grounds of prawn and fish juveniles.

b. Control fishing power

Any attempt to change the tonnage or engine power of fishing vessels requires permission from DOF Malaysia. This measure has been established to limit the number of vessels.

c. Moratorium of license issuance

To reduce the fishing effort, DOF Malaysia has established a moratorium for the issuance of new or additional fishing licenses. The purpose is to ensure that the current high fishing pressure on the limited coastal fishery resources will not increase to prevent overexploitation. Recently, a license moratorium was set for issuance of new A, B and C-zone licenses, while C2-zone licenses can be applied for since the DOF Malaysia attempted to increase the number of larger vessels. The vessels in zone C2 also can re-new their licenses if they complete the following:

- A vessel operational report (Laporan Operasi Vesel/LOV) of fish landings that documents at least 350 tons of landings per year; and
- A monitoring, control and surveillance (MCS) report that documents at least 80% of fishing activities were conducted in Malaysian waters.

d. Registration of fishers

This measure attempts to control the access of new individuals into the fishing industry. Each fisher, both Malaysian and non-Malaysian, is required to hold a fisher registration card. For local fishers, if they have a registration card, they can get subsidies from the Government allocated by the Fisheries development authority of Malaysia (Lembaga Kemajuan Ikan Malaysia/LKIM). To apply for a registration card, local fishers must prove that their main income comes only from fisheries verified by fisher's association and that they have sailed more than 120 times. For foreign fishers, to apply for a card, they must submit the name of the vessels where they have worked on, passport, and sailors book issued by their country.

1.4.2. Technical controls

Two management measures considered as technical controls have been used for years in the Malaysian purse seine fishery:

a. Conservation of marine resources

Conservation of marine resources has always been the main concern of DOF Malaysia. Together with the Department of Marine Park, DOF have attempted to ensure closed area/ban for fishing activities in the fish spawning areas to conserve fishery resources. At present, some islands off the East Coast Peninsular Malaysia (ECPM) have been declared Marine Parks (Talang-talang Besar Island, Talang-talang kecil Island and Satang Island). In these areas, the collection of marine fauna and flora is prohibited, while in Tanjung tuan and Besar Island, fishing is prohibited without a specific license (Figure 6). The Departments also plan to conduct closed seasons at certain times to ensure fishery resources are not exploited without control. However, it has not implemented yet.

b. Rehabilitation of resources

To ensure marine enhancement in Malaysian waters, 66 artificial reefs and 20 boat reefs have been established. The reefs are used as a tools for fisheries management in maximizing fishing exploitation, habitat rehabilitation, resource conservation and diminishing overfishing effects.

1.4.3 Output control or quota system

Malaysia has tried to set TACs as a quota system since 2008, which was documented in National Plan of Action for the Fishing Capacity in Malaysia (Plan 2) (Department of Fisheries Malaysia 2015). Malaysian fishery managers thought that setting a quota system might be not applicable or practical in Malaysian waters due to its multilevel and multispecies fisheries (Department of Fisheries Malaysia 2013). However, DOF Malaysia has conducted a pilot project and feasibility study on purse seiners on the East Coast and West Coast of

Peninsular Malaysia (ECPM and WCPM), although the quota system has not yet been assessed or implemented (Department of Fisheries Malaysia 2015).

To support a feasibility study of quota system implementation in purse seine fishery management, the prerequisites of its implementation need to be considered. Before starting a quota system, fishery managers must decide the TAC as an annual catch limit, which is usually based on scientific advice or catch data known as allowable biological catch (ABC) (Punt 2010, Anderson et al. 2018). This requires data of each species individually as fitted and applied in single-species stock management models (Hilborn and Walters 1992, Cadrin and Dickey-Collas 2015).

Malaysia has applied single-species approaches (particularly Schaefer's and Fox's surplus production models) in fisheries management for years. The use of surplus production models has gained a wide acceptance in Malaysia due to the general absence of mathematical models, and no attempt has been made to model using an age or length base (Pascoe and Greboval 2003). Theoretically, a surplus production models describe how the maximum yield is produced through logistic line (Schaefer 1954) and exponential line (Fox 1970), which were initially developed for temperate stocks.

A single-species fish stock approach assumes fishing exploitation of a single stock by a homogenous fishing fleet. However, most fisheries, including Malaysian fisheries, must deal with multi stocks or multi fleets chasing the same fish resources (Sparre and Venema 1992). Therefore, to implement a quota system in a multispecies fishery such as the purse seine fishery in Malaysia, information related to the species (including habitat and seasonal life stages) is needed. Consequently, by applying this measure, managers can modify catch control, particularly for more vulnerable species (Pascoe and Greboval 2003).

The Malaysian Government has conducted almost all management measures, including input and technical controls (De Young 2006). Neither input nor technical controls could restrict the fleet to catch certain vulnerable species that might be economically valuable key stocks (Pascoe and Greboval 2003). It should, however, be stressed that the success of fisheries management is evaluated and judged almost solely by the conservation status of the valuable species (Marchal et al. 2016). Therefore, it is necessary to confirm whether output controls, which can comply with the gap of input control implementation, can be applied in multispecies fisheries such as in the Malaysian purse seine fishery.

The implementation of output controls requires the definition of each species, area and seasonal life stages. It is critical to confirm whether the purse seine fishery multi-species fisheries in Malaysia can be easily localized by areas (spatially) or by seasons (temporally) before the implementation of output controls.

1.5 Aim of this study

The aim of this study is to assess the applicability of output control implementation in the multispecies purse seine fishery in Malaysia. The study was conducted by analyzing the spatial and temporal patterns of the purse seine fishery in Malaysia.

Two research questions were formulated:

(1) To attest the applicability of output control implementation in multispecies purse seine fishery in Malaysia:

To what extent can the multispecies purse seine fishery in Malaysia be structured with respect to spatial distribution and temporal distribution

(2) To confirm the output control overcoming the problems of applying multispecies fisheries approach:

To what extent can output controls that have been validated in single-species fisheries be implemented in multispecies fisheries?

1.6 Structure of the thesis

This thesis comprises four chapters to present the purse seine fishery management in Malaysia. In the chapter I, the current purse seine fishery management and its problems related to sustainability are described. The implementation of output control as one management measure to solve the problems yet raises complications concerning the prerequisites of output control to obtain spatial and temporal species-specific information.

In the chapter 2, the output control applicability in the Malaysian purse seine fishery is confirmed spatially and temporally. This chapter presents an overview of the purse seine fishery in Malaysia by defining species diversity and cluster analyses to confirm the spatial and temporal structure of the fishery.

After confirming the multispecies situation in the fishery, in the chapter 3, the prospective harvest control rule (HCR) as an output control that was previously validated in single-species fisheries is introduced and validated to be implemented in such a multispecies fishery. In this chapter, the validation of the HCR is performed by a simulation study.

To sum up, chapter 4 discusses the conclusions. General issues of purse seine fishery management in Malaysia are clarified. Future works and considerations are also offered to improve purse seine fishery management in Malaysia

2. OVERVIEW OF THE PURSE SEINE FISHERY IN MALAYSIA

2.1. Background

Over the past several decades, pelagic fisheries have become the largest part of marine production in Malaysia due to the contribution of the purse seine fishery (DOF Malaysia 2015, Harlyan and Matsuishi 2017). During 2002 to 2016, the purse seine fishery contributed 21.8 – 29.4% of the total marine production making it the second highest contributing gear after trawls (Department of Fisheries Malaysia year of 2002-2016 2016). The increasing demand for fish encourages fishers with highly-equipped fleets to continuously race for fish, which can lead to overcapacity and resource depletion (Purcell and Pomeroy 2015, Amornpiyakrit and Siriraksophon 2016).

Overfishing and overcapacity critically threaten sustainable management, so consideration of multiple measures has increased by the implementation of the FAO International Plan of Action for the Management of Fishing Capacity (FAO 2004) and the Regional Plan of Action for Management of Fishing Capacity (RPOA-Capacity) (Amornpiyakrit and Siriraksophon 2016, SEAFDEC 2017). Being the first country in the Association of Southeast Asian Nations (ASEAN) to develop a plan of action for fishing capacity, Malaysia has developed a National Plan of Action Fishing Capacity as a template for ASEAN member states (Department of Fisheries Malaysia 2015).

Recently, the DOF Malaysia has adopted various measures for Malaysian pelagic fisheries: technical measures (i.e., closed fishing area, zoning and conservation of marine habitat); input control (i.e., control on number of issuance fishing license and registration of fishers); and community based fisheries management (DOF Malaysia 2015). Combination of multiple measures is the most effective for lessening the risk of stock collapse including increasing biological and economic yields (Stefansson and Rosenberg 2005). Moreover, reinforcing multiple measures can increase the resilience of the fishery overall (Salas et al. 2007).

The implementations of multiple measures have led to valuable progress in Malaysian fisheries management. However, some measures have not been clearly shown as the key performance indicators (KPI), particularly regarding the implementation of output controls such as setting an Individual Quota System (IQS). An IQS was conducted for the purse seine fishery in the ECPM, however, no assessment or implementation has been affirmed for the study results (Department of Fisheries Malaysia 2015). The IQS is set by total catch since the data used are not categorized by species (Jamaludin et al. 2017) because the catches comprise multiple species (Kato 2008).

To set a quota based-system, catch data statistics of each species are required (Kindt-Larsen et al. 2011, Yuniarta et al. 2017). Some doubts of providing species-separated data, however, make its prerequisites seem difficult to implement in Malaysian fisheries (Department of Fisheries Malaysia 2013). Therefore, it is necessary to confirm whether implementation of the IQS can comply with the current measures applied in Malaysian fisheries where only mixed-data are available. As a prerequisite of implementation, the IQS needs some information from related species which specifically describe the ecosystem preference of the species (including habitat and seasonal life stages of each species), so that by applying quota systems, the managers might be able to control the catch of more vulnerable species (Pascoe and Greboval 2003, Dunn et al. 2011). Therefore, it is imperative that managers be given a feasibility study as a reference to confirm the applicability of the IQS, a part of national plans, towards the fisheries before its implementation.

In this chapter, the overview of the purse seine fishery is considered as the feasibility study for the implementation of the IQS. There are three issues that need clarifying information on the overview of purse seine fishery in Malaysia: the structured patterns of purse seine fishing areas; the species contributing most to create the species diversity; and the patterns of purse seine fishing zones and seasons.

2.2. Materials and Methods

To confirm the condition of purse seine fishery in Malaysia, two important factors including fishing grounds (spatial distribution) and fishing seasons (temporal distribution) were analyzed. A list of purse seiners was obtained from the Southeast Asian Fisheries Development Center (SEAFDEC)/ Marine Fishery Resources Development and Management Department (MFRDMD) in Kuala Terengganu, which is daily updated. In 2016, the list comprised 3642 licensed vessels, 41.34% operated in ECPM, and the rest distributed in the WCPM (30.31%), Sabah (24.61%), Sarawak (3.35%) and Federal Territory (0.39%). The sizes of vessel were dominated by GRT <70 (66.94%) and GRT 40−69.9 (25.21%) (Department of Fisheries Malaysia year of 2002-2016 2016). The lists indicated that purse seiners were more numerous in ECPM area than in other areas, and most were larger sizes.

Sample respondents were randomly selected from fishers in the landing sites. Interviews were conducted in the early morning as most purse seine landing times were before noon. A total of 137 owners of purse seiners were interviewed. Their vessels measured 14.48−26.46m in length; 4.50−8.70m in width; 1.20−3.94m in depth; and 28.64−229.71 in GRT. The numbers of one-day fishing trips were 1−25 days/month. When inconsistencies were identified in the data collection during analysis, the SEAFDEC team and local authorities contacted the selected fishers again to gather more information.

2.2.1. Study area and data sources

ECPM is surrounded on three sides by the South China Sea. It is made up of four states from north to south: Kelantan, Terengganu, Pahang and Johor. Three field surveys (Table 2) were conducted at six fishing landing centers located in those states which were taken as research sites (Table 3, Figure 7). Generally, fishing activities in Malaysian waters are conducted throughout the year, even though activities decreases between November and January due to strong winds (Islam et al. 2014).

As revealed in the previous chapter, the fishing activities managed by zonation are categorized into four zones based on fishing ground distance from shore (Figure 5). Purse seine vessels are larger than 40 GRT and fishing areas occur in the Indian Ocean, so all purse seine vessels operate in zone C, C2 and C3. C is 12–30 nm from shore; C2 is 30 nm from shore to the Economic Exclusive Zone (EEZ) boundary; and C3 is the high seas. In this study, the observed zones were C and C2, since C3 is only for tuna long-liners and tuna purse seiners (Table 1).

C-zone vessels hold C zone licenses, while C2-zone vessels hold C2-zone licenses. In the zonation, vessels that hold a license can fish in that zone and all zones offshore of that zone, but not in zones closer to shore. Therefore, C-zone vessels can operate zones C, C2 and C3. However, C2-zone vessels can operate only in C2 and C3.

The data for this study was obtained from face-to-face interviews of local authorities and fishers using a questionnaire. Prior to field data collection, intense discussions with MFRDMD/SEAFDEC staffs were conducted to improve the questionnaire and gather information on fisheries management, data collection and fishery operation.

The questionnaire consisted of three forms covering several issues: Form 1 covered information on the current fisheries management and its implementations; Form 2 covered information about how fisheries data are collected; and Form 3 covered information about fishery activities including landing composition, fishing grounds, fishing operations and fishers' behavior (Appendixes, Appendix 1-3). To acquire the fishing ground data, participatory mapping was applied to assist respondents in identifying and marking the fishing grounds.

2.2.2. Data analysis

As provided in the preceding part, the field surveys were conducted in three survey periods. Each survey was performed at six different landing sites along the ECPM coast. Data collected included species information about its landing site, period of landing, fishing ground, vessel zone and the amount of landing. The data were inputted and classified based on that information. For further analyses, the data were looked up by applying pivot table application.

To broadly describe information about the structured patterns of purse seine fishing areas, four analyses were conducted to provide the possible structures of fishing areas:

(1) Species diversity

To describe the species diversity of each fishing ground, two indices (i.e., Shannon-Wiener index diversity (S-W index, *H'*) and The Margalef's index of species richness (*S*) (Zhu et al. 2011, Boyle et al. 2016)) were used as follows:

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

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

where p_i is the fraction of the caught species, while i represents the number of species caught 1, 2, 3,.., s. and n is the number 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 wealth of species in a community (Peet 1974, Lipps et al. 2014). In this study, the calculation of H' and S was applied for describing the diversity of species composition on each fishing ground spot.

(2) Spatial and temporal analysis

To investigate the patterns of purse seine fishing zones and seasons, spatial and temporal analyses were conducted. Spatial analysis was conducted in zones, C and C2. A zone distribution map was created by QGIS software (QGIS Development Team 2009), which can descriptively show the distribution of both C and C2 vessels during the periods.

Analysis of variance using distance matrices for partitioning distance matrices among sources of variation was used by permutation test with pseudo-*F* ratios, named Adonis function under Vegan package (Oksanen et al. 2018). It is directly analogous to Multivariate ANOVA based on dissimilarities. Significance tests are applied using the *F*-test based on sequential sums of squares from permutations of the data. For both spatial and temporal analysis, the Adonis function was used to determine if there were any significant effects of vessel zone distribution, period of survey distribution and the interaction between these factors.

Analysis of similarity (ANOSIM) provides a way to test statistically whether there is a significant difference between two or more groups of sampling units. This function operates directly on a dissimilarity matrix, which is produced by function "dist". If two groups differ in their species composition, the compositional dissimilarities between the groups must be greater than those within the groups. The ANOSIM statistic R is based on the mean difference ranks between groups and within groups. This analysis was applied to analyze the significant difference of zones.

Temporal analysis was also applied to portray the plot distribution of survey periods. A survey period distribution map was also created by QGIS software (QGIS Development Team, 2009), which can descriptively show the distribution of three different periods. As applied for spatial analysis, ANOSIM was also applied for temporal analysis to analyze whether there were any significant differences in three survey periods.

(3) Cluster analysis

To group 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 a number of clusters based on the observed values of several variables. A total of 137 fishing ground spots considered as observations, while 26 species and their catch weights were the reflected variables and values, respectively. The purpose of cluster analysis is to maximize the similarity among observations within each cluster while maximizing the dissimilarity among group clusters that are initially unknown. Hierarchical cluster analysis is a method for finding relatively homogenous clusters based on dissimilarity (the Euclidean distance) between variables. In this method, at first each data point is considered as an individual cluster. Afterward, the similar clusters merge with other clusters until a single cluster is formed containing all observations. A hierarchical dendrogram is generated to show the relationship between clusters. The Euclidean distances are computed from raw data (Roy et al. 2015). Below is the formula of the Euclidean distance between two n-dimensional vectors x and y:

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

where i is the number of variables. In this study, if there are two fishing ground spots, x and y, the Euclidean distance between these two spots $d_{x,y}$ is calculated by considering abundance proportion of the i species in the whole data set.

On the dendrogram, there are two values in different colors, red and green. The red color defines the Approximated Unbiased ρ value (AU value), which is approximately unbiased ρ value computed by multiscale bootstrap resampling and has better approximation than (BP bootstrap probability) value shown in green computed by normal bootstrap resampling. For a cluster with AU ρ value > 0.95, the hypothesis that 'the cluster does not exist' is rejected with significance level 0.05, or in other words, these highlighted clusters do not exist due only to sampling error, but might stably be observed if the number of observations is increased (Suzuki and Shimodaira 2017).

After clustering, to determine localization of fishing potential areas, the fishing grounds of each cluster along with their species compositions were plotted.

(4) Principal component analysis

To explore the species contribution during the three survey periods, principal component analysis (PCA) was conducted. PCA describes and extracts information from a data table into a set of new orthogonal variables called principal components. Thus, it shows the similarity pattern of the observations and variations as points. The goal of PCA is to analyze the structure of observations and variables to more easily simplify the description of the data set. Next, the size of data set is compressed so that only the most important information is kept (Abdi and Williams 2010), since PCA can be useful for eliminating components without losing variations.

PCA was used to determine which species contributed most to the similarity within fishing grounds by extracting important variables in large sets of available variables, since there are many predictors and many observations. PCA was performed using built-in R functions prcomp and princomp (R Core Team 2018). To confirm the contributive species in the PCA, the FactoMineR function was applied under R packages of vegan, permute and lattice (Le et al. 2008, Oksanen et al. 2018)

2.3. Results

2.3.1. Species composition

Owing to surveys, 26 species were found, which only nine taxonomic groups, trash and mixed fish were tabulated (Figure 8). These 11 species groups composed 98.42% of total samples. The composition was dominated by category species such as *Decapterus* spp (Scads) (34%), *Thunnus tonggol* (Long tail tuna) (13%) and *Euthynnus affinis* (Mackerel tuna) (10%) and comprised small portions of other species. A large percentage of aggregated species were trash (20%) and mixed fish (4%). Trash fish were low-value fish, while mixed fish were small-sized *Sardinella* spp, *Decapterus* spp, etc. used for processed products, such as fish snacks.

Aggregation of catch categories based on genus also occurred for some dominant species composing nearly 65% of landing, except *Thunnus tonggol* (13%), *Atule mate (*Yellowtail scads) (2%), *Euthynnus affinis* (10%), *Selar crumenophthalmus* (Bigeye scads) (5%), *Rastrelliger kanagurta* (Indian mackerel) (3%) and *Selaroides leptolepis* (Yellowstripe scads) (2%), which composed 35% of the landings. From the interviews, sorting of different species into groups lessen the sorting time so that they can work for more vessels. Most of the dominant species in the landing composition survey in 2017−2018 (Figure 8) were also dominant during 2003−2016 (Figure 4).

2.3.2. Species diversity

There are 137 sites sampled in three surveys and the 26 species collected are mapped in Figure 9. Each fishing ground comprised various species, which are widely distributed. To describe the diversity of species in the ECPM, two indexes called species richness and species diversity were shown. The species richness index showed that the number of species varied by each fishing ground with an overall range of 1.0− 9.0 (Figure 10). With similar results, the species diversity showed that the diversity also varied by each fishing ground in five ranges between 0 and 1.78 (Figure 11). For some fishing areas, there were some overlaps between areas with low and high species richness, which also occurred for the species diversity index. No structured species diversity pattern was found for either index (Figure 10, Figure 11).

2.3.3. Spatial and temporal analysis

The results of spatial and temporal analysis ANOVA show that all factors and interaction had significant effects in structuring the species composition at each site (ρ value ≤ 0.05). Both factors had more significant effects than their interaction. Regarding the strength of each factor, it is explained by the percentage of each factor towards the sums of squares, which were about 5.9%, 2% and 1.4% for the zone factor, period of survey factor and its interaction, respectively (Table 4).

Regarding the vessel zone distribution map (Figure 12), vessels with C- and C2-zone licenses were diversely distributed. Some vessels from southern areas fished in middle or even northern areas. Few C-zone vessels went into zone C2. Most C2-zone vessels were in C2, however a few were in zone C, which is prohibited. From the species composition of these two zones (Figure 13), 65% of 23 species were dominantly caught by the C-zone vessels, and half of them were caught only by these vessels. Some neritic tunas, such as *Thunnus tonggol* and *Euthynnus affinis* were dominantly caught by C2-zone vessels.

Statistically, there was a significant difference between C- and C2-zone vessels of their species distribution (ρ value=0.0001), while the statistic R value was 0.2203 (Figure 14) which expressed that the zone factor had a small effect to species distribution. Figure 14 shows that the dissimilarity between zones was higher than that in each zone. The dissimilarity within group of C2-zone vessels was less than to that of C-zone vessels.

The period of study distribution map (Figure 15) shows that some points of the three surveys overlapped and aggregated in the northern part of ECPM. There was a significant difference in species distribution (ρ value=0.001), while the statistic R value was 0.106 (Figure 16), which showed that the survey period had a small effect on the structure of species composition in ECPM. The plots showed that the second survey (July 2018) had a higher dissimilarity in species contribution than in other periods and the mean difference between periods.

2.3.4. Cluster analysis

Another way to identify the structured pattern of fishing ground in multispecies purse seine in ECPM is by clustering the fishing ground that resulted in seven groups of species (Figure 17) as shown in Figure 18. These clusters have different sizes, which depend on the similarity distances of each species. Cluster VII had the largest number of fishing grounds (98), which were distributed widely, while cluster I, III and IV each contain only 2 sites.

By plotting the latitudes and longitudes of the clustered fishing grounds, cluster V and VI clearly show different distributions; cluster V occurred further south than cluster VI (Figure 19). These group relationships might reveal a structured pattern of the fishing grounds in ECPM. The species composition of clustered groups revealing that almost all species were diversely distributed in all groups (Figure 20). Comparing the composition on cluster V and VI, *Thunnus tonggol* was found with a large percentage (>50%) in the cluster VI but in small portions in the other groups. Based on Figure 19, the potential fishing area of ECPM is $103^{o}36^{'}$ - $104^{o}19^{'}$ E; $3^{o}36^{'}$- $5^{o}57^{'}$ N.

2.3.5. The most contributive species

The PCA results were applied to determine the most contributive species in regards of creating species diversity in the ECPM. From the scree plot, the fraction of total variance in the data as explained by each dimension or principal component showed that the explained variances of each dimension were relatively low with maximum of 8.3% and 7.1% at dimension 1 and 2, respectively (Figure 21). The six most contributive species to create the species diversity and their contributive percentages were *Selar crumenophthalmus* (22.21%), mixed fish (13.87%), *Decapterus* spp (12.15%), *Alepes* spp (9.26%), *Rastrelliger kanagurta* (8.52%), and *Pampus argentus* (8.39%) (Figure 22). Seven clusters of 137 fishing grounds were also plotted together with the factor map. It shows that all clusters are overlapped and could not reflect the variations generated by the six contributive species. These species were located far from the center as a center of similarity, including mixed species, which comprised a group of species, while the clusters are layered in the center of similarity.

2.4. Discussion

For years, as a country with multispecies fisheries, Malaysia has implemented a guideline in management measures and their application to not apply output controls since they sound impractical due to the many species involved and rather to focus only on a combination of input controls and technical measures (Cochrane 2002). To manage multispecies fisheries, a combination of those controls is the best management option, yet both still could not restrict the fleet to catch certain species, which might be valuable stocks (Pascoe and Greboval 2003, Kvamsdal et al. 2016). Output control as a management measure to control and protect stocks confirm its necessity to be applied since the success of fisheries management is evaluated and judged almost solely by the conservation status of valuable species (Marchal et al. 2016).

Recently, output control has been used in the purse seine fishery (Department of Fisheries Malaysia 2015, Harlyan and Matsuishi 2017). As it is believed that this measure might be designed not only to constrain the quantity of fish being caught, such as number and weight of fish, but also to constrain other qualitative catch characteristics, such as protected species, size limitation, sex and maturity stages (Morison 2004), which will benefit by dealing with overcapacity issues related to the imbalance between fishing capacity and stock availability (Pascoe and Greboval 2003, Department of Fisheries Malaysia 2015). However, some structures are needed to implement catch management measures, such as the centralized nature of catch management in command and control approaches; and monitoring, enforcement and advisory structures, which also include scientific assessment of the stock size (Cochrane 2002). Some cases have documented that this measure might cause other serious impacts for multispecies fisheries such as discarding, high-grading, racing among competing fishers, costly real-time monitoring system and landings of more bycatches (FAO Fishery Resources Division and Fishery Policy and Planning Division 1997, Cochrane 2002) in the absence of limited entry, technical measures and monitoring systems.

In the purse seine fishery in Malaysia, which has been well-equipped with good monitoring, controlling and surveillance systems and implemented almost all measures (De

Young 2006, DOF Malaysia 2015, Jamaludin et al. 2017), the initiation of catch measures as a management measure might be prospective action to achieve management objectives. However, to implement this measure, fishery managers need detailed information about where the fish are caught (FAO Fishery Resources Division and Fishery Policy and Planning Division 1997). Therefore, in this study, some detailed knowledge of the purse seine fishery in Malaysia were revealed to confirm its applicability of catch management measures.

The catch composition documented in annual fisheries data statistics showing that the species composition of the purse seine fishery has remained stable and varied little for almost 15 years was also confirmed in the landing composition recorded during the surveys. Some species composing the largest portion of landings, such as *Decapterus spp, Rastrelliger spp* mixed and trash fish, were aggregated species. This might be due to a lack of financial and technical support in species separation (Yuniarta et al. 2017), which lead to failure in providing individual biological and fisheries information of each species.

Decapterus spp and *Rastrelliger* spp*,* the two most dominant species, are typical pelagic species that occur mainly in Indian Ocean coastal waters and open banks at depths not exceeding 100 meters. *Decapterus* spp including *D. maruadsi* and *D. macrosoma* are year-round species that can be caught by purse seine and trawl fisheries. The species can recover from overfishing quickly (Zheng and Walters 1988). Consequently, no known major threats were observed, however, heavy fishing pressure could affect the population if it is not well managed by strict licensing control (Qiu et al. 2010). As Malaysian fisheries have conducted license measure for years (De Young 2006), the species have remained the most contributive species in purse seine fishery landings. *Rastrelliger* spp are highly valuable and commonly not recorded separately as three different species (i.e., *R. kanagurta*, *R. brachysoma* and *R. faughni*). Global landings of *Rastrelliger* spp have increased and are assumed to increase in the coming years (FAO 2018). Therefore, *Decapterus* spp*.* have persisted as the second most contributive species for the purse seine fishery in Malaysia.

Temporal analysis shows all seasons in the ECPM generated almost similar species distribution. No clear structure shift occurred, which may have been due to the high of growth rates observed in fish that mature at early age at and spawn year-round (Smith-Vaniz 1984, Zheng and Walters 1988, Abdussamad et al. 2010). Therefore, a high growth rate might gain advantage for purse seine fishery to maintain their catch variability even in high-fishing pressure conditions (Pascoe and Greboval 2003).

To attain the fishing ground data for spatial analysis, participatory mapping was applied. Even though remote sensing and other geographic evidence can provide the locations of fish schools more efficiently, it is still challenging to exhibit species-specific site information by these methods (Klemas 2013). On the other hand, it is also understandable that fishers can be reluctant to share their fishing ground spots precisely (Corbett and Keller 2006). Therefore, it needs to be cautioned that all spatial analysis results in this study hinge on some uncertainty since the results were not combined with independent tracking surveys (Navarrete Forero et al. 2017).

Spatial analysis showed some overlapped areas in the northern part of ECPM as some vessels from southern parts fished in northern parts to avoid Indonesia's maritime boundary. The other concern of spatial analysis is about implementation of zoning criteria that delineate permissible fishing areas for both C- and C2-zone vessels. The results that revealed some C2-zone vessels fished in zone C (<30 nm from the coast line), but they hinge on uncertainty of participatory mapping.

The species compositions of C- and C2-zone vessels were different. This might be due to incomparable wide fishing areas for both vessel types. The C-zone vessels can go enter zone C2, but C2-zone vessels could not enter C. The limitation of C-zone vessels to go as far as C2-zone vessels is only their capability of having larger fish hold and taking more fishing supplies, such as fuel, food and ice. In this situation, the C2-zone vessels have more capacity to catch more valuable and important transboundary resources such as the neritic tunas, *Thunnus tonggol* and *Euthynnus affinis*. These tunas were mostly caught by C2-zone vessels as these two tunas occur widely around the Pacific Ocean further from the ECPM coastline (Siriraksophon 2017).

Peninsular Malaysia has very high species richness (Parravicini et al. 2013) and species diversity (Jenkins and van Houtan 2016). However, in this study it is challenging to structure the patterns of fishing grounds based on these diversity indexes, since the adjacent fishing grounds could not provide similarity to each other or comparable index values. Also, neighboring and overlapping fishing grounds could not perfectly reflect the species composition and distribution. Cluster analysis is another way to reveal the structure of a fishing ground, which could provide a clear pattern for certain species.

The cluster analysis clearly found that *Thunnus tonggol* is a species that might have been individually localized in the middle to northern areas of ECPM (102º22º –104 º22º E; 5º7º –6º42ºN). Among other pelagic species in the ECPM, *Thunnus tonggol* might have a slower growth rate, which would make it grow more slowly, live longer and be more vulnerable to overexploitation by fisheries (Griffiths et al. 2009, Collette et al. 2011). Therefore, fishery managers in Southeast Asia have recognized the importance of neritic tuna as an important and rich transboundary fishery resource in the region by establishing the Regional Plan of Action on Sustainable Utilization of Neritic Tuna in the ASEAN Region to ensure its sustainable use (SEAFDEC 2017).

Based on the genetic stock structure of *Thunnus tonggol* in Southeast Asia, there are two stocks across the region: Pacific Ocean and Indian Ocean stocks (Willette et al. 2016). In ECPM, which is part of the Pacific Ocean, the stock size *Thunnus tonggol* in 2013 was in safe condition. The total biomass (TB) was higher than the MSY level (TB/TB_{MSY}=2.22) since the fishing mortality (F) was in underfishing condition (F/F_{MSY}=0.18). The risk catch assessment stated that if the catch amount increased to the MSY level of 196,700 mt, the risk of violating the TB_{MSY} and F_{MSY} would be about 50%. However, it is necessarily to be cautioned that there was an indication of high catch variability for this species. The catch of *Thunnus tonggol* in the region peaked in 2008, but sharply decreased in 2013 (SEAFDEC 2015b).

Therefore, it is important to improve fishing capacity management by prohibiting fully or partially specific fishing gears in particular fishing grounds (SEAFDEC 2017). However, even though the delineated habitat of *Thunnus tonggol* can be provided, it is still not sufficient to suggest closure management for this transboundary species without seasonal migration and age structure information. In this situation, implementation of output control (i.e., TAC determination) through management strategy evaluation can be an option (SEAFDEC 2015b). Concerning the TAC determination for *Thunnus tonggol*, it is critically needed to manage this separately from the multispecies approach by maintaining regional improvement on its species-specific information reliability.

The results of the six most contributive species that created species diversity in ECPM might not be accurate since some of these species literally are groups of species. This also revealed uncertainty in annual data statistics in which there were differences between fisheries data statistics and actual landings. Inaccuracy in species separation will cause misreporting, which will lead to unreliable fish stock estimation (Yuniarta et al. 2017). The other concern about species aggregation is the large proportion that was recorded in all landing compositions. Nearly 25% of total landings, for trash and mixed fish along with aggregation of catch categories roughly 40% of total landings, were huge aggregations that might lead to difficulties in defining habitat for each species particularly (Roberts et al. 2005). However, there have not been any previous catch analysis studies to confirm the species composition of trash and mixed fish that might later be used to adjust the annual fisheries data statistics.

In fact, the determination of fishing grounds depends on the fisher's possession of FADs, which are distributed widely to support fishing operations for dominant species like *Decapterus* spp, *Atule mate*, *Selar crumenophthalmus*, *Rastrelliger kanagurta* and *Thunnus tonggol* (Hassan 1992). Fishers will ensure their FADs function before fishing, even though no fixed amount of catch is guaranteed from the FADs (Macusi et al. 2017).

Recognizing that the condition of multispecies fisheries, where assemblies of species are caught by the same or different gear, it is critical to manage such fisheries by a single-species approach (Shertzer and Williams 2008). There is a huge species aggregation on catch categories, which leads to inability to provide species-separated data. Apart from

Thunnus tonggol, no specific pattern has been found in localize species spatially or temporally since, multispecies fisheries are subject to widely distributed and homogenously mixed fish stocks, which lead to non-selective exploitation (Murawski et al. 1983, Murawski 1991). Regarding the needs to apply the IQS for purse seine fishery management in Malaysia, a tactical short-term management approach, i.e., harvest control rule, can be an option to respond to the demands of data-limited management which might occur in multispecies fisheries (Anonymous 2015, Yuniarta et al. 2017, Harlyan et al. 2019).

3. PROPOSED MANAGEMENT MEASURES FOR THE PURSE SEINE FISHERY IN MALAYSIA: AN OUTPUT CONTROL FOR SUSTAINABLE FISHERIES

3.1. Background

Most world fisheries are multispecies fisheries, where a multitude of species are exploited by the same or different gear simultaneously (Welcomme 1999, Möllmann et al. 2014). Especially in tropical regions, where many mixed or multispecies fisheries exist, Malaysia, have attempted to use single-species stock assessment even though it is difficult owing to the use of various types of gear and sympatric assemblages of abundant species (Johannes 1998, Welcomme 1999, Mace 2001). However, for years, Malaysian fisheries management has been based on a scientific model designed for temperate regions, wherein maximum sustainable yield (MSY) is calculated for a few key species (Pascoe and Greboval 2003), although the applicability of this model is limited in multispecies tropical/subtropical fisheries (Pomeroy 1995). Moreover, Malaysian fisheries, as in other fisheries in SEA, have to deal with lack of financial and technical support in species separation which might also lead to failures to provide species-separated data (Yuniarta et al. 2017).

Harvest control rules (HCRs), as algorithms to determine pre-agreed harvest management actions such as allowable biological catch (ABC) from catch statistics and biological information, are used for making a wide range of fisheries decisions, such as setting total allowable catch (TAC) (Deroba and Bence 2008, Punt 2010, Wiedenmann 2013, Kvamsdal et al. 2016). HCRs, as a tactical management approach, can be one option for output control implementation in fisheries management in Malaysia, which can solve overfishing problems by directly limiting the exploitation of fish target stocks. Recently, several HCRs have been evaluated across various uncertainties in stock dynamics through simulations based on management strategy evaluation (MSE), a technique used to mimic realistic conditions over various exploitation histories and diverse population characteristics (Butterworth 2007, De Oliveira et al. 2008, Carruthers et al. 2014, Punt et al. 2016, Wiedenmann et al. 2016).

The feedback HCR (Tanaka 1980) has garnered success and is now widely applied in Japanese fisheries management (Ichinokawa et al. 2017). The Fishery Agency of Japan introduced a TAC system in 1997 as the main instrument of fisheries management, which is specialized for stocks where the biomass is not estimated (Matsuda et al. 2010, Makino 2011). The feedback HCR is one of the Japanese harvest control rules that calculate scientific recommendations for annual catch quotas (i.e., ABC) under a TAC system by taking the previous stock abundance index into consideration for the future catch. In the feedback strategy, the resource can be assumed as a control system with catch quota as an input and stock abundance index as an output. In this case, the catch quota is adjusted based on the stock abundance index (Magnusson 1992). Therefore, the feedback HCR designs ABC to stabilize the stock size and ensure continued utilization. The TAC system has proved effective in achieving decreases in the exploitation rate of the stocks, as compared with the stocks managed using other systems (Ichinokawa et al. 2017).

Some studies have evaluated the robustness of the feedback HCR through several models that used single-stock data (Hurtado-Ferro et al. 2010, Hoshino et al. 2012, Ohshimo and Naya 2014, Ichinokawa et al. 2015), but none considered validating the robustness of the feedback HCR for a mixed-species fishery. Such validation would be a valued response to recent calls for fishery management approaches under data-limited conditions and applicable to most countries.

In this chapter, the feedback HCR was considered as a prospective HCR in the context of mixed-species data from a multispecies fishery such as the Malaysian purse seine fishery. The sensitivity of its performance over several scenarios of population dynamics was examined and then compared across other modified HCRs.

3.2. Materials and Methods

3.2.1. Evaluation of the feedback HCR

To test the performance of the feedback HCR, a management strategy evaluation (MSE) was conducted over a range of scenarios covering fishes with various life histories and exploitation histories. An MSE that comprises operation, assessment, and management sub-models was developed. A single-species Schaefer production model was applied as an operating model (OM) to determine the population dynamics of a species. It is assumed that the distribution of a species is sympatric and homogeneous in the fishing ground, and that the fishing gear harvests a uniform portion of the fish in the fishing ground without species selectivity

To imitate mixed-species conditions, an abundance index for a group of species was provided using the total biomass of the species group. The feedback HCR was applied to determine a catch quota, and the catch amount in a multi-species fishery was assumed to equal the catch quota.

To compare the performance of the HCR between the mixed-species condition and the single-species condition, the single-species condition was developed by providing an abundance index for each separate species using the simulated biomass of each species. In this situation, the total catch was the total of the catch quotas for each species. The performance measures for a variety of HCR-tuning parameters were also examined. To evaluate the uncertainty of the process error of the population dynamics and the measurement error of the abundance index, this process was repeated 1000 times for each scenario.

The feedback HCR evaluated in this study is called the ABC rule 2-1 in the Japanese TAC system (Fisheries Agency and Fisheries Research and Education Agency of Japan 2017) and was previously validated for single-species stock data (Hiramatsu 2004, Ohshimo and Naya 2014, Ichinokawa et al. 2015). The formulas used for the ABC rule 2-1 are as follows:

$$C_y = \delta_y \times \gamma_y \times C_{y-2} \quad (4)$$

$$\gamma_y = 1 + k\left(\frac{b_y}{\overline{I_y}}\right) \quad (5)$$

$$\overline{\mathrm{I_y}} = \frac{1}{3}\left(I_{y-4} + I_{y-3} + I_{y-2}\right) \quad (6)$$

where C_y is the catch quota in year y, which equals to the catch amount for evaluating fisheries management strategies; δ_y is the weighing coefficient and the default values are set as 1.0, 1.0 and 0.8, denoting stock levels that are high, medium and low, respectively. The stock level is determined by the stock abundance index (I_y) in year $y - 2$ [1], using the thresholds made from the 33rd and 67th percentiles of the 20-year historical stock abundance index. Then, γ_y represents the trend of the stock abundance, when available, and this value comprises the weighted coefficient k (default 1.0); b_y is the regression coefficient of the stock abundance index I_{y-4}, I_{y-3}, I_{y-2}, against year; and $\overline{\mathrm{I_y}}$ is the mean of I_{y-4}, I_{y-3} and I_{y-2}.

The coefficients δ and k are tuning parameters that adjust the response of the biomass-trend index on the ABC. In this chapter, different k values were applied to the alternative feedback HCRs. In a similar theoretical study, the coefficient k was named as the feedback gain between the index and future catch, which was applied to ensure the existence and stability of the trend of stock abundance (Magnusson 1992). The value of feedback factor k reflects the sensitivity of the catch quota that is changed by the biomass trends. If k is too large, the catch quota will greatly increase even when the biomass is slightly increasing, and vice versa, which may lead to high variability in catches due to random fluctuation in the biomass index.

Table 5 shows the tuning parameters used in this study. Furthermore, the abbreviation (1-1-1-0.8) indicates that k is 1.0, and δ is 1.0, 1.0 and 0.8, corresponding to high, middle and low stock levels. Thus, the abbreviation 1-1-1-0.8 defines the default feedback HCR.

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[1] see eq. 10 for the abundance index formula.

3.2.2. Management strategy evaluation

3.2.2.1. Operating models

The population dynamics in the operating model (OM) were based on a single-species production model for three species. To simulate mixed-species data, an abundance index was calculated from the total biomass of the three species, though the population dynamics of each species were calculated independently. It was assumed that interspecific relationships among the species are negligible and that all the species exist in closed stocks.

Each model run was simulated for a 51-year period, which was divided into a pre-management period (21 years) and a management period (30 years).

For the pre-management period, the population dynamics are described as follows:

$$B_{i,y+1} = \left\{B_{i,y} + r_i \cdot B_{i,y}\left(1 - \frac{B_{i,y}}{K_i}\right)\right\}\hat{\varepsilon}_{i,y} - qX_sB_{i,y} \tag{7}$$

where $B_{i,y}$ is the biomass of species i (i=1, 2, 3) in year y; r_i is the intrinsic growth rate of species *i*; K_i is the carrying capacity of species i; q is catchability; and X_s is fishing effort for each scenario s (s = 1, 2, 3) described below . As a cautionary note, the catchability (q) was assumed to be uniform. In this situation, the distribution of all species is sympatric and homogeneous in the fishing ground, and the fishing gear harvests a constant portion of fish in the fishing ground without species selectivity. To express the process error of the population dynamics, a log-normal error $\hat{\varepsilon}$ was induced as follows:

$$\hat{\varepsilon}_{i,y} = \exp\left(\sigma_R\varepsilon_{i,y} - \frac{1}{2}\sigma_R^2\right) \tag{8}$$

where ε is a random number with standard normal distribution, and σ_R is the scale of variance for the process error.

To cover various changes in stock size in the pre-management period, three scenarios were considered, following the method of previous simulation studies (i.e., Hiramatsu 2004, Ohshimo and Naya 2014, Ichinokawa et al. 2015). Exploitation histories for the pre-management period were reflected in the value of the initial biomass (B_1) and the value of the terminal biomass (B_{21}), which was defined as either high (B_H), medium (B_M), or low (B_L) biomass at 75%, 50% and 30% of total carrying capacity, respectively. Three scenarios, B_L

– B_H, B_M – B_M, and B_H – B_L, showed that the biomass changes from the initial biomass B_1 to the biomass at the end of the pre-management period B_{21} (Figure 23), given the derived fishing mortalities $q \cdot X_s$ at 0.025, 0.133 and 0.233 for B_L – B_H, B_M – B_M, and B_H – B_L, respectively and supposing the deterministic model ($\sigma_R = 0$). However, since the simulation run was conducted with process errors, B_{21} might have various values that did not exactly correspond to B_H, B_M or B_L (Appendices 4–6).

For the management period, the feedback HCR (eq. 4) was applied to calculate the annual catches as follows:

$$B_{i,y+1} = \left\{B_{i,y} + r_i \cdot B_{i,y}\left(1 - \frac{B_{i,y}}{K_i}\right)\right\}\hat{\varepsilon}_{i,y} - \frac{B_{i,y}}{\sum B_{i,y}} C_y \qquad (9)$$

where the catch C_y is calculated by eq. 4 and 5 in the management period. In the multispecies HCR simulations, the pooled abundance index with measurement error was given by:

$$I_y = \left(\frac{B_y + B_{y+1}}{2}\right)\exp\left(\sigma_I \eta - \frac{1}{2}\sigma_I^2\right) \qquad (10)$$

where B_y is the biomass at the beginning of the year y; η is a random number with a standard normal distribution; and σ_I is the scale of variance for the measurement error. The catch of each species in the total catch quota was allocated as proportional to the biomass of each species, which reflects a non-selective multi-species fishery.

To evaluate the robustness of the HCR, the magnitudes of σ_R and σ_I were assumed to be 0.2 for the default, as was assumed in former studies (i.e., Hiramatsu 2004, Ohshimo and Naya 2014, Ichinokawa et al. 2015). Additionally, σ_I= 0.4 was tested, and the results are provided in Appendices 7 and 8.

To accommodate diverse life histories, three types of species were assumed, with the intrinsic growth rate (r) ranging from 0.2 to 1.0, and the carrying capacity (K) ranging from 10 000 to 50 000, which are wider ranges than were included in previous studies to highlight uncertainty (Table 6). Following the conventional Schaefer model, MSY and biomass at MSY (B_{MSY}) were calculated as $K/2$ and $rK/4$, respectively, while fishing mortality at MSY

(F_{MSY}) was calculated as $\mathrm{MSY}/\mathrm{B_{MSY}}$. To ensure robustness of the results related to the relationship between r and K, other scenarios are given in Appendices 9a and 9b.

To compare the performance of the feedback HCR with mixed- and single-species data, simulations for the single-species data were also conducted. The catch for each species was based on the species-specific index of abundance:

$$B_{i,y+1} = \left\{B_{i,y} + r_i \cdot B_{i,y}\left(1 - \frac{B_{i,y}}{K_i}\right)\right\}\hat{\varepsilon}_{i,y} - C_{i,y} \tag{11}$$

$$C_{i,y} = \delta_i \times \gamma_i \times C_{i,y-2} \tag{12}$$

$$\gamma_{i,y} = 1 + k\left(\frac{b_{i,y}}{\overline{I_{\iota,y}}}\right) \tag{13}$$

$$I_{i,y} = \left(\frac{B_{i,y}+B_{i,y+1}}{2}\right)\exp\left(\sigma_I \eta - \frac{1}{2}\sigma_I^2\right) \tag{14}$$

$$\overline{\mathrm{I_{\iota,y}}} = \frac{1}{3}\left(I_{i,y-4} + I_{i,y-3} + I_{i,y-2}\right) \tag{15}$$

3.2.2.2. Performance measures

To evaluate the performance of the feedback HCR, a range of performance measures were calculated to meet a set of management objectives: overfishing prevention, stock conservation, yield optimization, extinction avoidance, and catch stability (Deroba and Bence 2008, Wiedenmann 2013, Carruthers et al. 2014, Punt et al. 2016, Wiedenmann et al. 2016). The performance measures considered five aspects:

(1) The probability of overfishing (P_{OF}) as the proportion of years in which fishing mortality ($F_{i,y}$) exceeded F_{MSY} in the management period, where $F_{i,y}$ was calculated as $C_{i,y}/B_{i,y}$.

(2) Biomass status (B/B_{MSY}), as the average biomass over the last 10 years (B_{42}–B_{51}) relative to B_{MSY}.

(3) Yield status (C/MSY), as represented by the mean catch over the management period relative to MSY.

(4) Management failure, which was defined as the proportion of the simulations run where $C_{i,y} \geq B_{i,y}$ over 1000 simulation runs.

(5) The coefficients of variation (CV) for biomass and catch, which reflect the extent of the biomass and catch variability under the simulation; the CV was calculated as the ratio of the standard deviation to the mean.

These performance measures were compared between the mixed- and single-species data over the various combinations of scenarios and tuning parameters.

3.3. Results

3.3.1. Performance measures of the default feedback HCR

The results present the performance of the default feedback HCR with mixed-species data and with single-species data, for three species, under three different scenarios, and for given different exploitation histories in the pre-management period (Table 7). The 20 trajectories of biomass and catch are depicted to illustrate performance of the feedback HCR under three scenarios B_L – B_H, B_M – B_M, and B_H – B_L (Appendices 4−6). As an example, in the B_M – B_M scenario (Table 7, Appendix 5), with both mixed- and single-species data, the biomass values of species 2 and 3 were generally above B_{MSY} (1.59–1.76 B_{MSY}), while the catch was consistently below the MSY (0.31–0.53 MSY). In contrast, the biomass of species 1 was generally below B_{MSY} (0.87–0.89 B_{MSY}), and the catch was occasionally above MSY (P_{OF} = 0.35–0.37).

Evaluation of the default HCR across the different scenarios in a Kobe-plot (Figure 24) showed that the level of fishing mortality, with both the mixed- and single-species data, was generally below the overfishing threshold (below F/F_{MSY}), except for species 1 under scenario B_H – B_L with mixed-species data. However, for the catch status (Figure 25), the default HCR showed that in all cases, the catch was below the *MSY*.

Comparing the performance of the default HCR between the single- and mixed-species data showed that for most cases, the performances of the two types of data were similarly scattered; however, minor differences in the performance measures were noted for species 1. The B/B_{MSY} of species 1 showed the same trend with single-species data and mixed-species data under scenario B_H – B_L (0.31 and 0.27, respectively) and under scenario B_M – B_M (0.89 and 0.87, respectively). However, the catch status of species 1 in scenario B_M – B_M showed that mixed-species data produced a slightly higher *C/*MSY (0.56) than that with single-species data (0.45) (Table 7).

Under the heavy-exploitation scenario B_H – B_L, the P_{OF} of species 1 was 40% lower with the single-species data than it was with the mixed-species data (0.49 vs 0.83). In terms of the management failure measure for the same species, the single-species data generated failure as high as 0.44, whereas there were no failures using the mixed-species data. However, for species 3, these two measures performed similarly with the single- and mixed-species data, but for species 2, slight differences were evident (P_{OF} =0.13 and 0.05, respectively; Failure = 0.07 and 0.00, respectively) (Table 7).

Across the scenarios, the total *C/*MSY displayed similar ranges with the single- and mixed-species data, at 0.13–0.44 and 0.14–0.47, respectively. Similar performance with the single- and mixed-species data also occurred for total B/B_{MSY}, with values ranging 0.73–1.72 and 0.74–1.70, respectively. Concerning the P_{OF} for the total species, no overfishing was observed when applying either data type. However, in terms of the total management failure measure, the single-species data produced more failures (0–0.48) than did the mixed-species data (0.01) (Table 7).

To explore the robustness of the results with different life-history scenarios, the three species were given various r and K values (Figures 24, 25; Appendices 10−13). Changes of K and r gave similar results for biomass, catch, and fishing mortality status. However, an increase of r distributed the biomass above B/B_{MSY} in all cases, and thus put fishing mortality under the overfishing threshold, including for species 1 under scenarios B_H – B_L and B_M – B_M, and for the total species under scenario B_H – B_L, which had previously resulted in overfished stock status (Figure 24) under the original set of parameter values (Table 6).

3.3.2. Performance measures of the alternative feedback HCRs

To ensure robust performance of the default feedback HCR, alternative versions were compared by modifying the feedback factor values k (Figure 26; Appendices 14−17). In terms of biomass status, the feedback HCR responded similarly to the changes in k with the mixed-species data, but with the single-species data, the changes acted to increase the biomass ratio as k > 1 (k = 2.5), especially for species 1 under scenarios B_H – B_L and B_M – B_M, with ranges of 0.29–0.68 and 0.76–1.12, respectively. In most cases, the CV in biomass showed that there was no difference in performance with changes of the parameter k, except for species 1 with single-species data and under the heavy-exploitation scenario, which attained a high data dispersion of about 0.68 as k > 1 (k = 1.5). Across the modified feedback HCRs, the heavy-exploitation scenario revealed lower biomass than in the two other critical scenarios. These conditions were also reflected in the total biomass condition.

The whole-catch performance roughly showed that the difference in k did not influence the value of *C/*MSY. A similar performance resulted with the mixed- and single-species data, except for species 1 with mixed-species data, which produced a 0.1-higher yield than that with the single-species data under scenario B_M – B_M. However, the catch dispersion with single-species data showed that an increase in parameter k (k > 1) would enlarge the catch data dispersion, leading to poorer model fitness, especially for species 1 under scenario B_H – B_L at k = 2.5 (0.75). Conversely, with mixed-species data, the model fitness performed relatively similar with changes of k and was widely distributed below 0.50, except for species 1, which produced a CV slightly above 0.50 under the heavy-exploitation scenario.

Generally, across the different k parameters, the P_{OF} of the feedback HCRs scattered similarly, with values below 20%, except for the slow-growing species 1. For that species, overfishing occurred more often under the heavy-exploitation scenario (reaching about 80%) than under the other scenarios. Nonetheless, overfishing became less frequent once k > 1.5 for species 1 with the single-species data. However, over the various results across the different species, exploitation histories, and types of data, a state of frequent overfishing was not detected in the total fish community.

The other critical performance was in model failures of some adjusted k parameters in the default feedback HCR, which performed similarly for both the single- and mixed-species data. For each species, the performance of the failure measure acted differently, such that no failure was observed for the typically fast-growing species 3 across the modified k parameters. However, failure occurred more often for species 1 and 2, reaching 60% and 20%, respectively, when k < 1.5. The model failures for species 1 were similarly reflected in the total fish community.

3.4. Discussion

In this chapter, alternative feedback HCRs were evaluated with mixed-species data, and over a range of scenarios, to determine the robustness of the HCR and its effectiveness in attaining a set of management objectives. Previous studies have explored the development and testing of evaluation methods for HCRs for managing data-limited fisheries (Carruthers et al. 2014, Dowling et al. 2015b, Jardim et al. 2015). While Dichmont et al. (2012) published a reference of evaluating HCRs for fisheries with mixed-species data, to our knowledge, no previous validation for reference comparison has been published to evaluate any HCRs for mixed-species fisheries. Therefore, the present study attempted to accomplish fisheries management under a default HCR, which complies with data-limited and mixed-species conditions. A straightforward validation of mixed-species data was generated by comparing the default feedback HCR and its alternates in terms of their performances with single-species data, which have been validated previously (Ohshimo and Naya 2014, Ichinokawa et al. 2015). Under these circumstances, an ideal HCR could be a tool for limiting the frequency of overfishing, maintaining biomass, and generating more stable catches for mixed-species stocks—goals that were reflected in the five performance measures.

Catchability (q) is the value that might substantially influence simulation results, which reflects the efficiency of a fishery or the vulnerability of fish to fishing gear or fishing strategies. For this simulation, catchability was assumed to be uniform among species, therefore it must be cautioned that all results hinge on a constant catchability assumption. However, in some actual fisheries, the assumption for constant catchability may not be always satisfactory as it will vary based on abundance, fish behavior, population dynamics, fishing strategy and environmental conditions (Yamakawa et al. 1994, Maunder et al. 2006). On the other hand, changes in q would also generate additional uncertainty in the catch rate as an index of stock abundance, if q varied over time (Jul-Larsen et al. 2003). The interpretation of catchability can be different depending on how population units are chosen (Arreguín-Sánchez 1996). In this model, catchability was represented as a part of fishing mortality ($q.X$) units to express the number of fish caught in the population. This suggests that the fishing effort is considered uniformly distributed and of constant quality, and the population size is considered constant. Therefore, to obtain an index of total biomass where survey catchability is assumed uniform among species, effort standardization can be applied beforehand. As standardization aims to control species targeting and dynamics of the fleet or population (Squires and Vestergaard 2015).

By taking the constant catchability assumption, fisheries are characterized by multiple species which are subject to the relatively non-selective nature of fishing gears and the homogenous mixing of the fish stock (Murawski et al. 1983, Murawski 1991). Thus, deploying gears to different areas in a certain unit will result in a similar species composition since the fish are homogeneously distributed and have the same probability of being caught by the gears (Hoggarth et al. 2006). However, it is highlighted that the application of a constant coefficient is valid only for the conditions under individuals with similar catchability or the same quality of fishing effort (Arreguín-Sánchez 1996). A tropical purse seine fishery might be an example. In the case of the 2017 Indian Ocean Tuna Commission, including skipjack in the purse seine log-set (PSLS) CPUE provided no evidence of changes in its catchability over time (Kolody and Jumppanen 2018).

Across the scenarios observed for the default feedback HCR, the type of exploitation scenario considerably influenced the performance measures. The heavier the exploitation of the fishery, the poorer the performance of each feedback HCR. Under the riskiest scenario, B_H – B_L, the performance of the default feedback HCR produced the highest probability of overfishing, the least catch productivity, and the lowest biomass availability.

In most cases, the biomass performances with both the mixed- and single-species data indicated that the default HCR could maintain or rebuild a high stock biomass for some life histories, with the exception of species 1, a typically slow-growing and long-lived species, which responded differently. The catch performances also showed that the default HCR could generate a low-risk, low-level yield (below the potential yield) since the fishing mortality was considerably conservative (below the overfishing threshold). These results correspond to other evaluation studies that stated that the more conservative HCR would be compatible for meeting a set of long-term management objectives (Punt et al. 2008, Kleisner et al. 2013, Wiedenmann et al. 2016). The performances of these two parameters showed that there was a trade-off between biomass status and catch status. In a real-life fishery where effective management regulations exist, this trade-off will respond to a decline in stocks by trying to decrease the catch to gradually rebuild the biomass (Kleisner et al. 2013). Therefore, future impact assessments should further consider these two performance measures to improve the applicability of the feedback HCR. In addition, the confirmation of historical fishing pressures is recommended, as the results here revealed that given a relatively low initial exploitation, the performance measures of the default feedback HCR with either mixed- or single-species data were similar for each individual species.

The exploration of five different values of k is a validation of tuning parameters that adjust the trend of biomass indices on the default feedback HCR formula. Ohshimo and Naya (2014) suggested setting k lower to avoid the risk of a high catch CV and higher frequency of management failures. However, those are not the only objectives of management because managers should also try to achieve optimum yields. If an HCR has the capacity to balance the trade-offs between all management objectives, the P_{OF} level should be less than 0.5 across all scenarios (Wiedenmann et al. 2016). From this chapter, it was shown that that increasing k would worsen the model fitness, which would be undesirable in terms of stability of the fishery, even though it would lead to the projection of a higher stock size and catch. Setting a lower k, however, would cause a higher frequency of management failures. In terms of the occurrence of overfishing, no positive outcome was demonstrated through modification of parameter k. Thus, aside from the results of k modification, the default HCR appears to be robust enough to deal with most management objectives, thus there was insufficient reason to recommend a change to the default HCR.

Comparing the performance of different k values between the single- and multi-species data showed that the mixed-species data were less sensitive to k than the single-species data were. Changes in k would not affect all performances measures for mixed-species data.

Conversely, for slow-growing species under single-species data, the biomass ratio increased for k > 1, and lower levels of failure and diminished overfishing occurred for k > 1.5. This situation might be too risky for minor slow-growing species, since the total biomass estimation in the fishery would depend on the other major moderate- and fast-growing species. In this case, it is fair to assert that slow-growing species in a single-species fishery would be better managed separately, by applying the modified feedback HCR with k = 1.5, otherwise the estimation of biomass for slow-growing species would be overestimated.

Performance comparison of the default feedback HCR with the single-species and mixed-species data indicated that in most cases, both applications performed similarity over the four measures, but will be critical under the riskiest scenario, B_H – B_L, where the slow-growing species has a probability of overfishing that is doubled with the multi-species application yet its management failure occurred nearly 50% higher with the single-species application. However, it needs to be cautioned that the similar results of both applications might be due to the assumption of the current framework, which is centered on a uniform catchability across species. Moreover, diverse combinations of life history traits might result in different performances, particularly for the growth rate parameter, as the risk was higher for the slow-growing species than for other species. For the implementation of the feedback HCR in a real fishery, realistic catchability and life history traits can be applied in further simulations, which might cause diverse findings for all performance measures.

Other studies have also shown that unselective fisheries, as occurred in the multi-species application, might have an advantage for conserving the biomass of each species, since mixed-species fisheries cannot target the declined species (Hollowed et al. 2000, Iriondo et al. 2012, Gaichas et al. 2017). However, careful monitoring should focus on the minor species, as they are easiest to disappear in the multi-species body, and in such situation, the unselective assumption might be violated (Gaichas et al. 2017).

The default feedback HCR explored in this study ran on an original set of r and K parameter values, as we assumed that r and K are inversely related. However, in some circumstances the results may be sensitive to different parameter values. Therefore, two additional scenarios were included (Appendices 9a and 9b) to cover a range of life-history characteristics. The results showed the default feedback HCR was less sensitive to the diverse biomass production (K), but receptive to low intrinsic rates of increase (r) (Appendices 10–13). Growth characteristics certainly have a critical effect on population dynamics and fisheries management since fast-growing species mostly support higher estimations of MSY than do slow-growing species (Murua et al. 2017). Therefore, in this circumstance, since the fishing impact levels could be diverse for certain species and different biomass-level scenarios, special monitoring should be considered, particularly for slow-growing minor species, which may display lower biomass and a higher frequency of being overfished when compared with other species.

In this simulation study, the wide ranges of r and K parameter which reflected in three simulated species might represent the nature of the major fish species more than the previous study. It may cover uncertainty occurred in real fishery. However, future simulations with r and K parameter from more realistic species can be conducted for the implementation of the feedback HCR in a real fishery since these might generate more factual results.

In this chapter, implementation error was excluded as a source of error because the purpose was not to characterize the management performance with a given stock, but merely to focus on the performance of the feedback HCR. Consideration of implementation error might reveal remarkable patterns of the control rule's performance if the purpose is to evaluate a management system for a specific fishery (Wiedenmann et al. 2016).

In practice, the feedback HCR might be relevant for management in regions with multispecies fisheries where only mixed-species data are available, as in Malaysia and other Southeast Asian countries. Uncertainties that may cause future impacts to fisheries, if not convincingly handled, could severely degrade the fishery resources, such as depleting the stocks. Such fisheries require short-term tactical fisheries management that can also continuously protect a fishery from unacceptable or undesirable changes to stock size and yield (Anonymous 2015, Yuniarta et al. 2017). Therefore, a short-term management approach, such as the feedback HCR can technically respond to the demands of data-limited management.

Particular HCRs (reviewed in Deroba and Bence 2008) have specific functions, such as maximizing yield or profits, minimizing the risk of overexploitation by maintaining biomass above the MSY threshold, minimizing the stock's recovery time, or minimizing the variability of the yield and profits. Accordingly, this feedback HCR might not be credited as an optimal harvest policy for some data-limited fisheries as compared with some HCRs already reviewed in other studies (Wiedenmann 2013, Carruthers et al. 2014, Dowling et al. 2015a, Newman et al. 2015). However, the feedback HCR described here presents an initial step toward sustainably managing multispecies fisheries while contending with data-limited conditions. Accordingly, Malaysia and other SEA countries are still able to manage their fishery resource sustainably by strictly limiting fishing exploitation on target species while progressively improving their fishery data collection. Afterwards, future improvements to species-specific data availability will allow application of more sophisticated and optimal HCRs. The results of this chapter may be used as a simulation-based reference to expand the use of the default feedback HCR to handle not only single-species fisheries but also mixed-species fisheries.

4. GENERAL CONCLUSIONS

The current fisheries management in Malaysia has been concentrated into the National Plan of Action for the Management of Fishing Capacity (NPOA Fishing Capacity) Plan 2 2015 which shows the fulfillment of Malaysia's commitment to The Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fishing (CCRF) and FAO International Plan of Action for the Management of Fishing Capacity (IPOA-Capacity). The NPOA document addresses the imbalance between the number of fishing vessels and the standing stocks and emphasizes enhancing monitoring and evaluation as actions to manage fishing capacity. The main goal of the NPOA Fishing Capacity 2015 was to achieve an efficient, equitable and transparent management of fishing capacity in marine capture fisheries by 2018. According to the document, Malaysia needs to commit to maintaining sustainable fisheries to accomplish FAO's directives (DOF Malaysia 2015, Harlyan and Matsuishi 2017, Jamaludin et al. 2017) by applying multiple measures that include input and output controls.

In regard to input control implementation, Malaysia has reduced the number of vessels for all types and gears based on MSY level, while conducting regular assessments on the level of fishing capacity and evaluating the status of fishery resources. Fisheries management in Malaysia is based on the MSY level as a product of the conventional single-species stock assessment model. The model requires data from each species (Hilborn and Walters 1992, Shertzer and Williams 2008, Newman et al. 2018). Otherwise, it will lead to failures in adjustment on fishing capacity and assessment on the status of fish stocks due to unavailability on species-separated data. But, in Malaysia and other Southeast Asian countries, multispecies fisheries can provide only mixed-data. Therefore, assessment of the current MSY calculation and analyses is needed for future fisheries management.

For other input control implementation, for many years, a moratorium on vessels and gear give the impression that DoF is willing to increase the numbers of larger vessels ($\geq$70 GRT vessels) than the numbers of smaller vessels (<70 GRT vessels). This is because there has been a strict moratorium on issuances of smaller vessels, while increasing issuances of issuing larger-vessel licenses, as the Government’s policy to improve the capacity of vessels. The Government might reduce the number of vessels but continue to increase the fishing capacity by allowing larger vessels to operate more. In some cases, the fishing effort could remain relatively constant over time, such as number of nets, number of fishing days, while the increase of size of nets and total engine power of fishing vessels might substantially increase fishing capacity (Rahikainen and Kuikka 2002, Chae and Pascoe 2005, McCluskey and Lewison 2008).

In practice, license renewal for larger vessels seems to encourage fishers to land more fish as fishers must declare 350 tons of landings per year, which conflicts with the mandate of NPOA Fishing Capacity to preserve standing stocks towards the increase of fishing capacity. Filling in fishing logbooks (LOV) is necessary to provide information concerning the quantities caught and fishing zones (Duzgunes and Saglam 2008), which is critical to ensure traceability and to control transshipment (Morgan et al. 2007). Besides, the declaration of landings also improve the landing information of larger vessels, which can significantly affect fisheries management in Malaysia, in particular for improving fish stock assessment. However, setting the declaration of landings at a large amount will promote increasing fishing pressures on Malaysian waters. Therefore, it is strongly suggested to continue putting the declaration of landing, without setting a landing quota as a requirement for vessel license renewal.

In addition, to strengthen MCS capacity and capability, several programs are planned to systematically improve cooperation at regional levels, such as regional coordination meetings and joint surveillance with neighboring countries. However, these purposes seem to conflict with one requirement for getting vessel license renewals, which is to declare at least 80% of fishing monitoring tracking unit in Malaysian waters. This means that up to 20% would be in the EEZ of neighboring countries, which could lead to regional conflict to bordered countries.

Most fishers understand these situations and avoid southern areas near the border with Indonesia and concentrated fishing effort in northern areas (Forbes 2014). Indonesia has declared its national sovereignty over fisheries resources in its EEZ. The Indonesian government has strictly dealt with foreign illegal, unreported and unregulated (IUU) fishing since 2012 (McIlgorm and Campbell 2018). This has occurred because there are no international waters in this region.

The fact that multispecies fisheries that cannot provide species-separated data has lead Malaysia to rely on the previous management strategies conducted. Yet Malaysia remains still experiences excessive fishing capacity (Pascoe and Greboval 2003, Department of Fisheries Malaysia 2015), which can be solved by output control measures (FAO 2009), such as implementation of IQS.

Before implementing the IQS, managers must determine either single- or multi- species approach. For tropical countries, such as Malaysia and other SEA countries, to implement an output control, they should take a measure that can straightforwardly allow their mixed-species data. A validated default feedback HCR can be an option of other HCRs.

To determine the possibility of the default feedback HCR implementation in the purse seine fishery in Malaysia, some possible benefits and challenges need to be considered. Some benefits might be attained particularly in regard to data-limited situations. One of management objectives to obtain sustainable fisheries that have optimum catch and biomass along with less catch variation might be accomplished. Other benefits are related to the role of the default feedback HCR as output control measure to directly restrict the fleets from the certain target stocks. For slow-growing species, if Malaysian fisheries are capable of providing species-separated data, separate management should be considered by performing special monitoring along with assessment using the modified feedback HCR.

However, some challenges might arise in the implementation of feedback HCR. In some cases, introducing output control in the fishery where fishers familiar more with input control might lead to some confusion among the fishery stakeholders. Fishers will consider using their fishing licenses to catch as many fish as they can with no consideration of quota that will be produced from output control measures. Other problems might also arise from stakeholders and their interests, since too many licensed vessels operated previously need to be operated to get more fish, which contradicts with the purpose of output control to limit the exploitation of certain fish stocks.

There are some other important management approaches related to future purse seine management. Short-term management approaches should focus on maintaining multispecies fisheries with mixed-species data by feedback HCR. The feedback HCR might be one management measure until improvements on species-specific data are available. Therefore, in the long-term approach, applications of more sophisticated and optimum HCRs might be promoted under species-separated data support systems.

The current management zones in SEA fisheries are applied fishing zones as a spatial management tool to restrict fishing in certain areas, which is based on distance from shore. This tool seems to be inconsistent with the assemblage patterns observed. (Garces et al. 2006). Therefore, it is suggested to re-structure the management by taking into account the basic pattern of the fish assemblages.

Malaysian fisheries and other fisheries in SEA have similar characteristics and sustainability issues. Therefore, compiling a set of management measures for Malaysian fisheries can be used in other SEA countries. SEA might improve input control implementation by limiting fishing effort, but for some cases, it will not solve imbalance between the amount of effort and the standing stock, since it will not protect the stocks from gears. On the other hand, implementing output control solely will lead to critical fishery conflicts since fishers will compete to land the limited quotas. The fishers will race to fish by allocating all their effort to get more fish, which will lead to other fishery sustainability issues such as over-investment. Therefore, a combination of input and output controls will be the best option for providing sustainable fisheries management for Malaysian fisheries and other multispecies fisheries in the region. Concerning Malaysian multispecies fisheries, applying the feedback HCR might be a short management approach before implementing the IQS, which later will complete their multiple measures for sustainable fisheries.

This research pointedly suggests that data-limited multispecies fisheries can be managed sustainably by using multiple management measures, such as a combination of input, output and technical controls. However, it still must be cautioned that improvement on species-specific data availability for the major species or depleted species should be one of the main multispecies fishery issues to be solved in the near future. The availability of reliable species-specific data for certain major species and mixed-species data for other species will generate substantial progress for fisheries management in SEA.

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TABLES

Table 1. 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 2. Period of survey

No	Period of survey
1	July - September 2017
2	June - July 2018
3	September - November 2018

Table 3. 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 4. The ANOVA results of zone and period of survey. The zone factor is for vessel zone distribution (C and C2 vessel zones), 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	

Signif.codes: 0 '***' 0.001 '**' 0.01'*'

Table 5. The feedback factor values for the default feedback harvest control rule (HCR) (case marked with an asterisk) and the alternative HCRs used in this study. The abbreviation 1.0-1-1-0.8 signifies that k is 1.0, and δ is 1.0, 1.0 and 0.8, corresponding to high, middle and low stock levels.

Case	k	δ_{high}	δ_{middle}	δ_{low}	Abbreviation
1	0.5	1.0	1.0	0.8	0.5-1.0-1.0-0.8
2*	1.0	1.0	1.0	0.8	1.0-1.0-1.0-0.8
3	1.5	1.0	1.0	0.8	1.5-1.0-1.0-0.8
4	2.0	1.0	1.0	0.8	2.0-1.0-1.0-0.8
5	2.5	1.0	1.0	0.8	2.5-1.0-1.0-0.8

Table 6. Set of parameter values for the three species in the multispecies fishery.

Parameter	Definition	Species 1	Species 2	Species 3
r	Intrinsic growth rate	0.2	0.5	1
K	Carrying capacity	50 000	20 000	10 000
MSY	Maximum sustainable yield	2 500	2 500	2 500
B_{MSY}	Biomass produced at the MSY level	25 000	10 000	5 000
F_{MSY}	Fishing mortality in achieving MSY	0.1	0.25	0.50

Table 7. Results of performance measures (probability of overfishing [P_{OF}], yield status [C/MSY], biomass status [B/B_{MSY}], and management failure [Failure]) when applying the default feedback harvest control rule to three species (slow-growing [Sp. 1], medium- growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data and single-species data, under three critical biomass-trend scenarios: B_H – B_L, B_M – B_M, and B_L – B_H.

Scenario	Performance measures	Mixed-species results Sp. 1	Sp. 2	Sp. 3	Total	Single-species results Sp. 1	Sp. 2	Sp. 3	Total
B_H – B_L	P_{OF}	0.83	0.05	0.00	–	0.49	0.13	0.01	–
	C/MSY	0.23	0.66	0.45	0.45	0.12	0.59	0.50	0.43
	B/B_{MSY}	0.27	1.44	1.67	0.74	0.31	1.33	1.66	0.73
	Failure	0.00	0.00	0.01	0.01	0.44	0.07	0.01	0.48
B_M – B_M	P_{OF}	0.37	0.00	0.00	–	0.35	0.01	0.00	–
	C/MSY	0.56	0.53	0.31	0.47	0.45	0.53	0.33	0.44
	B/B_{MSY}	0.87	1.60	1.76	1.16	0.89	1.59	1.74	1.17
	Failure	0.00	0.00	0.01	0.01	0.07	0.00	0.01	0.07
B_L – B_H	P_{OF}	0.00	0.00	0.00	–	0.00	0.00	0.00	–
	C/MSY	0.24	0.12	0.06	0.14	0.20	0.11	0.06	0.13
	B/B_{MSY}	1.62	1.82	1.85	1.70	1.64	1.84	1.88	1.72
	Failure	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00

FIGURES

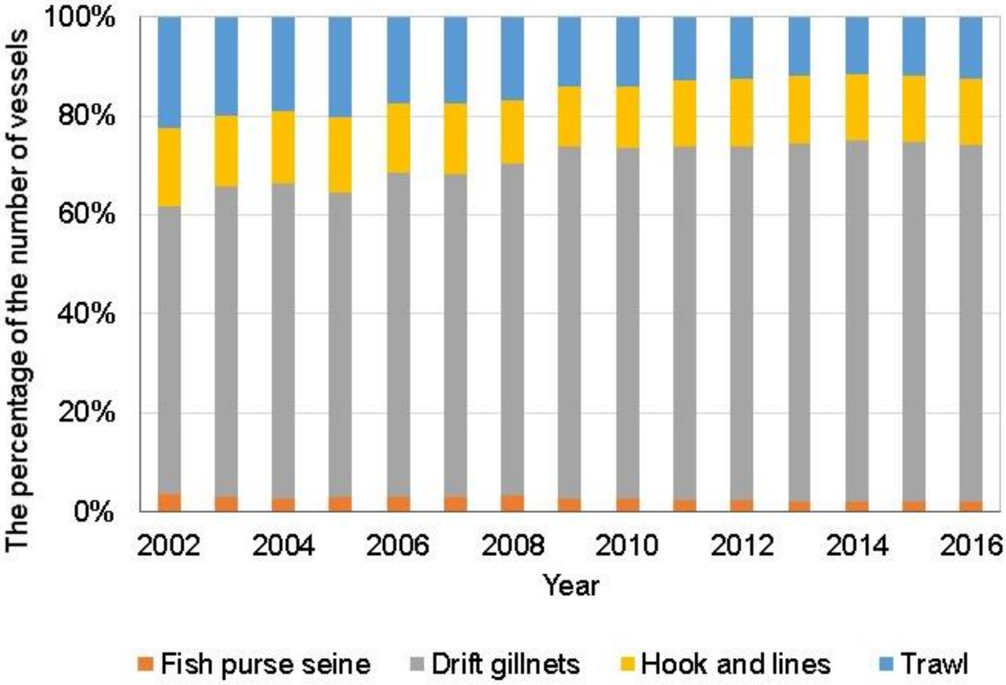


Figure 1. The percentage of the number vessels of dominant fishing gears in Malaysia (year of 2002-2016)

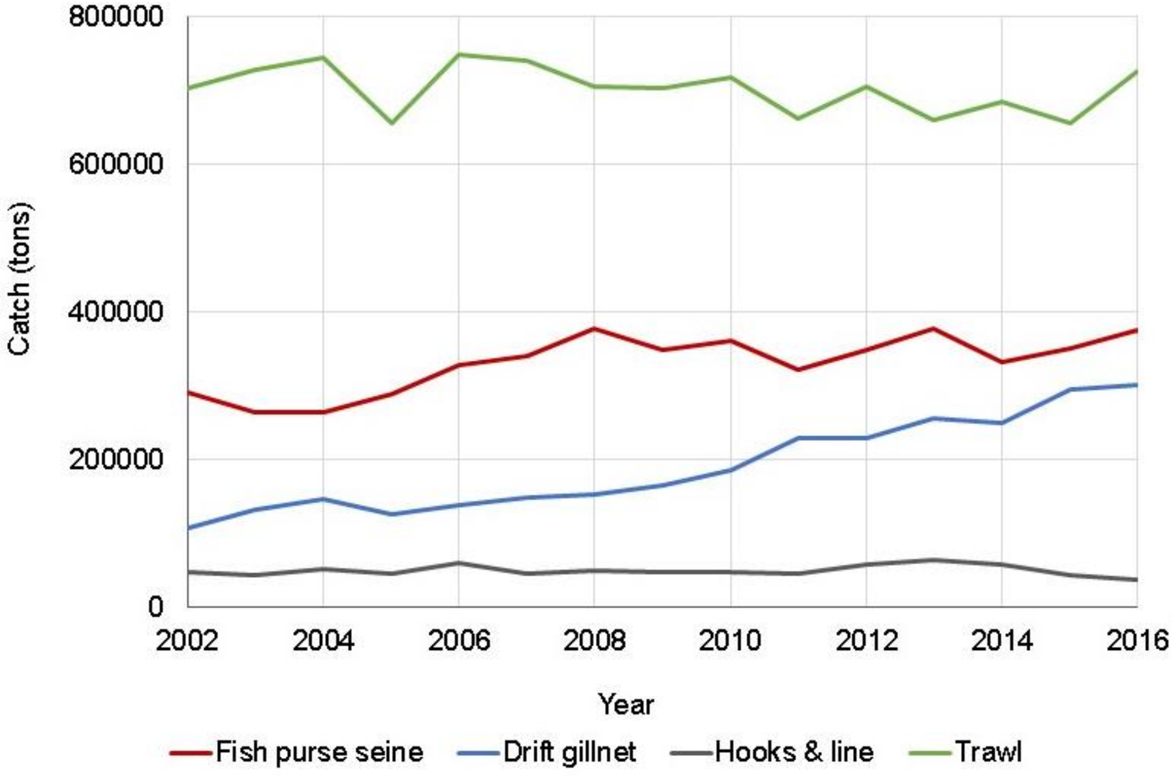


Figure 2. Catch of dominant fishing gears in Malaysia (2002-2016)

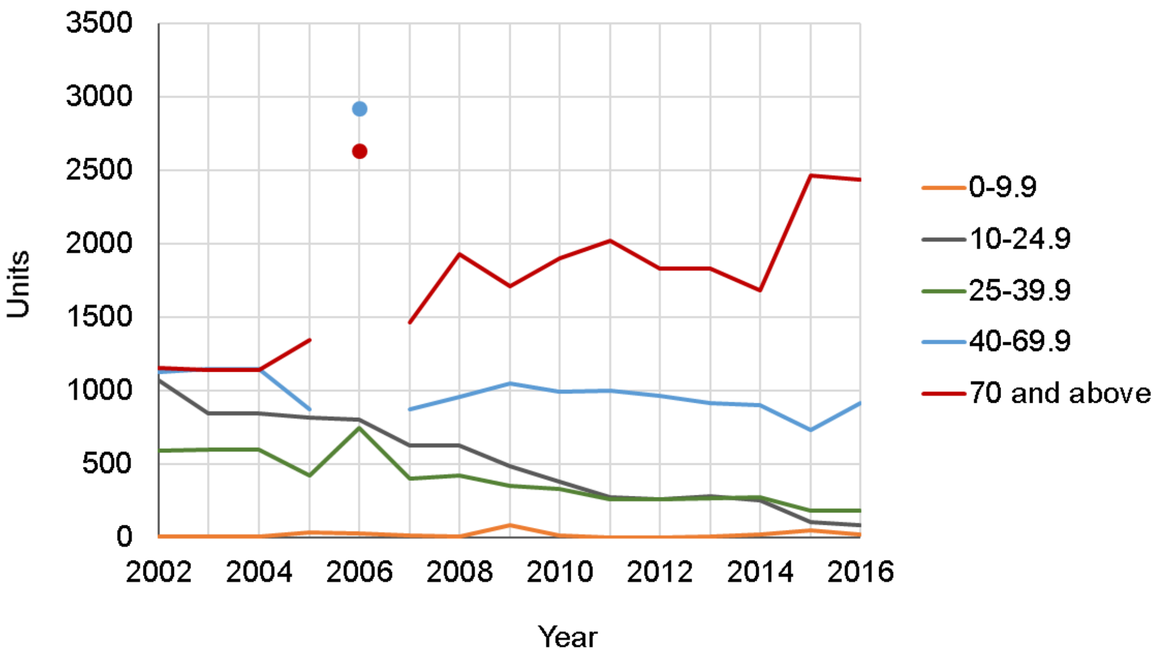


Figure 3. Purse seine fishing unit for different tonnage classes. In the year of 2006, there were two outliers which show unrealistic number for the purse seine vessels in tonnage class of >40 GRT and >70 GRT.

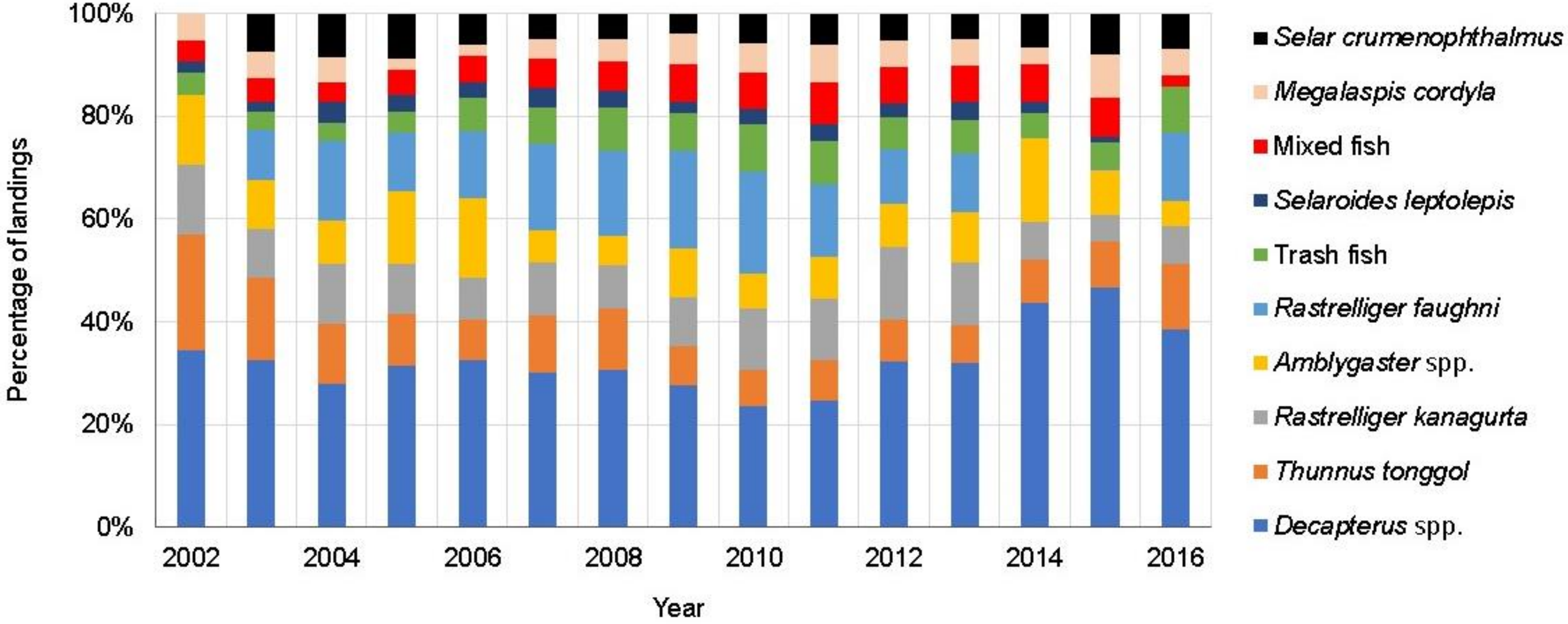


Figure 4. Catch composition of purse seine fishery in Malaysia (2002 – 2016)

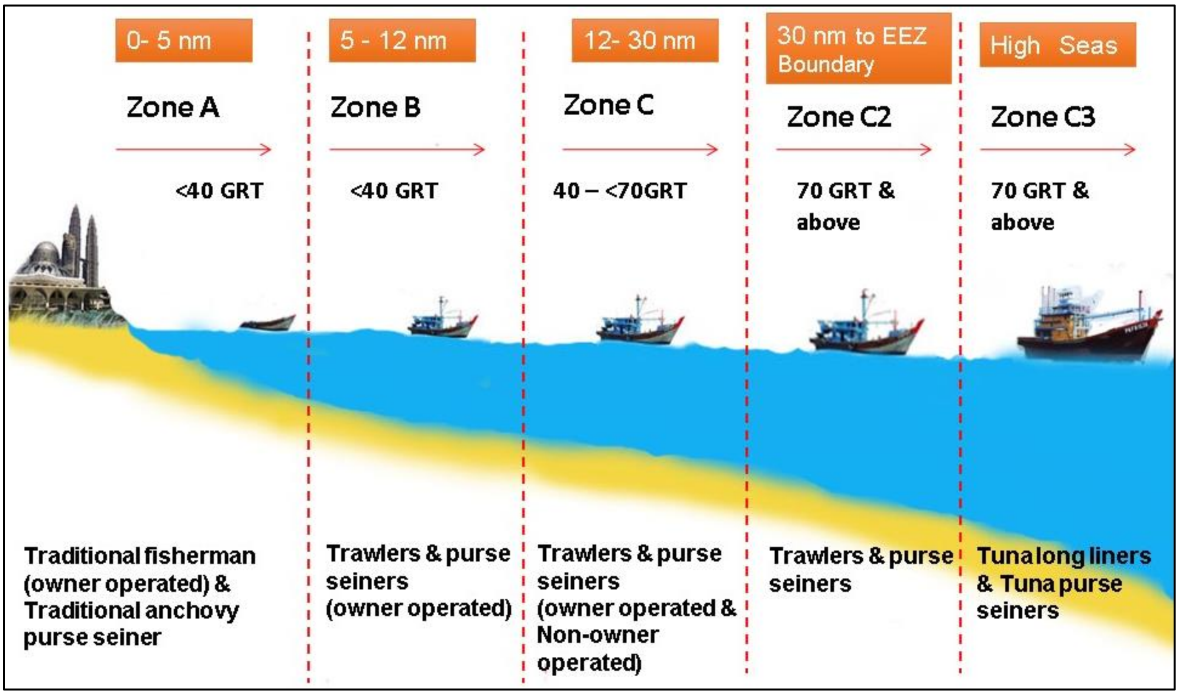


Figure 5. Current fishing zones in Malaysia (Source: DOF Malaysia 2015)

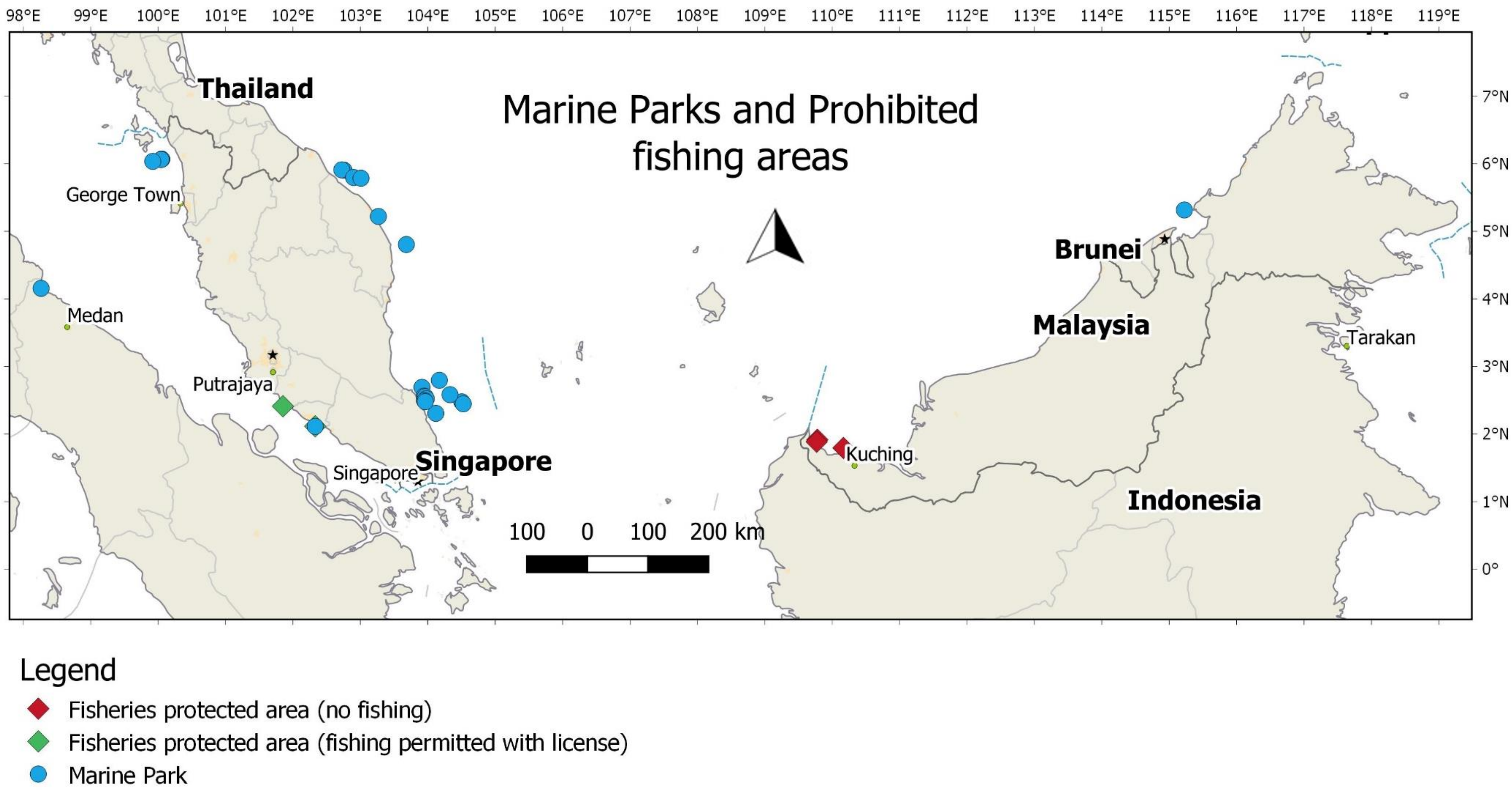


Figure 6. Marine parks and fisheries protected areas in Malaysian waters

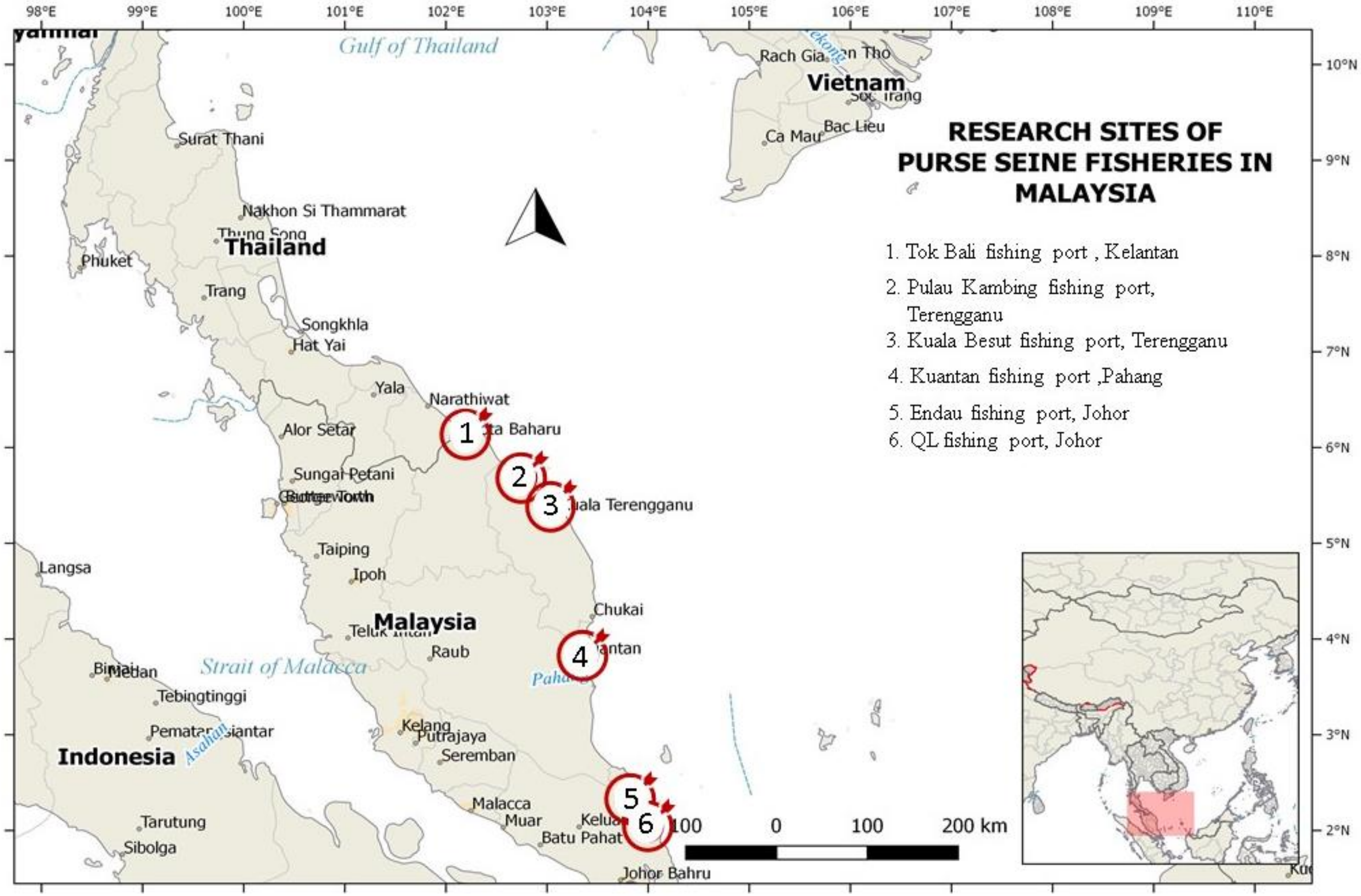


Figure 7. Research sites of purse seine fishery in Malaysia

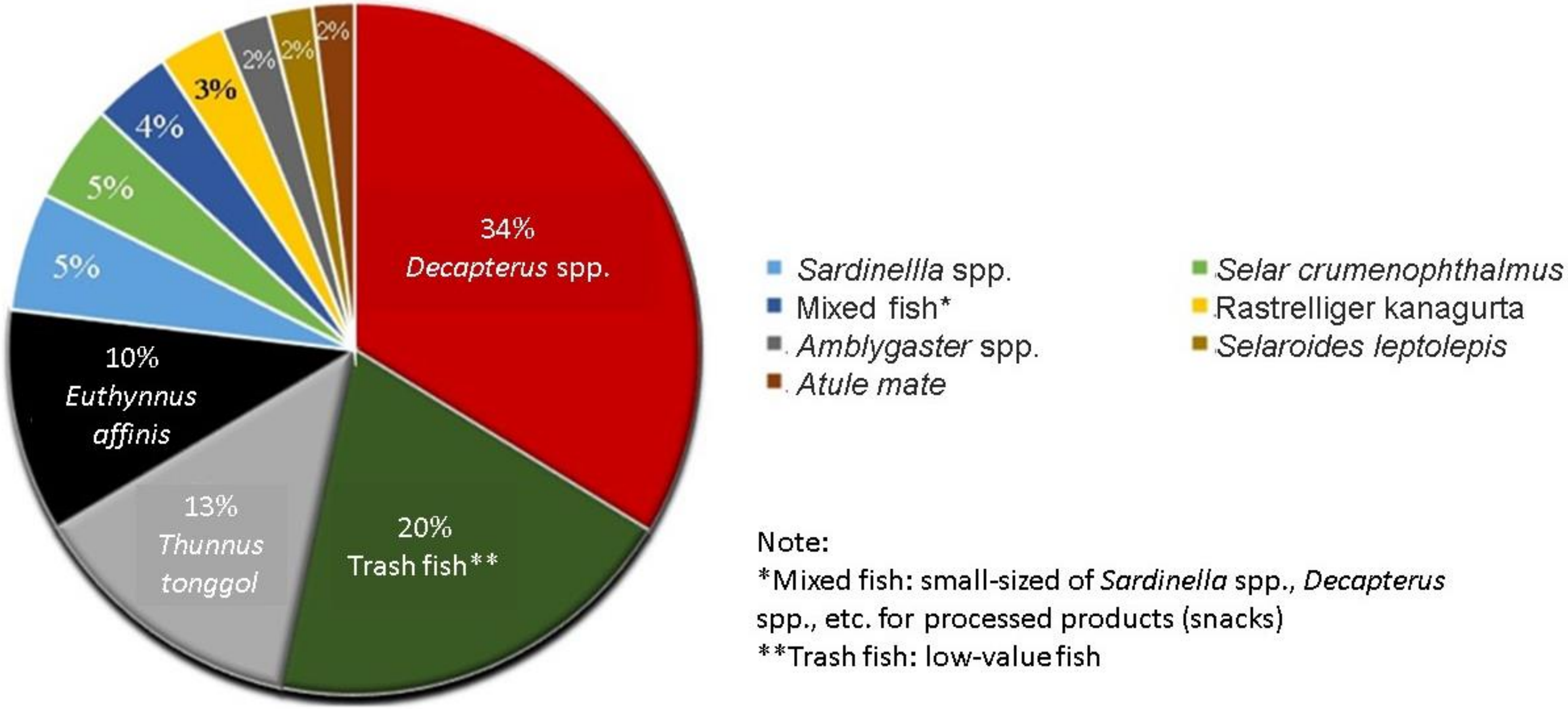


Figure 8. Landing composition based on survey data in 2017 & 2018

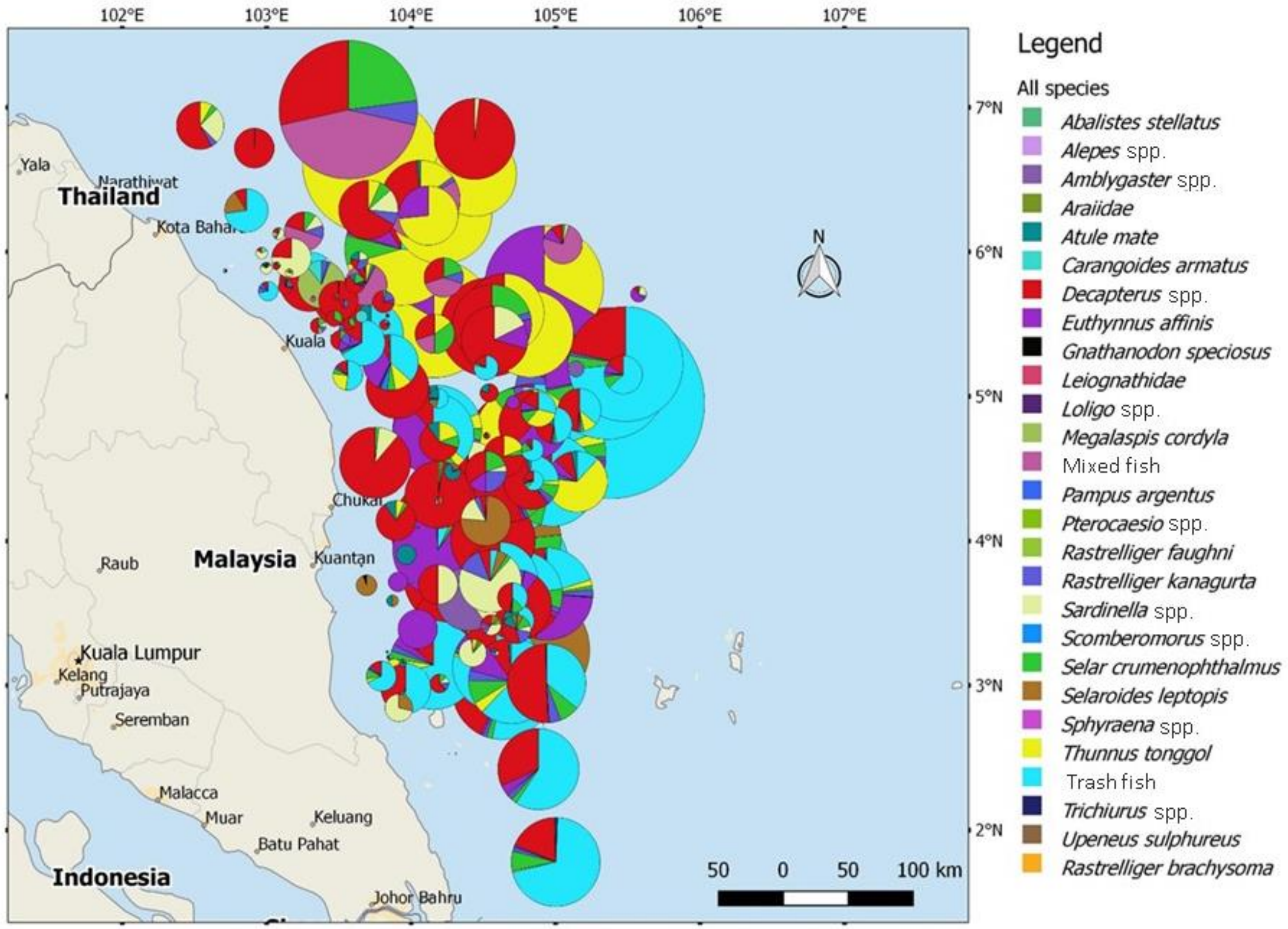


Figure 9. The multispecies condition of purse seine fishery in the East Coast Peninsular Malaysia. The diameter shows amount of individuals caught, while the color represents the species caught.

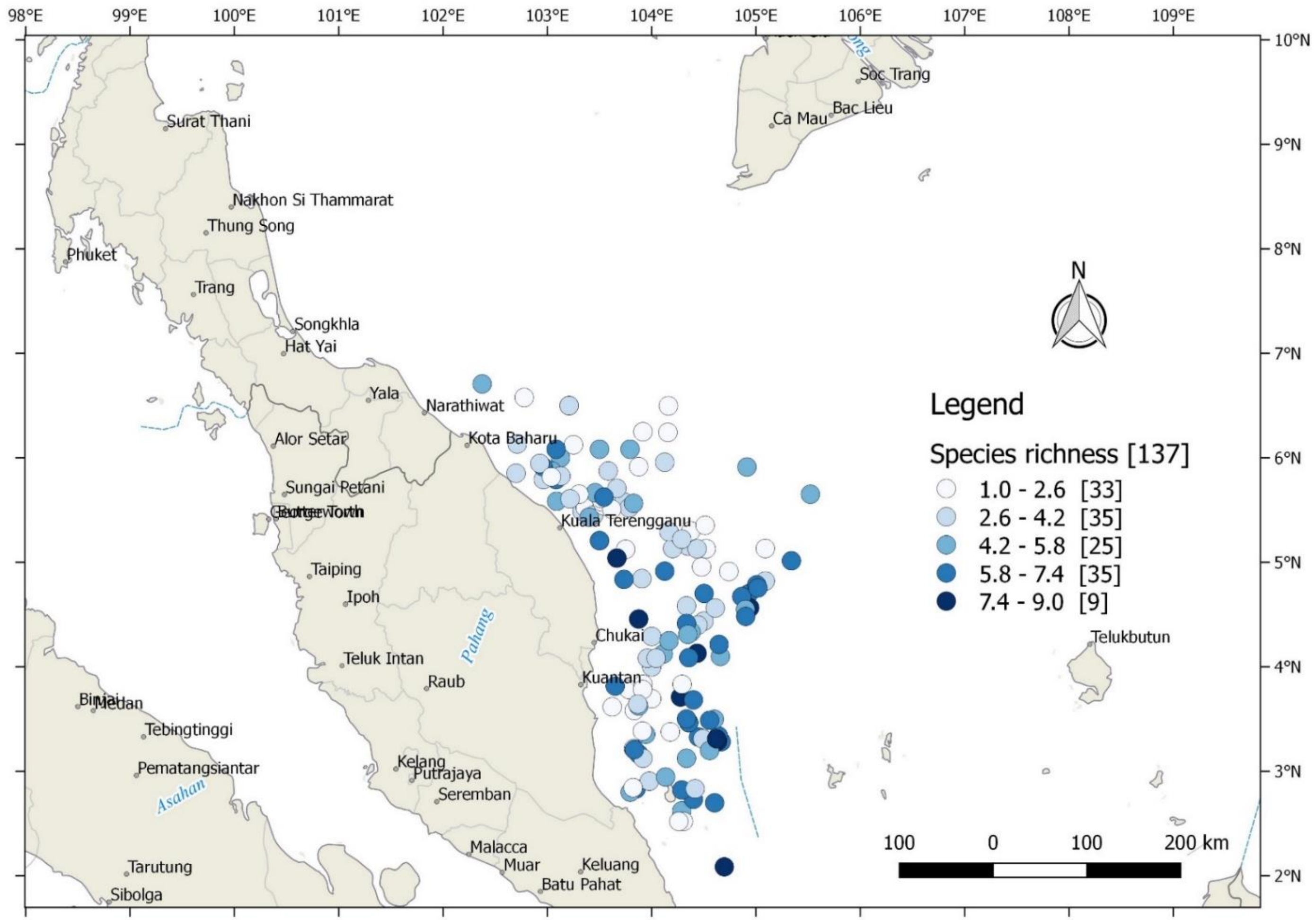


Figure 10. Species richness of the East Coast Peninsular Malaysia. Darker colors represent areas with higher species richness.

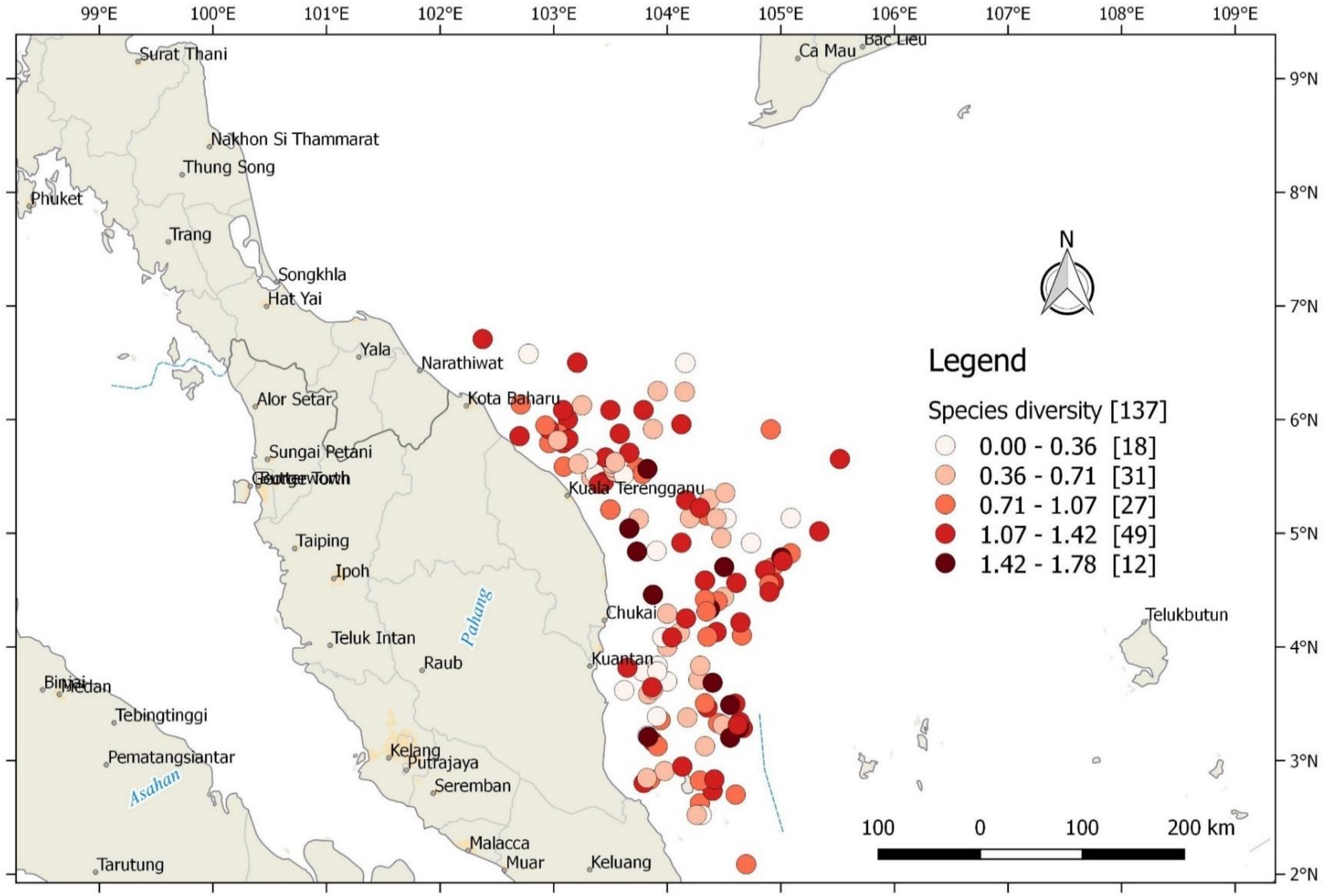


Figure 11. Species diversity of the East Coast Peninsular Malaysia. Darker colors represent areas with higher species diversity.

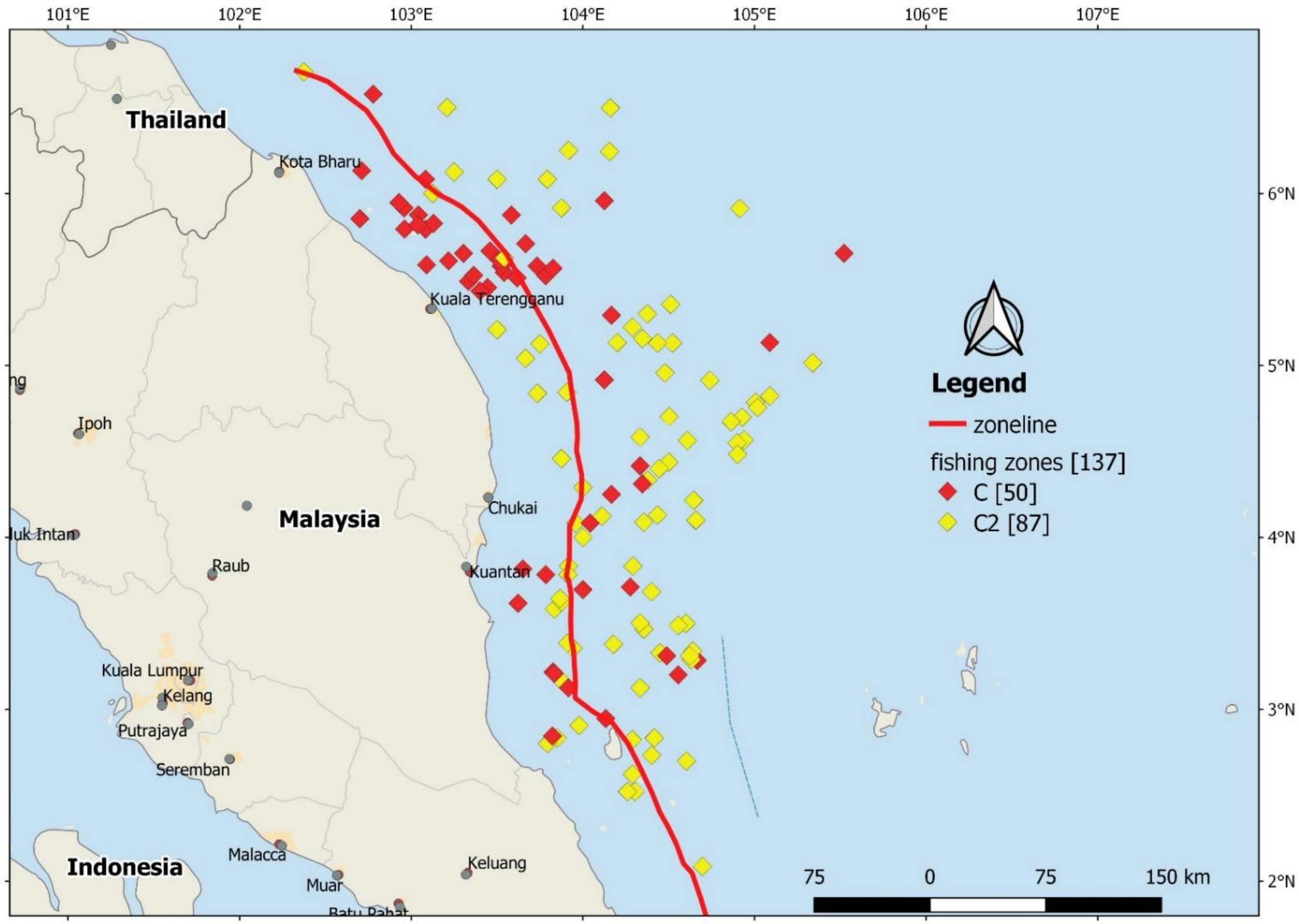


Figure 12. The vessel zone distribution map. The red line (30 nm from shore) indicates the border between C and C2 zones. C zone is the zone delineated from 12–30 nm; while the C2 zone is delineated from 30 nm to Economic Exclusive Zone (EEZ). The vessels in the zones that nearer to the coast line can go further, but not for another way around.

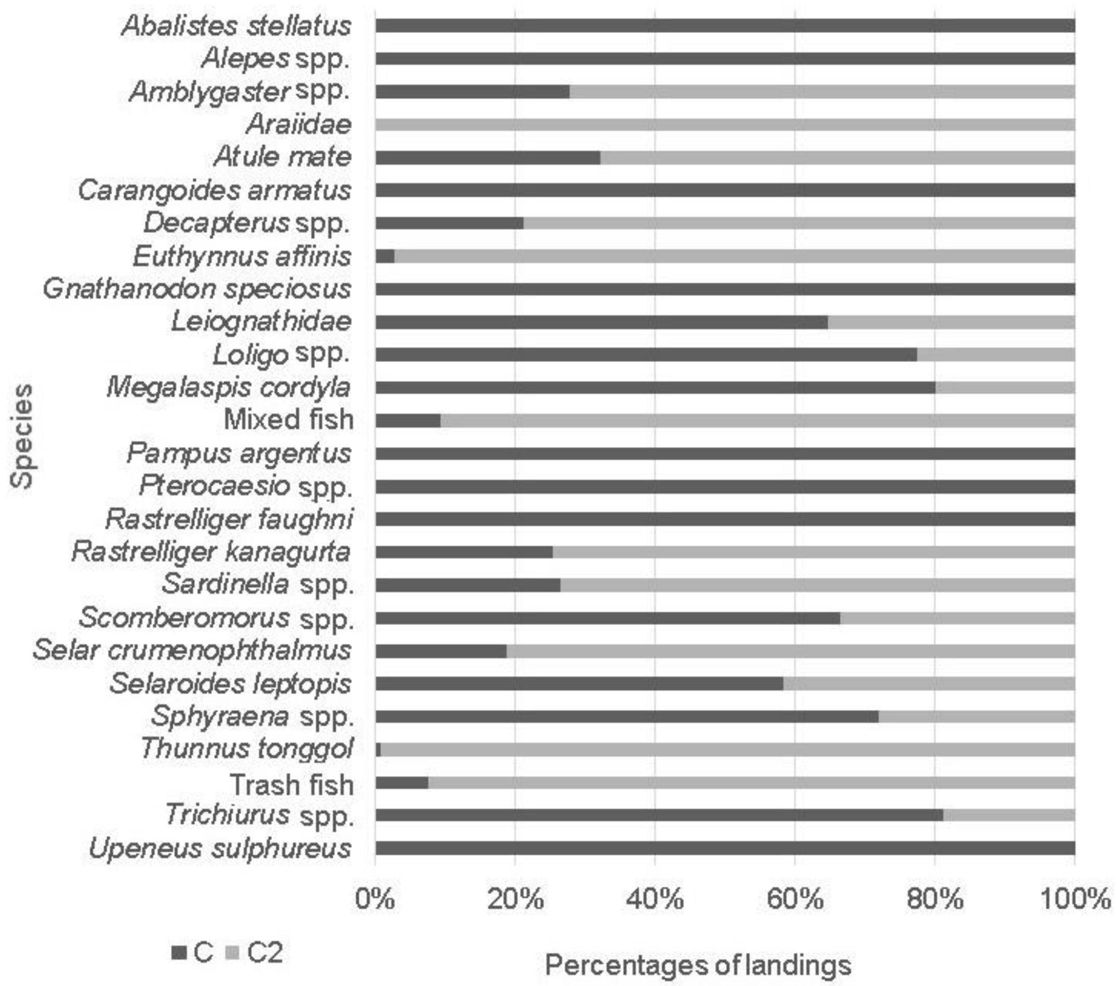


Figure 13. The percentage of origin for each landing species. The black bars indicate the percentage of landings from C-zone vessels, while the grey bars indicate that from C2-zone vessels.

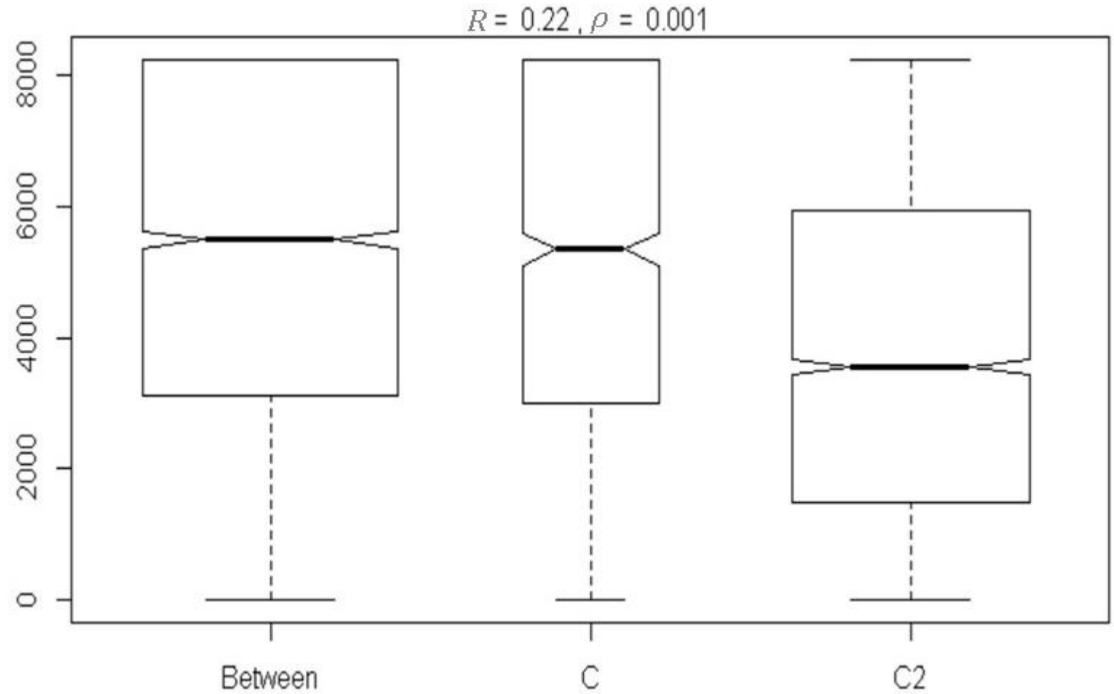


Figure 14. The results of ANOSIM for spatial analysis (vessel zones). The y-axis represents the dissimilarity level. The “between” plot showed the status of the mean difference between zones.

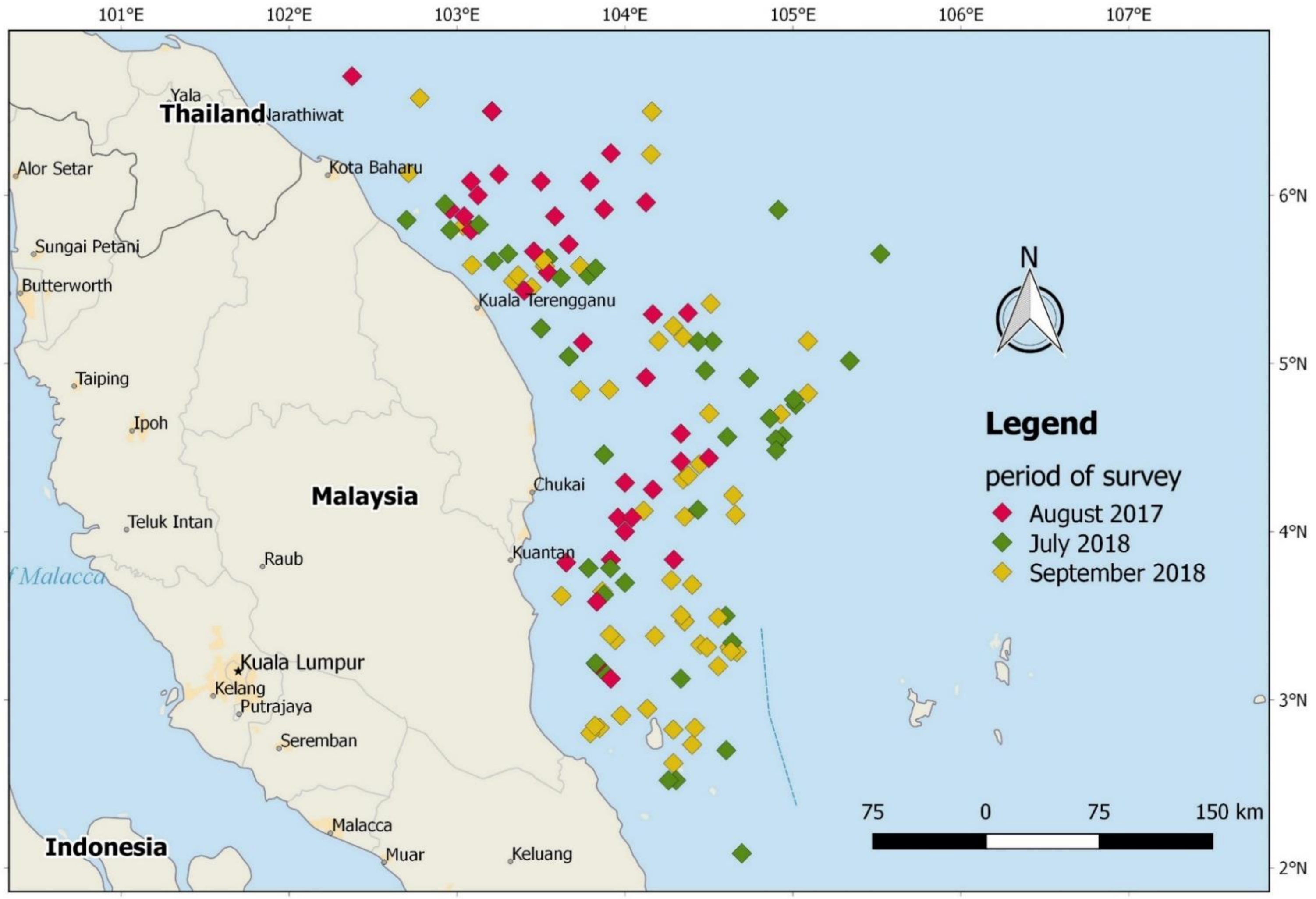


Figure 15. The period of survey distribution map

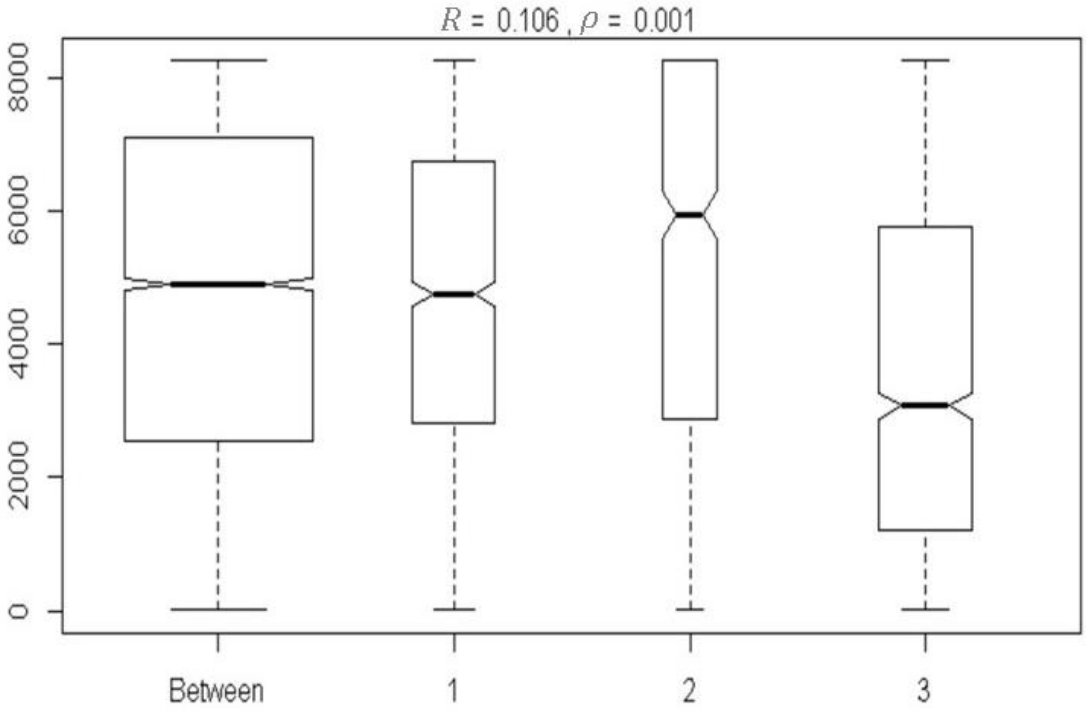


Figure 16. The results of ANOSIM for temporal analysis (period of surveys). The y-axis represents the dissimilarity level. The “between” plot showed the status of the mean difference between period of surveys.

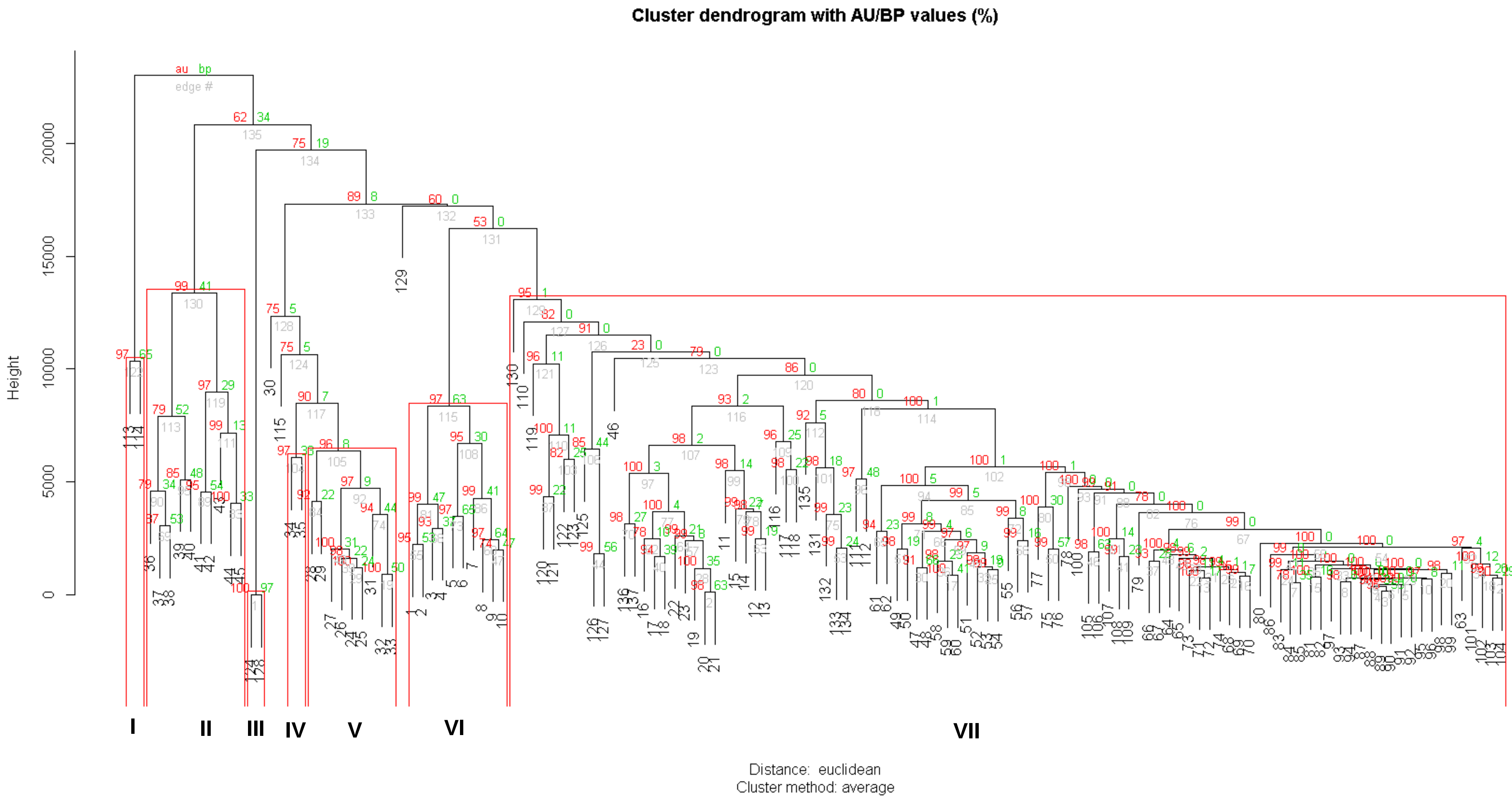


Figure 17. Dendrogram of clustered groups. The red character represents the value of approximated unbiased ρ value (AU values), while the green character represents the value of bootstrap probability (BP values). The red rectangles indicate the clusters which AU values >0.95.

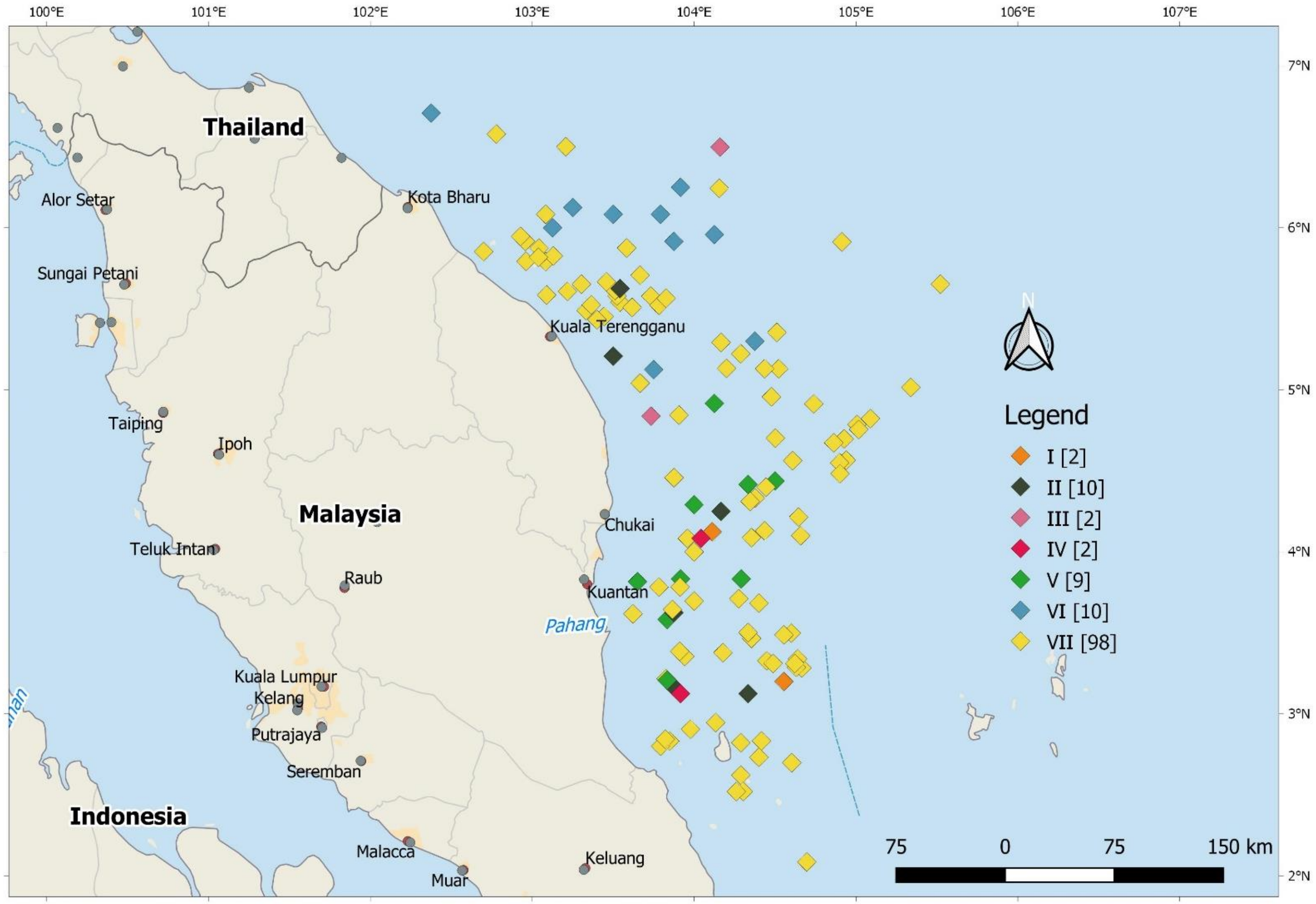


Figure 18. Clustered fishing grounds off the East Coast Peninsular Malaysia

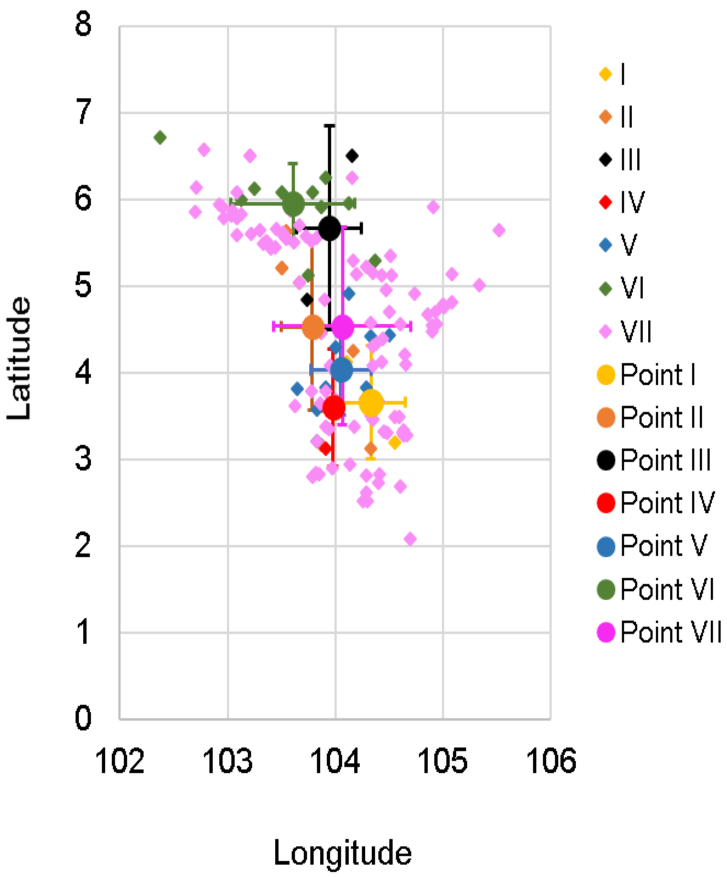


Figure 19. Plotted clustered group of fishing ground by the latitudes and longitudes of each fishing ground. The diamond points indicate the plot of each fishing ground. The circle points with standard deviation bars represent the aggregate fishing ground plots.

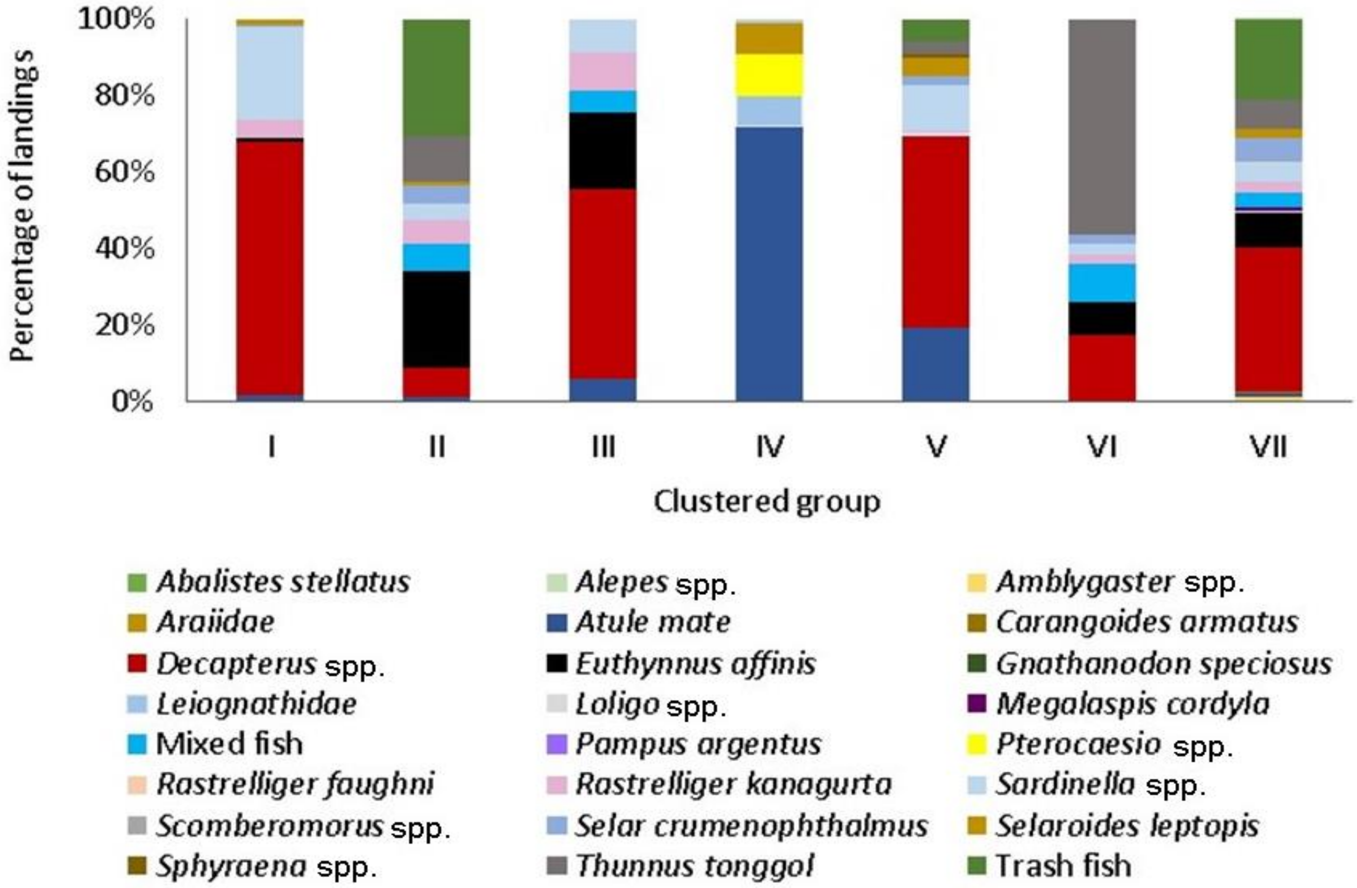


Figure 20. Species composition of clustered groups

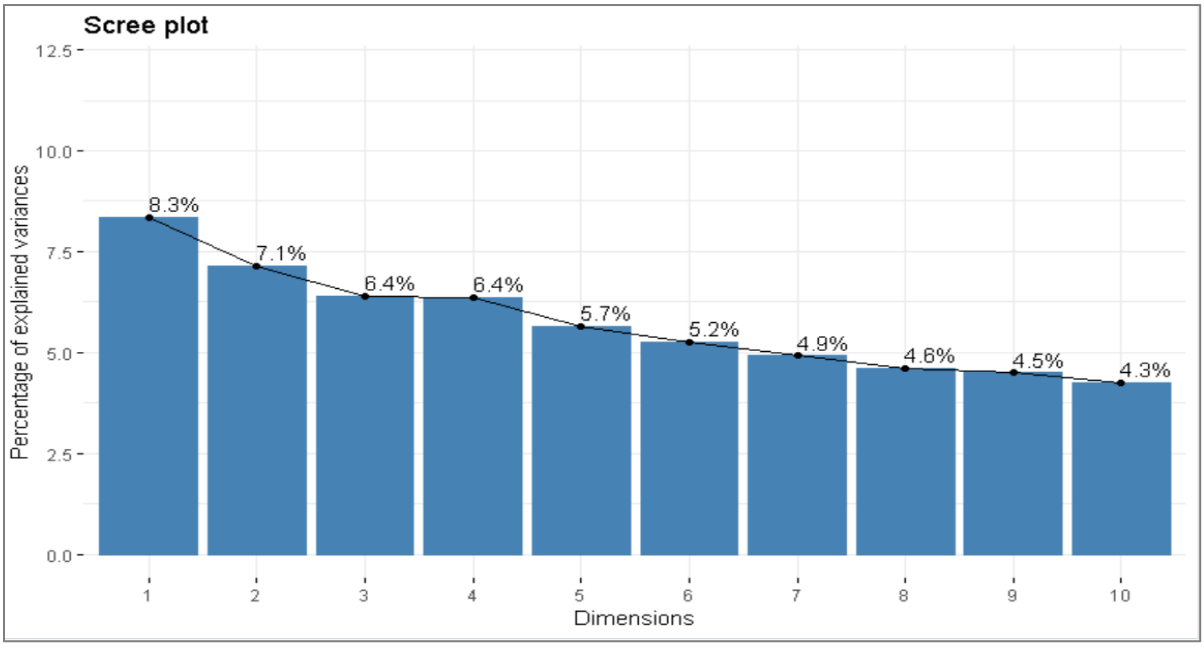


Figure 21. The scree plot of PCA

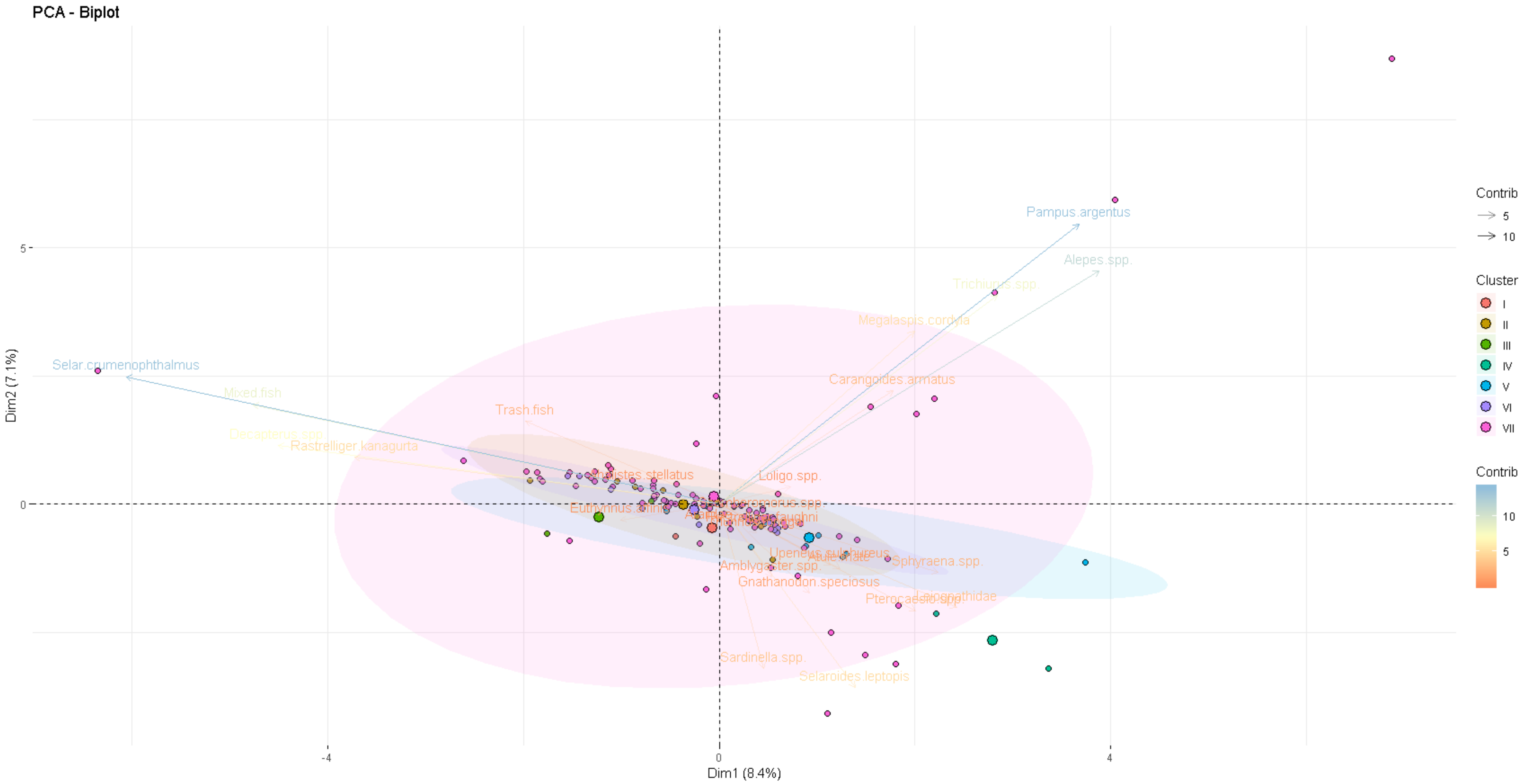
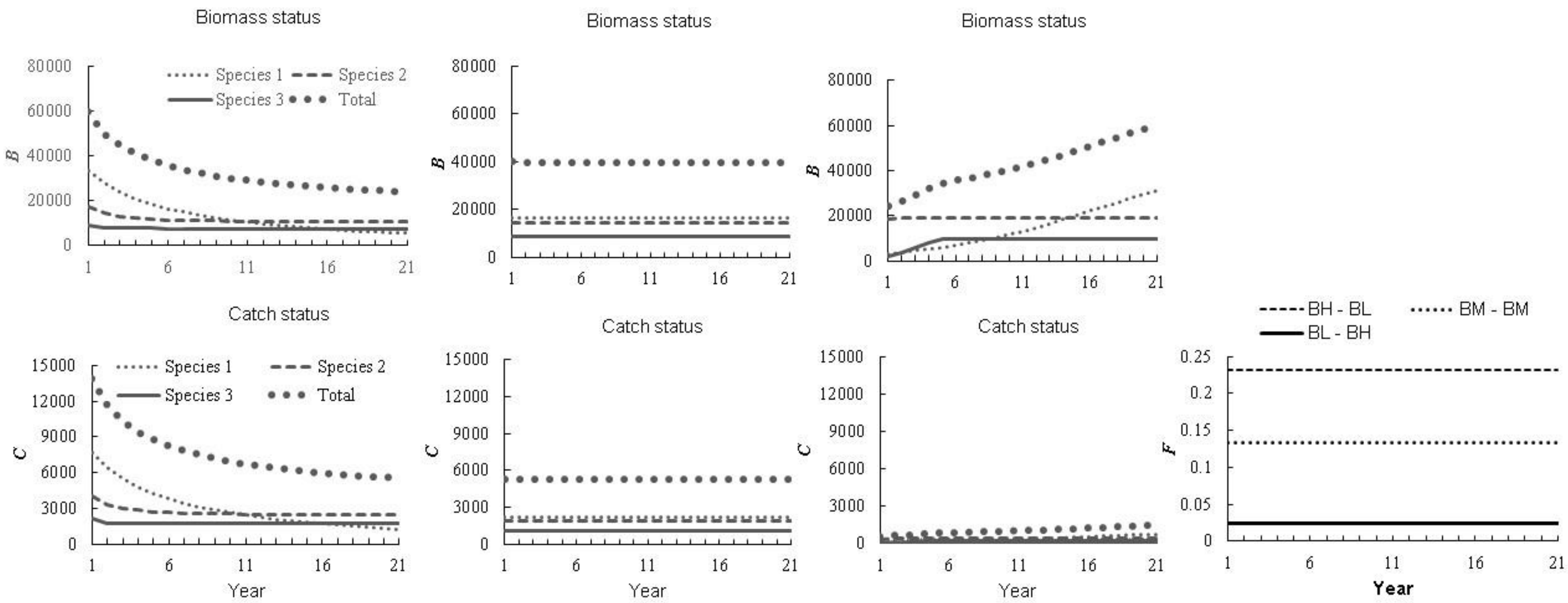


Figure 22. The factor map of PCA



Biomass and catch status graphs under $B_H – B_L$ scenario

Biomass and catch status graphs under $B_M – B_M$ scenario

Biomass and catch status graphs under $B_L – B_H$ scenario

Fishing mortality graph under three critical scenarios

Figure 23. Biomass status, catch status, and fishing mortality under three critical biomass-trend scenarios during the pre-management period: BH – BL, BM – BM, and BL – BH.

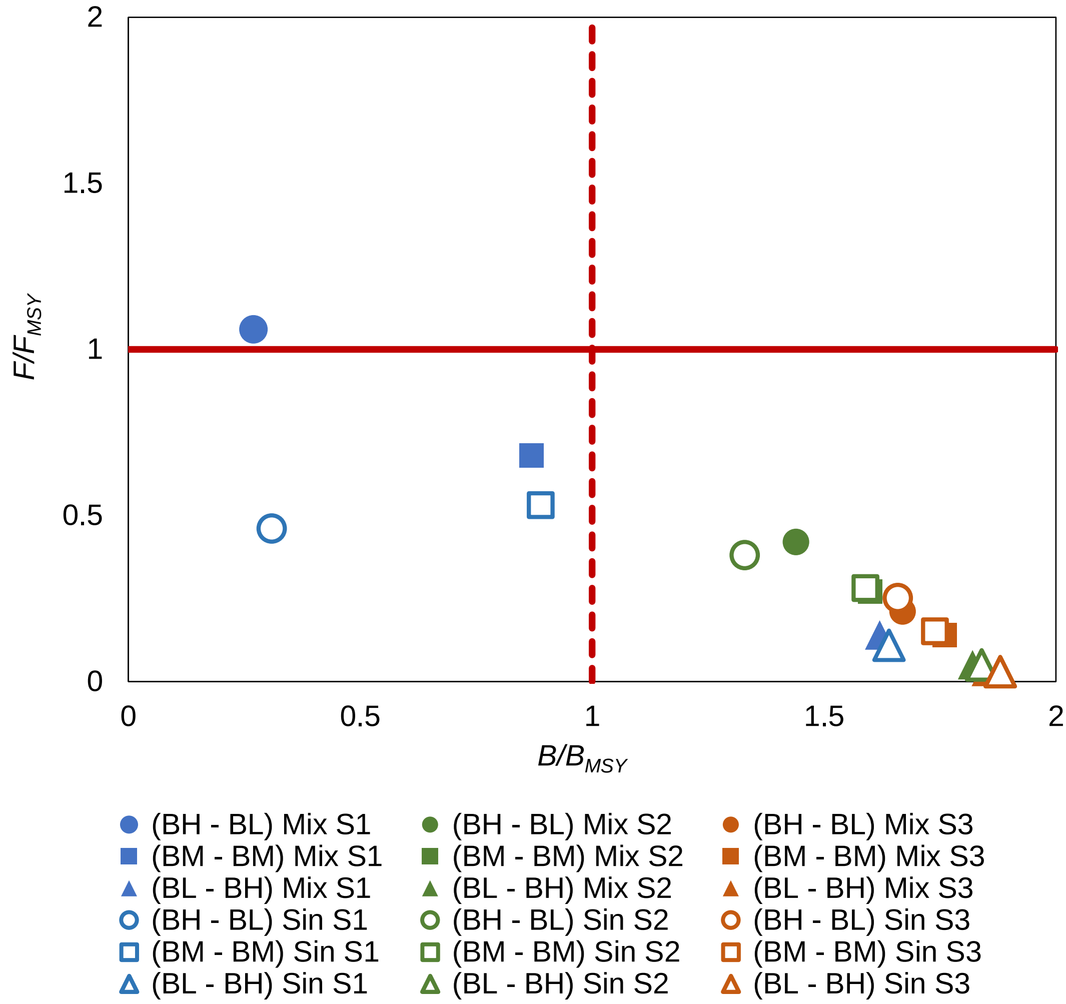


Figure 24. Kobe-plot for the last management year, after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8), to mixed-species data (solid colors) and single-species data (outline colors), under three critical biomass-trend scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios $B_H – B_L$, $B_M – B_M$ and $B_L – B_H$, respectively. The solid line indicates the overfishing threshold, while the dashed line defines the overfished line.

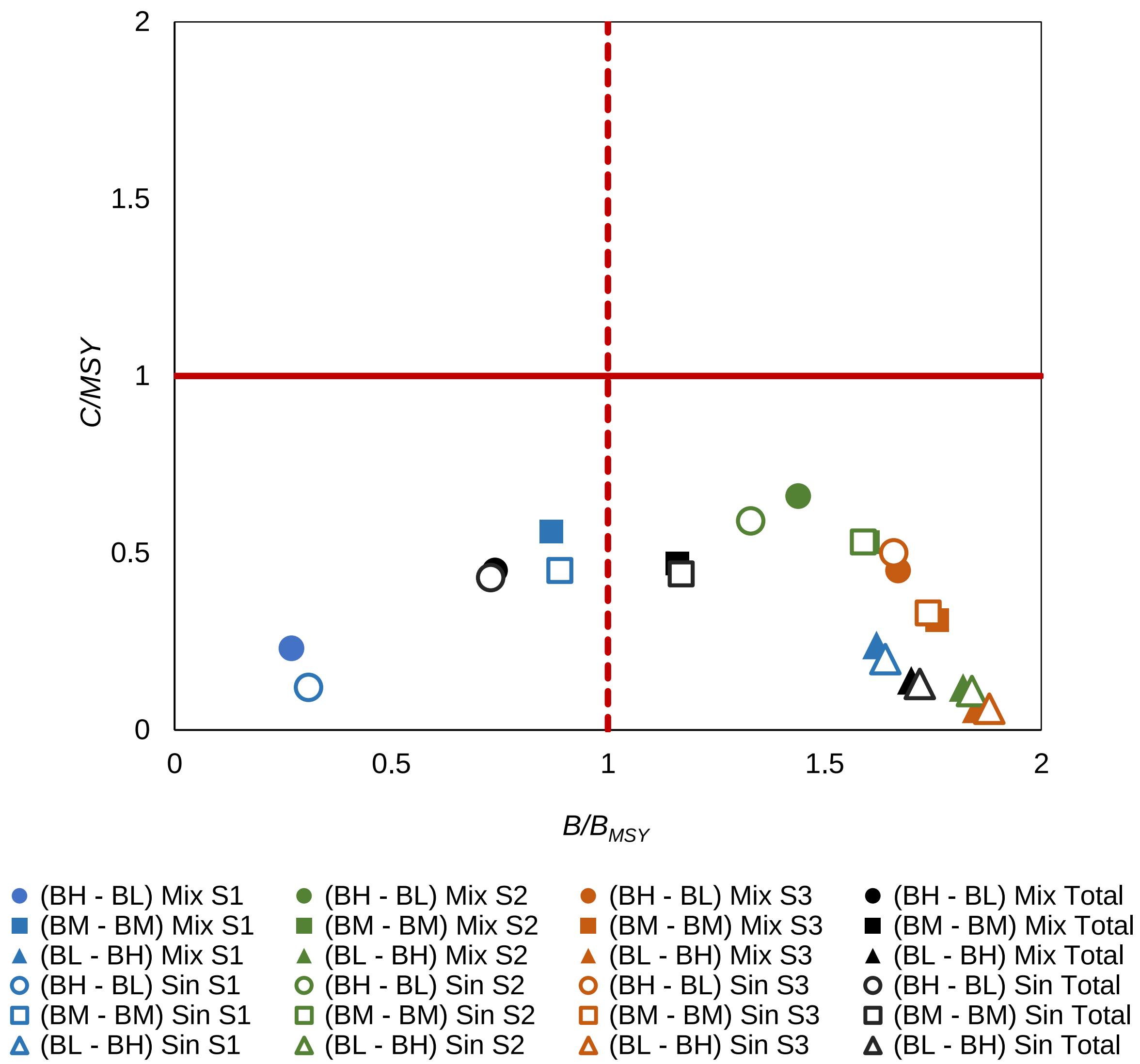


Figure 25. Biomass and catch status performance of the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8), to mixed-species data (solid colors) and single-species data (outline colors), under three critical biomass-trend scenarios. Blue, green, orange and black indicate species 1, 2, 3 and the total species, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios BH – BL, BM – BM and BL – BH, respectively. The solid line indicates the MSY level, while the dashed line defines the overfished line.

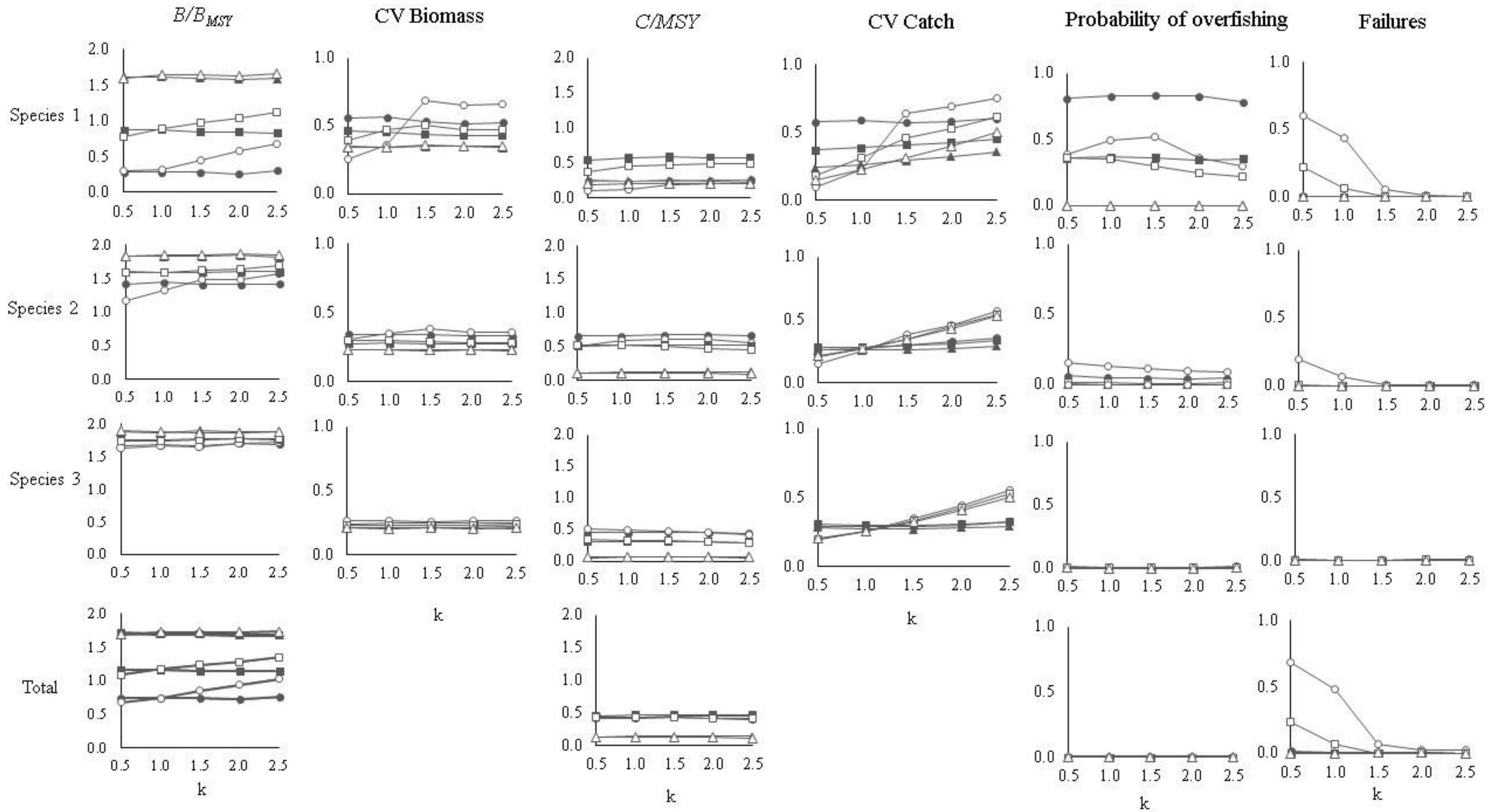


Figure 26. Performance measures of the alternative feedback harvest control rules (HCRs), created by modifying the adjusting parameter k, with mixed-species data (black points) and single-species data (white points), under three critical biomass-trend scenarios (B_H – B_L, B_M – B_M, and B_L – B_H, denoted by circles, squares and triangles, respectively). The x-axis is the various k-modified feedback HCRs, and the y-axis is the performance measures, namely biomass status, coefficient of variation (CV) for the biomass, catch status, CV for the catch, probability of overfishing and management failure

APPENDICES

Appendix 1. The fisheries management form

Fisheries management form

Date:
State:
District:

Interviewee
- **Name/phone:**
- **Position:**

Stakeholders

1. DoF (Jabatan Perikanan Malaysia), which is in charge of:	**4. Fisheries development authority of Malaysia (Lembaga Kemajuan Ikan Malaysia)**
- licensing Y/N	which is in charge: socio-economic of the fishermen Y/N
what kind of licenses?	what fields are include in their authority?
	5. Fishermen
- fisheries policies Y/N	- Vessel owner Y/N
what kind of policies?	
	- Local fishermen Y/N
	How to get fishermen card?
- regulations Y/N	
what kind of regulations?	What are the previlages of the local fishermen?
	- Foreign fishermen Y/N
2. DoF state level (Jabatan Perikanan Negeri) which is in charge of	How large the percentage of foreign fishermen of the total fishermen?
	Vessel A: Vessel B: Vessel C: Vessel C2:
	How to get permission of fishing (as a foreign fishermen)?
3. DoF district level (Jabatan Perikanan Daerah) which is in charge of	
	6. Distributors
	- Tauke (1st middleman) --> from fishermen Y/N
	- Pemborong (2nd middleman) -->from tauke Y/N
	- Traditional market seller Y/N

Fisheries management form page 1 of 5

Management measure

A. Zonation

1. Zoning management is based on:

- vessel tonnage Y/N
- gear type Y/N
- ownership pattern Y/N

Remarks:

The existing fishing zones

No	Zone A (No-take zone)	Zone B	Zone C	Zone C2
Purposes	Prohibited to do fishing (Marine Park) / Traditional fisheries	Commercial fisheries	Commercial fisheries	Commercial fisheries
Owner	Must be in the vessel	Doesn't have to be in the vessel	Doesn't have to be in the vessel	Doesn't have to be in the vessel
Vessel size	<40 GRT	<40 GRT	40-70 GRT	>70 GRT
Fishing areas	<8 nm	8-15 nm	>15 nm	Indian Ocean

Remarks:

The new fishing zones are applied only in West Coast? Or have applied in East Coast?

Monitoring of fishing zones

- Conducted by Agensi Penguatkuasaan Maritim Malaysia (APMM) (Malaysian maritime enforcement agency) Y/N
- Using monitoring controlling and surveilance (MCS) for vessel C2 Y/N

NOW

Start using Automatic Identification System (AIS)

1. Safety navigation Y/N
2. Security Y/N
3. Protection of marine environment Y/N

For vessel A and B will be provided by government Y/N

For vessel C must self-equipped Y/N

Remarks

How about vessel C2?

How about the implementation of AIS now?

Implementation

1. Not allowed to change the owner for 1 year (change of vessel owner will remove all faults) Y/N
2. If it occurred again, the same sanction as in point 1 for 5 years Y/N
3. Having justice in court Y/N

Remarks

Management measure

A. Zonation

2. Conservation and rehabilitation of marine ecosystem
- through Marine protected areas (MPAs)

Remarks:

3. Encourage relocation fishers to other economic activities, such as
- Aquaculture Y/N
- Ecotourism Y/N

Remarks:

B. Limiting fishing effort

1. Closed fishing area

The purpose is for reducing fishing pressure in no-take zone Y/N

- Commercial trawlers & purse seiners are not allowed to fish <5 nm Y/N
- To protect nursery ground of juveniles Y/N
- No closed season implemented Y/N

Remarks:

2. Control on size and fishing power

The purpose is to limit the number of vessels Y/N

- Change tonnage or engine power or apply new vessel need permission from DoF Y/N
- An owner is only allowed to have one vessel (vessel A and B) Y/N

Remarks:

3. Fishing licenses
- Licenses are attached to the boat licenses Y/N
- A moratorium for new issuance licenses of vessel zone A, B and C Y/N

Remarks:

These are for reducing the number of trawlers Y/N

For C2

a. To apply new license need:
- Paper work/ documents Y/N
- Prove their effort or activity Y/N
- Market availability Y/N
- Jetty availability Y/N

Remarks:

b. To renew their license need:
- Minimum 350 tones of landings per year Y/N
- 80% of fishing area must be in Malaysian waters Y/N

Remarks:

Fisheries management form page 3 of 5

Management measure

3. Registration of the fishermen

- Implemented for foreign and local fishermen Y/N

a. Foreign fishermen need to submit:
- boat licenses (where they work on) Y/N
- passport Y/N
- seamanship book (issued by their country) Y/N

Remarks:

b. Local fishermen need to prove that:
- their main income is from fisheries Y/N
- verification from fishermen association Y/N
  what kind of verification?
- having sailed for more than 120 times Y/N

-> After registration, they will get fishermen card Y/N

-> Getting incentives from government allocated by LKIM Y/N

Remarks:

C. Sustainable fisheries

1. Research and development on potential resources and eco-friendly gears
   Remarks:

2. Prohibition of destructive fishing methods

- Explosive and poisons Y/N
- Pair trawling Y/N
- Mechanized push net Y/N
- Beam trawl Y/N
- Moro ami Y/N
- Electric fishing Y/N

Remarks:

3. Imposition of specification for trawl nets
- Codend mesh size > 38 mm Y/N
- Head rope length < 40 m Y/N

Remarks:

4. Implementation of quota system through Total allowable catches (TACs)

Remarks:

Issues and challenges ***(source: National plan of action 2015)***

A. Resource management 1. Resources being overfished Y/N 2. Overcapacity Y/N 3. Encroachment of local fishing vessel into prohibited areas Y/N Remarks: B. Inadequate fisheries data 1. Data of fisheries resource What should be improved from data collection in fisheries resource? Remarks: 2. Gear specification What should be improved from data collection in gear specification? Remarks: C. Fisheries policies 1. Decisions inconsistent with current policies Remarks:	2. Incentives Remarks: 3. Lack of political will and awareness towards conservation and management Remarks: D. Overseas issues 1. Encroachment of foreign vessels Remarks: 2. Foreign fishermen working on board local fishing vessels Remarks:

Fisheries management form page 5 of 5

Appendix 2. Fisheries data collection form

Data collection form

Date:

State:

District:

Interviewee

- Name/ phone:

- Position:

1	**Frequency**	
	Vessel data-based collected regularly	Y / N
	Remarks:	
2	**Methods**	
	One enumerator for each landing	Y / N
	Remarks:	
	Different methods for different vessel type	Y / N
	- A/B/C collect directly from fishermen daily/sampling day	
	- C2 must fill in the LOV by themselves and submit to Jabatan Perikanan	
	Remarks:	
3	**Type of data**	
	- Catch data	
	- Effort data contains of trips, hours, hauls, days, and units	Y / N
	Remarks:	
4	Input data	
	All data are inputted to Fisheries landing information system (Sistem Maklumat Pendaratan Perikanan (SMPP)	Y / N
	- by the officer of fisheries districts	Y / N
	- in the end of the month	Y / N
	Remarks:	

5	**Catch composition**				
	Of each vessel, the data comprises:				
	- total landing				Y/N
	- species composition				Y/N
	- price of each species				Y/N
	Remarks:				
6	**Dominant species**				
	Less of biological information and publication (online) related to				
	- Aya hitam	Y/N	- Lolong		Y/N
	- Aya kurik	Y/N	- Pinang		Y/N
	- Baja	Y/N	-Selar		Y/N
	- Barakuda	Y/N	- Selar kuning		Y/N
	- Bawal	Y/N	- Selar papan		Y/N
	- Biji nangka	Y/N	- Selar pucat		Y/N
	- Campur	Y/N	- Selayang		Y/N
	- Cencaru	Y/N	- Sotong		Y/N
	- Kembong	Y/N	- Tamban		Y/N
	- Keropok	Y/N	- Tamban beluru		Y/N
	- Kikik atau kekek	Y/N	- Tenggiri		Y/N
	Remarks:		- Layur		Y/N
7	**Biological data**				
	Collected by Fisheries Research Institute				
	It contains of :				
	- Total length	Y/N	- Body weight		Y/N
	- Maturity stage	Y/N	- Gonad weight		Y/N

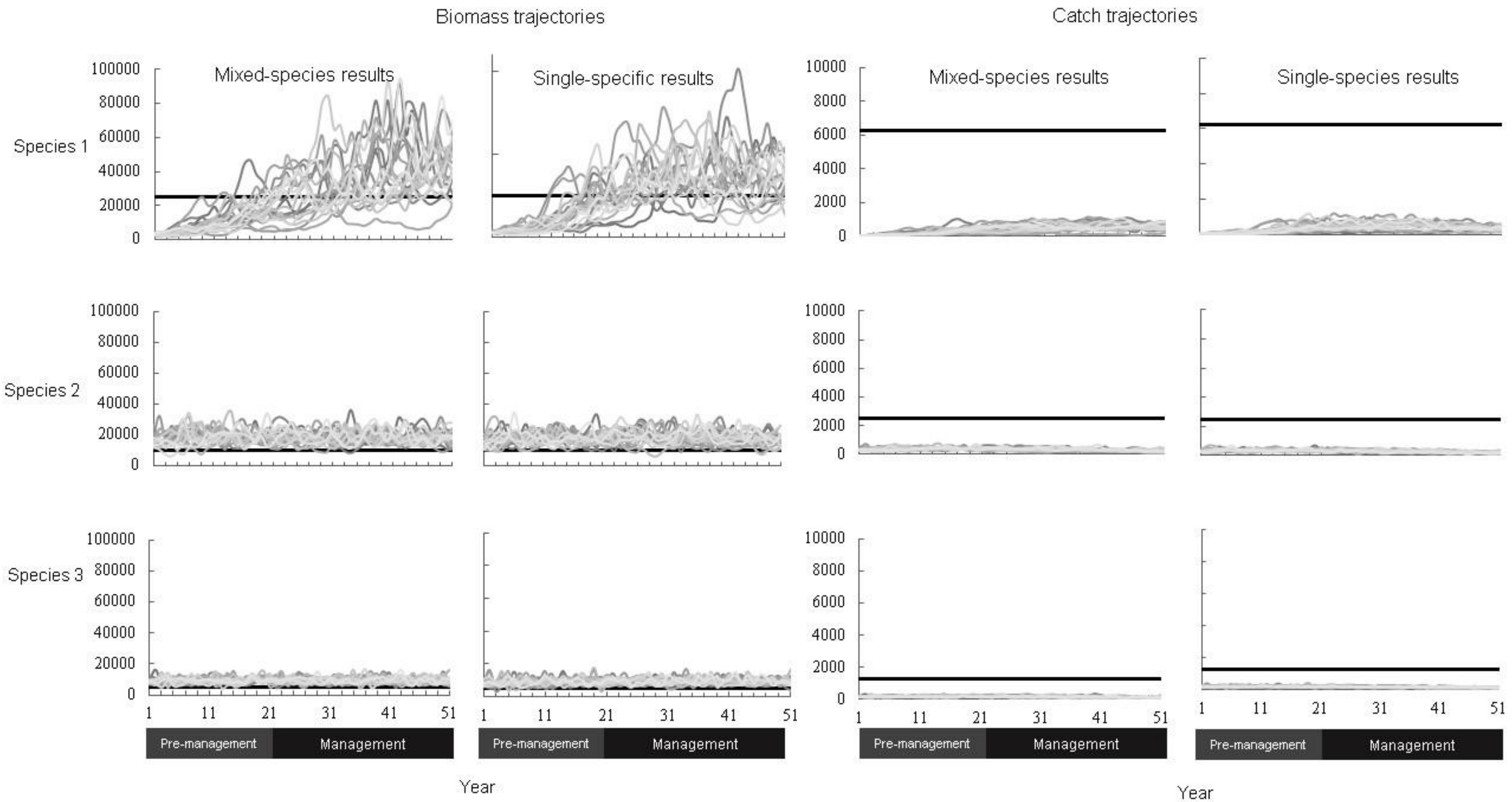
Appendix 3. Fishery survey form

Fishery survey form

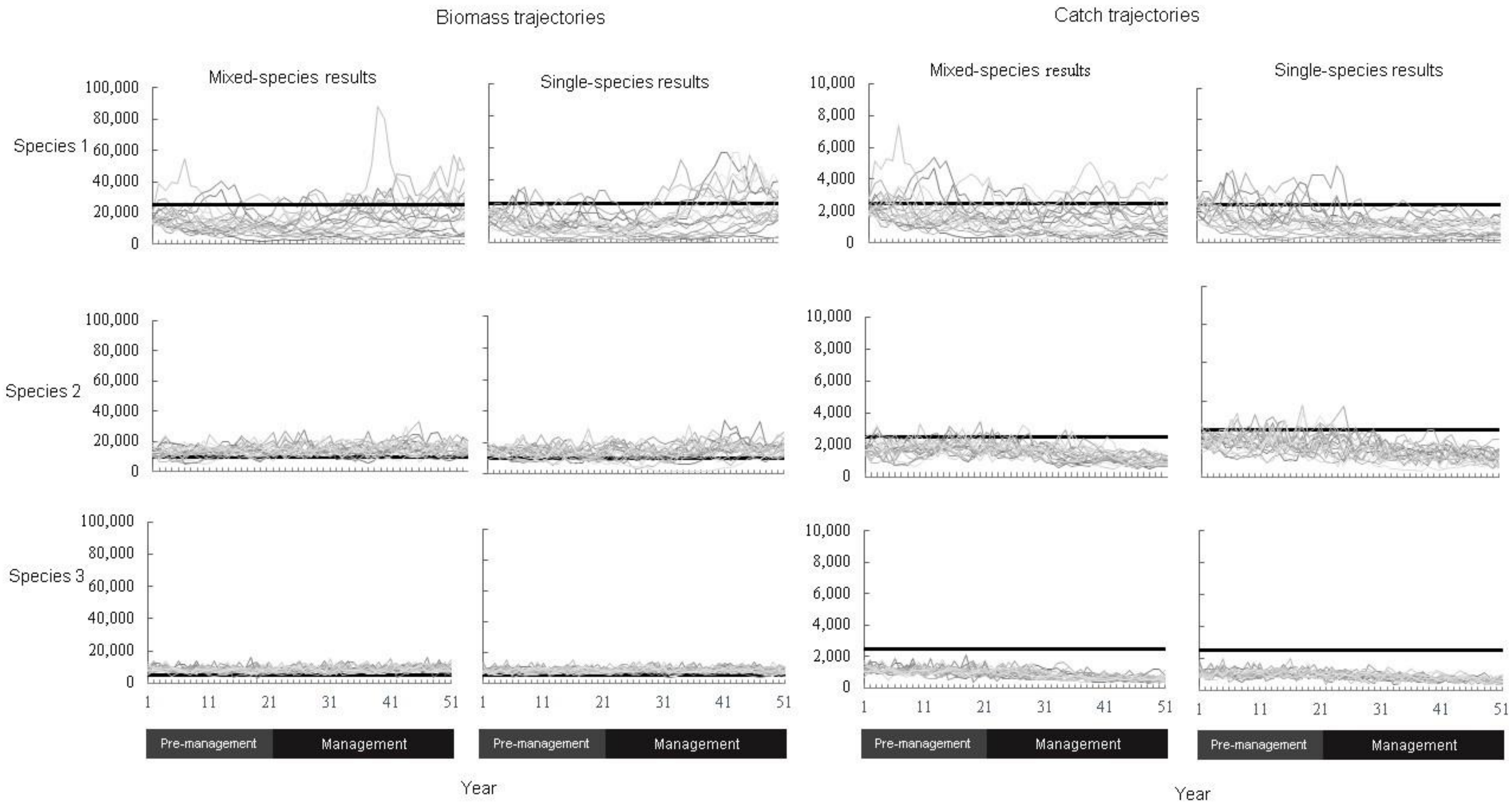
Date:	**Vessel**	**Vessel dimension**	**Fishing operation**	**Dimension of gear**
SurveyID:	Name	Length: m	∑ haul/day:	Length: m
DataID:	GT	Width: m	∑ trip/month:	Depth: m / feet
	Owner	Depth: m	Duration: days	Mesh size: inch
State	**Fishing Location**	**Landing**	**Crews**	**Code**
District	- Latitude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

No	Species	Quantity (kg)	Price (RM/kg)	Length (cm)	No	Species	Quantity (kg)	Price (RM/kg)	Length (cm)
1					13				
2					14				
3					15				
4					16				
5					17				
6					18				
7					19				
8					20				
9					21				
10					22				
11					23				
12					24				

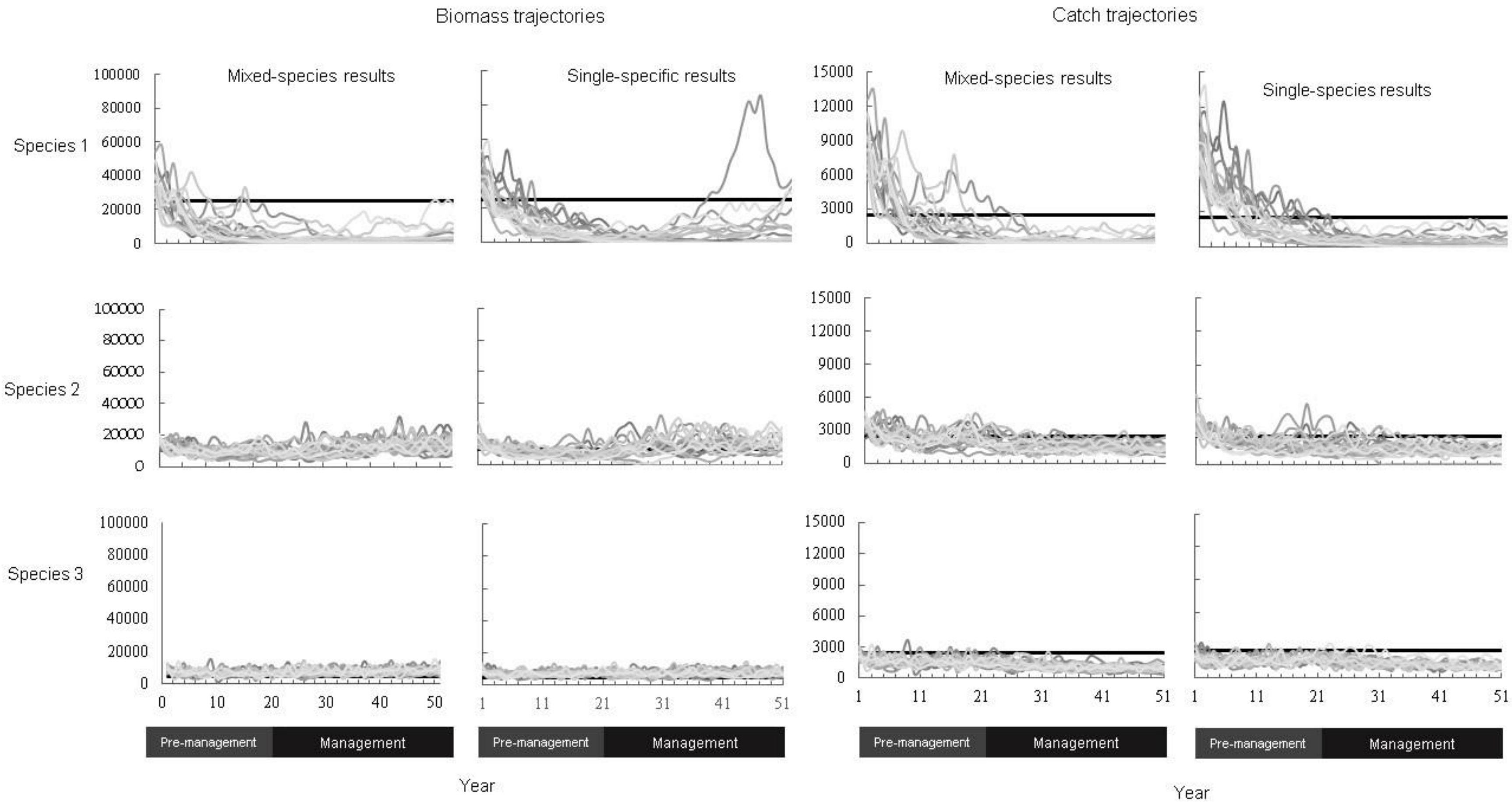
Appendix 4. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for B_L – B_H scenario. Only 20 trajectories are shown in each figure; both σ_R and σ_m were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the B_{MSY} level and MSY level



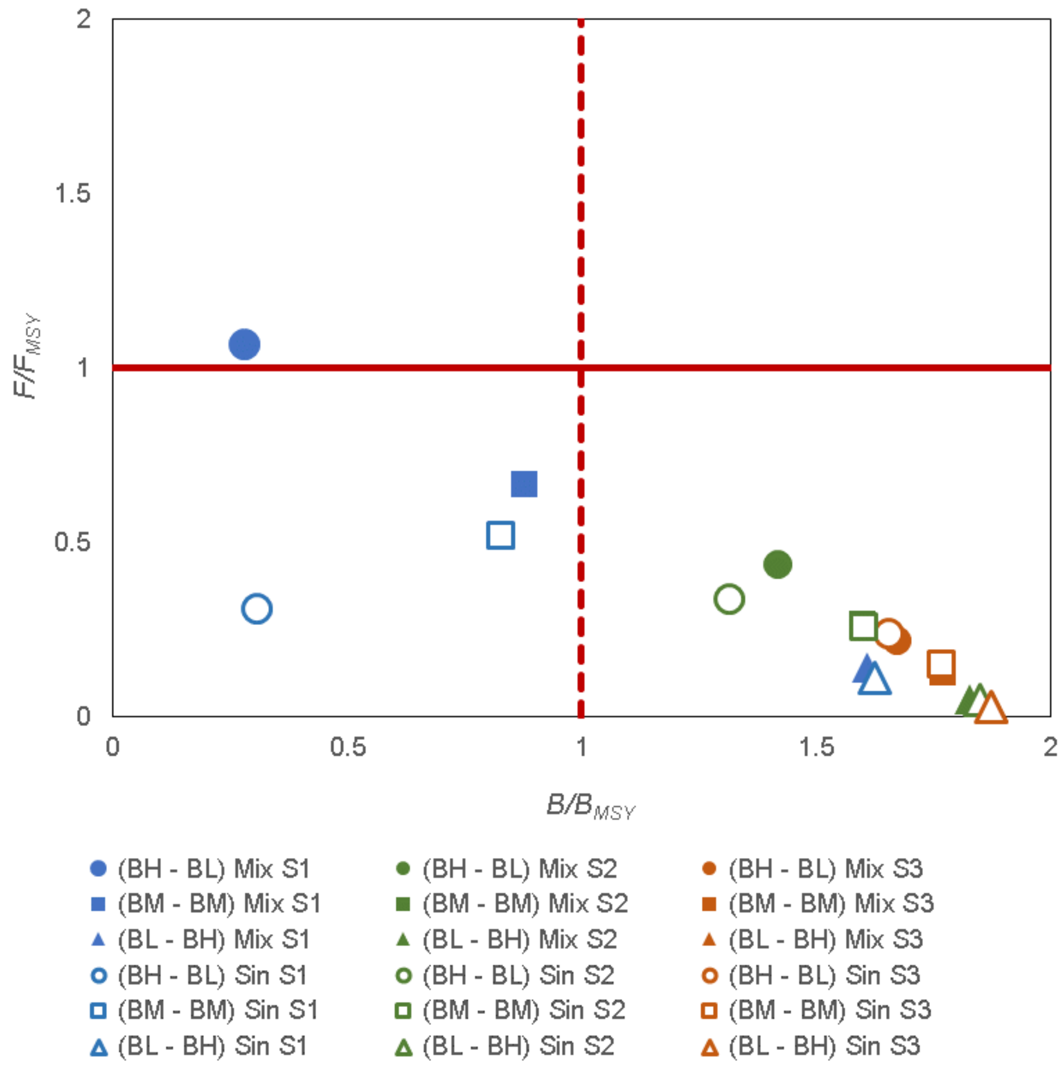
Appendix 5. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for B_M – B_M scenario. Only 20 trajectories are shown in each figure; both σ_R and σ_m were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the B_{MSY} level and MSY level.



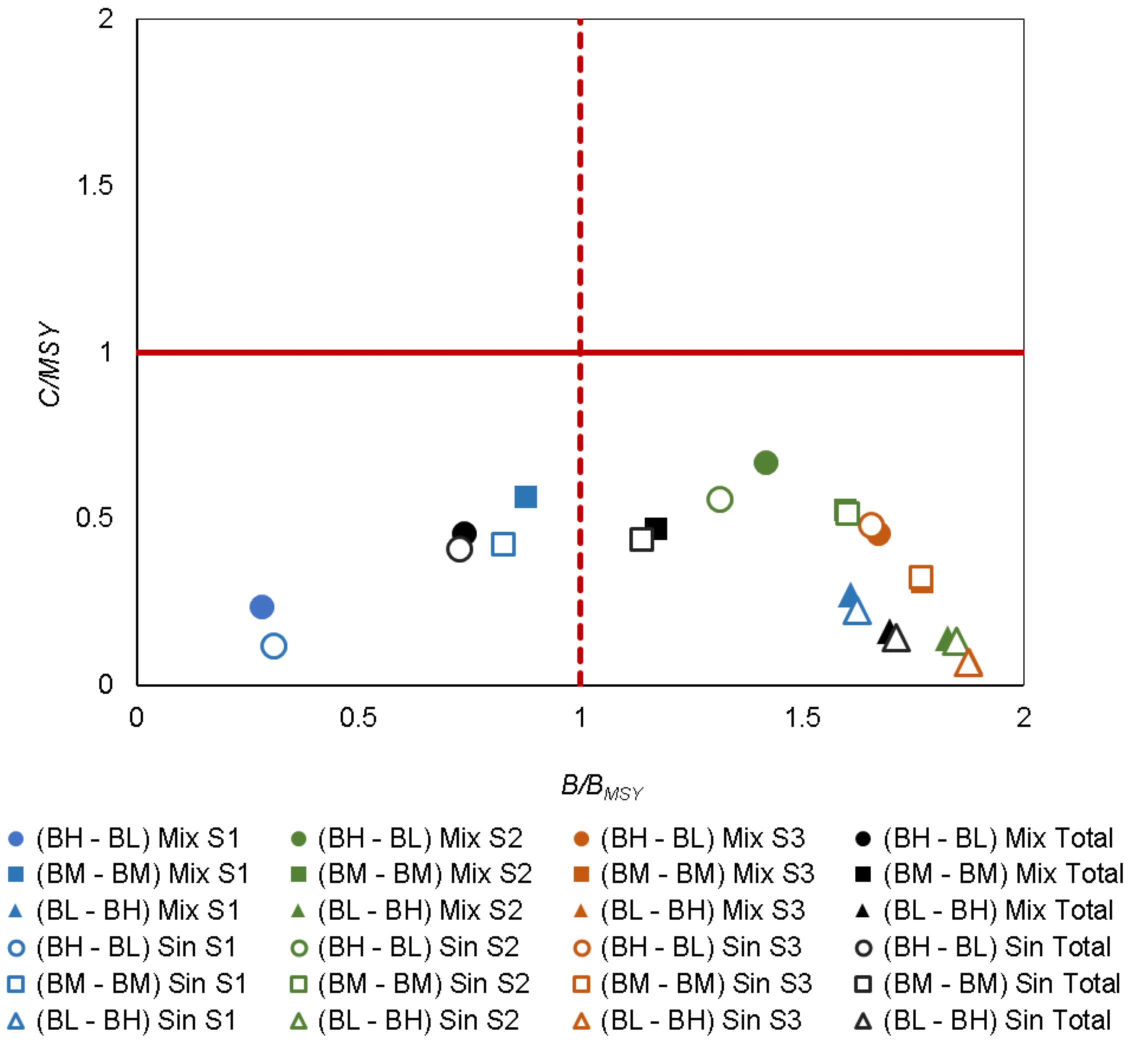
Appendix 6. Biomass and catch trajectories for three species after applying the default feedback harvest control rule (denoted by the abbreviation 1.0-1.0-1.0-0.8) to both mixed-species and single-species data, for $B_H – B_L$ scenario. Only 20 trajectories are shown in each figure; both σ_R and σ_m were fixed at 0.2. Bold horizontal lines through the biomass and catch trajectories, respectively, indicate the B_{MSY} level and MSY level.



Appendix 7. Kobe-plot for the last management year, after applying the default feedback harvest control rule using σ_R = 0.2 and σ_I = 0.4 to mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios B_H – B_L, B_M – B_M and B_L – B_H, respectively. The solid red line indicates the overfishing threshold, while the dashed red line defines the overfished line.



Appendix 8. Biomass and catch status performance of the default feedback harvest control rule σ_R = 0.2 and σ_I = 0.4, with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. The shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios BH – BL, BM – BM, and BL – BH, respectively. The solid red line indicates the MSY level, while the dashed red line defines the overfished line.



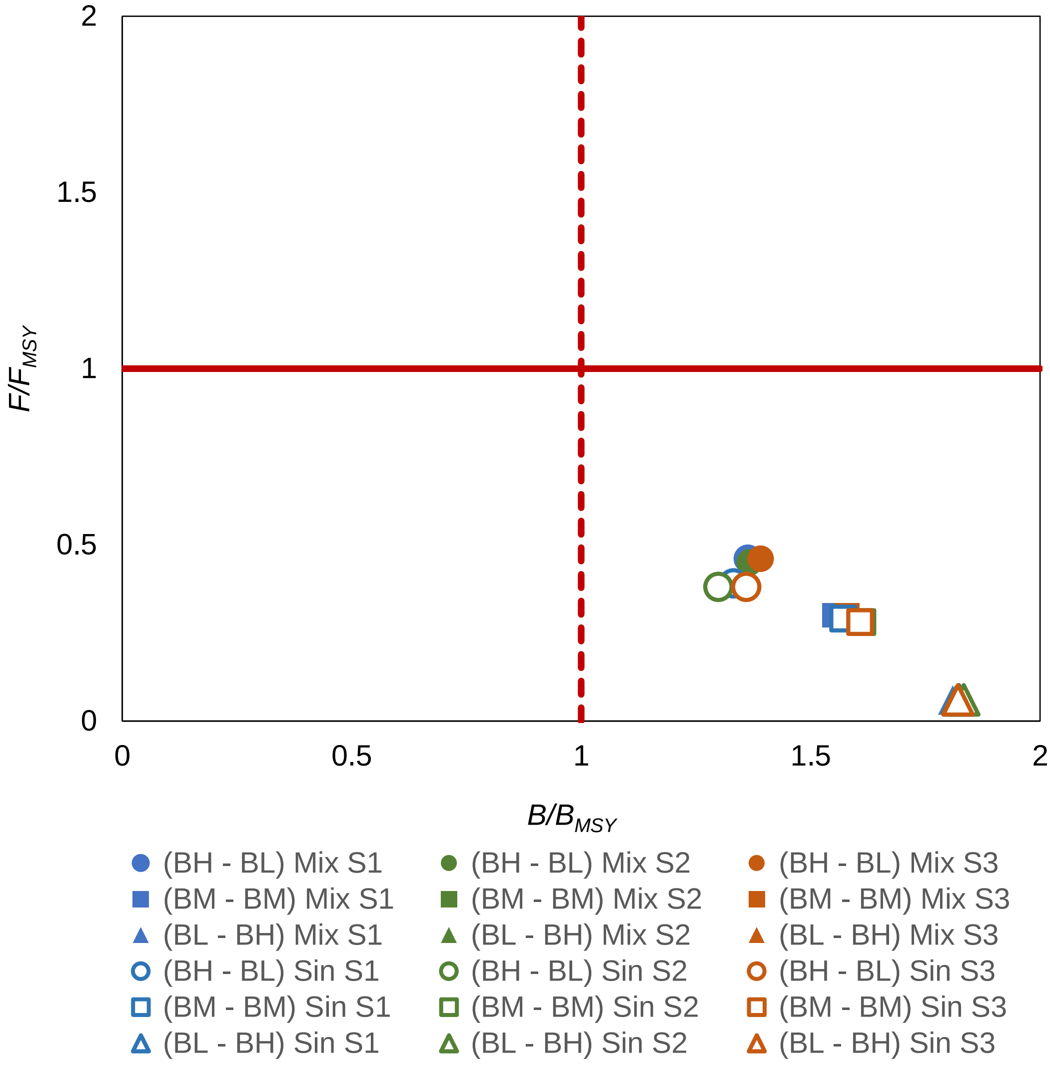
Appendix 9a. Alternative set I of parameter values for the three species in the multispecies fishery under assumption of surplus production model (Schaefer model) without process error.

Parameter	Definition	Species 1	Species 2	Species 3
r	Intrinsic growth rate	0.5	0.5	0.5
K	Carrying capacity	50 000	20 000	10 000
MSY	Maximum sustainable yield	2 500	2 500	2 500
B_{MSY}	Biomass produced at the MSY level	25 000	10 000	5 000

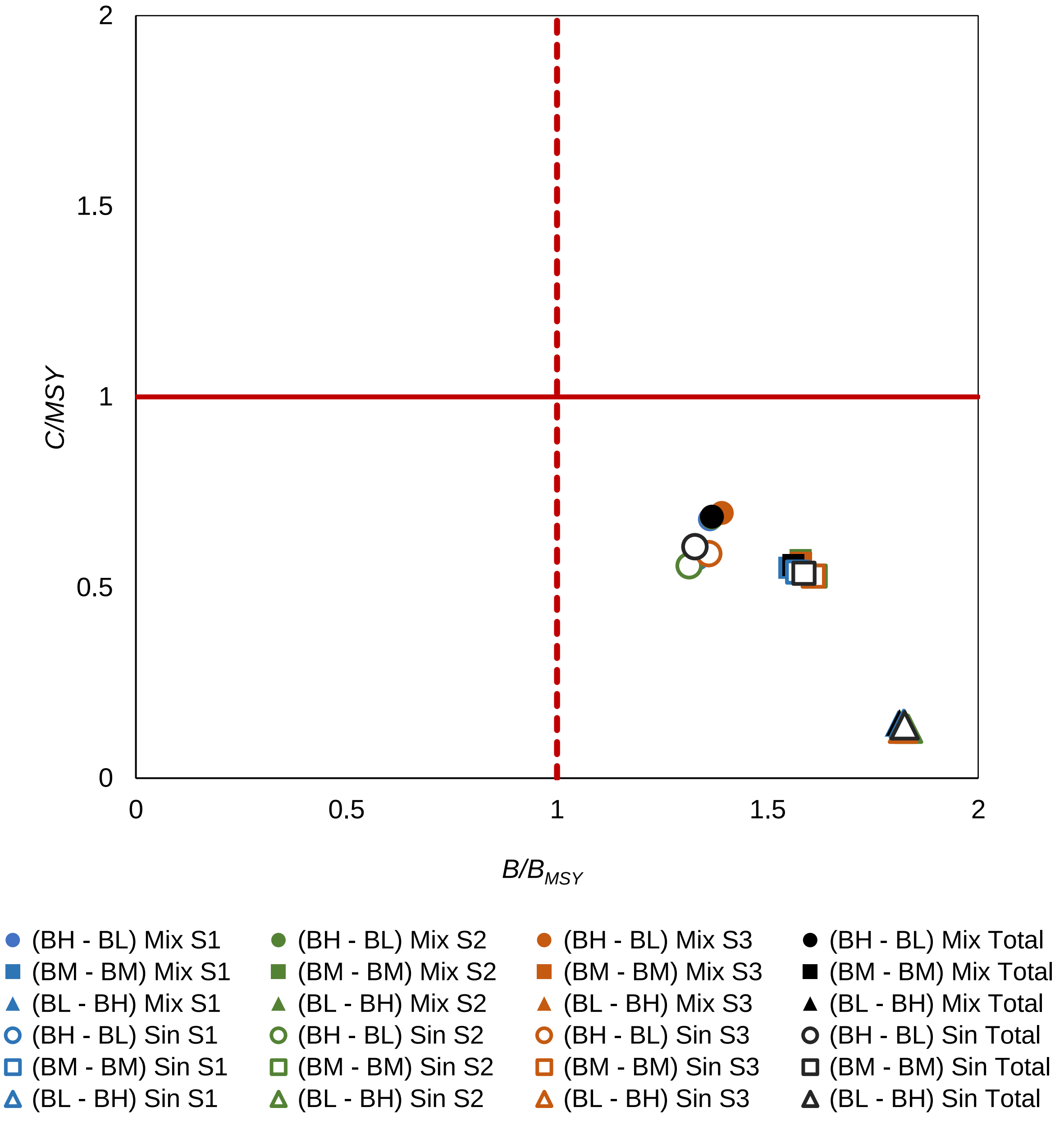
Appendix 9b. Alternative set II of parameter values for the three species in the multispecies fishery under assumption of surplus production model (Schaefer model) without process error.

Parameter	Definition	Species 1	Species 2	Species 3
r	Intrinsic growth rate	0.2	0.5	1.0
K	Carrying capacity	20 000	20 000	20 000
MSY	Maximum sustainable yield	2 500	2 500	2 500
B_{MSY}	Biomass produced at the MSY level	25 000	10 000	5 000

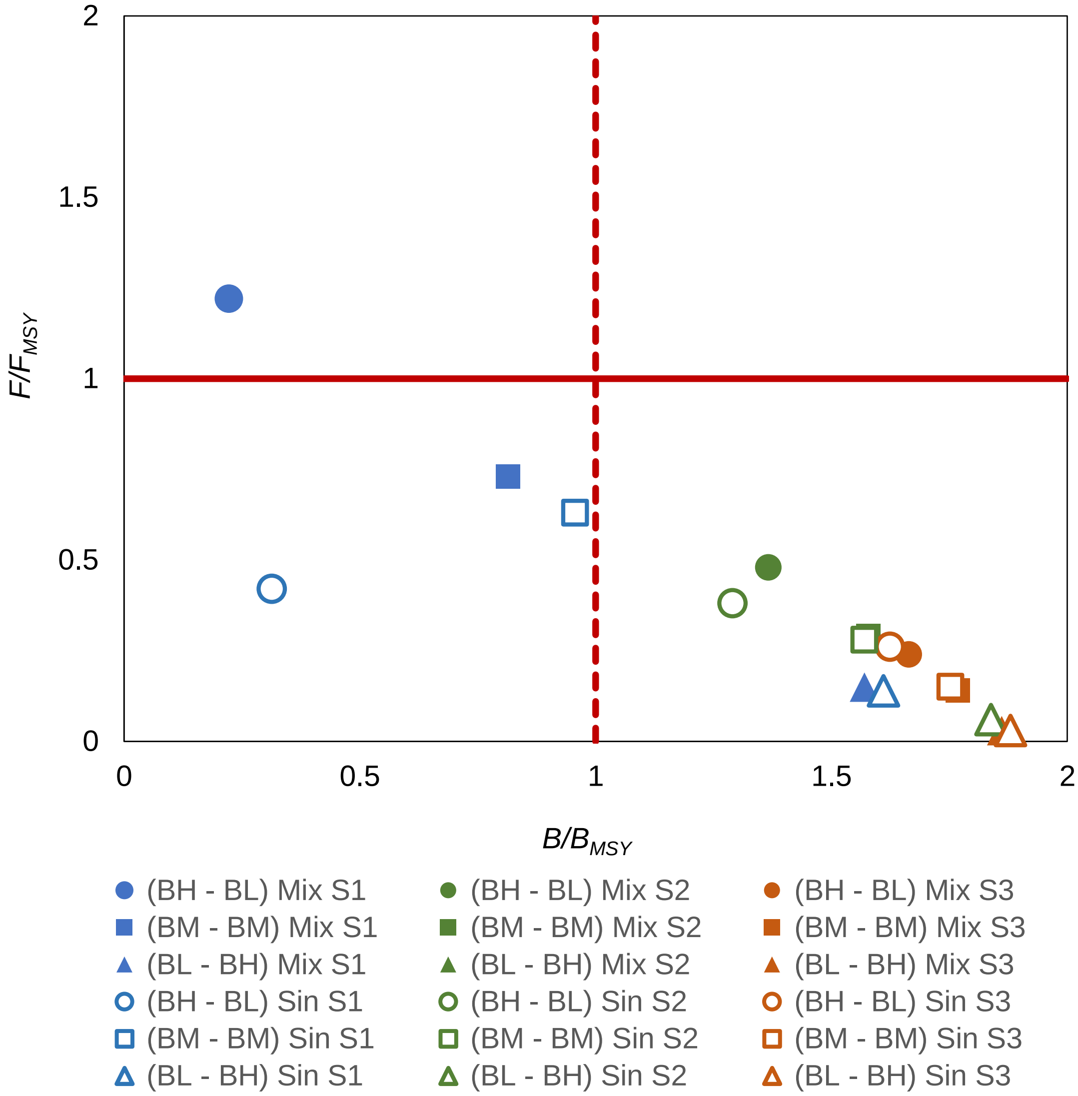
Appendix 10. Kobe-plot for the last management year, after applying the default feedback harvest control rule under alternative set I (Appendix 9a) to mixed-species data (solid color) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. Shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios B_H – B_L, B_M – B_M and B_L – B_H, respectively. Solid red line indicates the overfishing threshold, while dashed red line defines the overfished line.



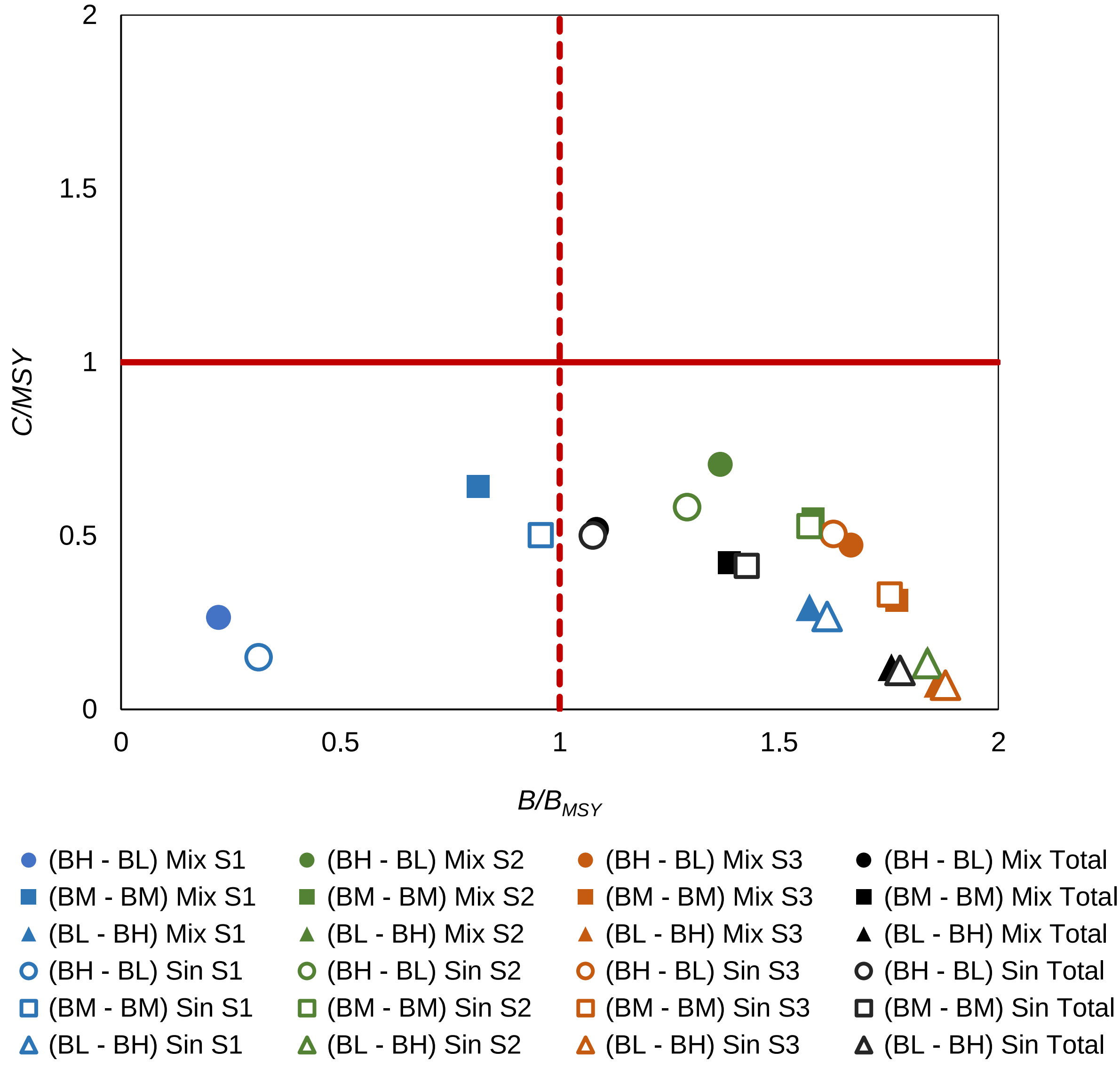
Appendix 11. Biomass and catch status performance of the default feedback harvest control rule under alternative set I (Appendix 9a) with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. Shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios $B_H – B_L$, $B_M – B_M$, and $B_L – B_H$, respectively. Solid red line indicates the MSY level, while dashed red line defines the overfished line.



Appendix 12. Kobe-plot for the last management year, after applying the default feedback harvest control rule under alternative set II (Appendix 9b) to mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green and orange indicate species 1, 2 and 3, respectively. Shape of the points denotes the type of biomass-trend scenario, with circles, squares and triangles used for scenarios B_H – B_L, B_M – B_M and B_L – B_H, respectively. Solid red line indicates the overfishing threshold, while dashed red line defines the overfished line.



Appendix 13. Biomass and catch status performance of the default feedback harvest control rule under alternative set II (Appendix 9b) with mixed-species data (solid colors) and single-species data (outline colors), under three critical scenarios. Blue, green, orange and black indicate species 1, 2, 3, and the total species, respectively. Shape of the points denotes the type of biomass-trend scenario, with circles, squares, and triangles used for scenarios $B_H - B_L$, $B_M - B_M$, and $B_L - B_H$, respectively. Solid red line indicates the MSY level, while dashed red line defines the overfished line.



Appendix 14. Summary of the performance measures (probability of overfishing [P_{OF}], yield status [C/MSY], biomass status [B/B_{MSY}], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 0.5-1-1-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: B_H – B_L, B_M – B_M, and B_L – B_H..

Scenario	Performance measures	Mixed-species results								Single-species results							
		Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV	Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV
B_H – B_L	P_{OF}	0.81	–	0.06	–	0.00	–	–	–	0.39	–	0.16	–	0.01	–	–	–
	C/MSY	0.25	0.58	0.66	0.26	0.45	0.29	0.46	–	0.10	0.10	0.50	0.15	0.51	0.19	0.42	–
	B/B_{MSY}	0.28	0.56	1.41	0.34	1.66	0.24	0.73	–	0.29	0.26	1.17	0.30	1.62	0.26	0.68	–
	Failure	0.01	–	0.00	–	0.01	–	0.02	–	0.60	–	0.19	–	0.01	–	0.68	–
B_M – B_M	P_{OF}	0.36	–	0.00	–	0.00	–	–	–	0.36	–	0.02	–	0.00	–	–	–
	C/MSY	0.54	0.37	0.52	0.28	0.31	0.31	0.46	–	0.37	0.18	0.53	0.21	0.34	0.20	0.44	–
	B/B_{MSY}	0.87	0.46	1.60	0.28	1.76	0.23	1.16	–	0.76	0.40	1.58	0.29	1.73	0.23	1.09	–
	Failure	0.00	–	0.00	–	0.01	–	0.01	–	0.22	–	0.01	–	0.01	–	0.23	–
B_L – B_H	P_{OF}	0.00	–	0.00	–	0.00	–	–	–	0.00	–	0.00	–	0.00	–	–	–
	C/MSY	0.23	0.24	0.12	0.26	0.06	0.28	0.14	–	0.19	0.15	0.12	0.21	0.06	0.20	0.13	–
	B/B_{MSY}	1.61	0.35	1.83	0.23	1.87	0.21	1.70	–	1.59	0.34	1.83	0.23	1.89	0.21	1.69	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–

Appendix 15. Summary of the performance measures (probability of overfishing [P_{OF}], yield status [*C*/MSY], biomass status [B/B_{MSY}], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 1.5-1-1-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: $B_H – B_L$, $B_M – B_M$, and $B_L – B_H$.

Scenario	Performance measures	Mixed-species results								Single-species results							
		Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV	Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV
$B_H – B_L$	P_{OF}	0.83	–	0.04	–	0.00	–	–	–	0.52	–	0.11	–	0.01	–	–	–
	C/MSY	0.25	0.58	0.68	0.30	0.46	0.29	0.46	–	0.19	0.64	0.61	0.38	0.48	0.35	0.43	–
	B/B_{MSY}	0.28	0.53	1.41	0.34	1.66	0.25	0.73	–	0.44	0.68	1.48	0.38	1.64	0.26	0.85	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.05	–	0.01	–	0.01	–	0.07	–
$B_M – B_M$	P_{OF}	0.36	–	0.00	–	0.00	–	–	–	0.30	–	0.01	–	0.00	–	–	–
	C/MSY	0.58	0.41	0.53	0.30	0.31	0.30	0.47	–	0.48	0.46	0.52	0.35	0.32	0.33	0.44	–
	B/B_{MSY}	0.84	0.44	1.59	0.28	1.77	0.23	1.14	–	0.97	0.51	1.61	0.29	1.76	0.23	1.23	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–
$B_L – B_H$	P_{OF}	0.00	–	0.00	–	0.00	–	–	–	0.00	–	0.00	–	0.00	–	–	–
	C/MSY	0.24	0.30	0.13	0.26	0.07	0.27	0.14	–	0.20	0.32	0.11	0.35	0.06	0.33	0.13	–
	B/B_{MSY}	1.60	0.35	1.83	0.23	1.90	0.21	1.69	–	1.64	0.36	1.85	0.23	1.86	0.21	1.72	–
	Failure	0.00	–	0.00	–	0.01	–	0.01	–	0.00	–	0.00	–	0.01	–	0.01	–

Appendix 16. Summary of performance measures (probability of overfishing [P_{OF}], yield status [C/MSY], biomass status [B/B_{MSY}], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 2.0-1-1-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: B_H – B_L, B_M – B_M, and B_L – B_H.

Scenario	Performance	Mixed-species results								Single-species results							
	measures	Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV	Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV
B_H – B_L	P_{OF}	0.83	–	0.04	–	0.00	–	–	–	0.36	–	0.09	–	0.01	–	–	–
	C/MSY	0.24	0.58	0.68	0.33	0.45	0.30	0.46	–	0.20	0.69	0.61	0.46	0.45	0.44	0.42	–
	B/B_{MSY}	0.25	0.52	1.41	0.33	1.70	0.25	0.72	–	0.57	0.66	1.48	0.36	1.70	0.26	0.94	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.01	–	0.01	–	0.01	–	0.03	–
B_M – B_M	P_{OF}	0.35	–	0.00	–	0.00	–	–	–	0.24	–	0.01	–	0.00	–	–	–
	C/MSY	0.58	0.43	0.53	0.31	0.31	0.31	0.47	–	0.49	0.53	0.48	0.45	0.30	0.43	0.43	–
	B/B_{MSY}	0.84	0.43	1.60	0.28	1.77	0.23	1.15	–	1.04	0.47	1.64	0.28	1.78	0.23	1.28	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.01	–	0.01	–
B_L – B_H	P_{OF}	0.00	–	0.00	–	0.00	–	–	–	0.00	–	0.00	–	0.00	–	–	–
	C/MSY	0.25	0.33	0.13	0.27	0.07	0.28	0.15	–	0.21	0.40	0.11	0.43	0.06	0.41	0.13	–
	B/B_{MSY}	1.58	0.35	1.85	0.23	1.87	0.21	1.68	–	1.63	0.35	1.87	0.23	1.87	0.21	1.72	–
	Failure	0.00	–	0.00	–	0.01	–	0.01	–	0.00	–	0.00	–	0.01	–	0.01	–

Appendix 17. Summary of performance measures (probability of overfishing [P_{OF}], yield status [*C/MSY*], biomass status [B/B_{MSY}], management failure [failure], and coefficient of variation [CV]) when applying an alternative harvest control rule (denoted by the abbreviation 2.5-1-1-0.8) to three species (slow-growing [Sp. 1], medium-growing [Sp. 2], and fast-growing [Sp. 3]), with mixed-species data or single-species data, and under three critical biomass-trend scenarios: B_H – B_L, B_M – B_M, and B_L – B_H.

Scenario	Performance measures	Mixed-species results								Single-species results							
		Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV	Sp. 1	CV	Sp. 2	CV	Sp. 3	CV	Total	CV
B_H – B_L	P_{OF}	0.78	–	0.05	–	0.00	–	–	–	0.30	–	0.09	–	0.01	–	–	–
	C/MSY	0.26	0.61	0.67	0.36	0.44	0.33	0.45	–	0.22	0.75	0.57	0.57	0.42	0.56	0.41	–
	B/B_{MSY}	0.30	0.52	1.42	0.33	1.68	0.25	0.75	–	0.68	0.66	1.56	0.36	1.71	0.27	1.03	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.01	–	0.01	–	0.01	–	0.03	–
B_M – B_M	P_{OF}	0.36	–	0.00	–	0.00	–	–	–	0.22	–	0.01	–	0.00	–	–	–
	C/MSY	0.57	0.46	0.53	0.33	0.31	0.32	0.47	–	0.49	0.62	0.46	0.54	0.29	0.52	0.41	–
	B/B_{MSY}	0.82	0.43	1.60	0.27	1.76	0.23	1.13	–	1.12	0.47	1.70	0.28	1.77	0.24	1.35	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–
B_L – B_H	P_{OF}	0.00	–	0.00	–	0.00	–	–	–	0.00	–	0.00	–	0.00	–	–	–
	C/MSY	0.26	0.36	0.13	0.29	0.07	0.29	0.15	–	0.21	0.50	0.10	0.53	0.06	0.50	0.12	–
	B/B_{MSY}	1.59	0.34	1.82	0.23	1.87	0.21	1.68	–	1.65	0.35	1.85	0.23	1.88	0.21	1.73	–
	Failure	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–	0.00	–