

Reconstructing a century of marine landings and fishing effort in Malaysia and Singapore

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Abstract

Marine capture fisheries are crucial for many coastal communities in Malaysia and Singapore. However, knowledge of the historical state of the marine fishing resources, particularly during the British colonial period, remains limited. We compiled annual species landing data and fishing metrics from colonial and contemporary fishery reports spanning 114 years, from 1907 to 2021. Our results revealed a steady increase in species landings over 90 years, peaking in 2016 before declining in recent years. Through three case studies, we highlight high colonial landings of fusiliers (Caesionidae) from Singapore, reflecting extensive fishing operations across Southeast Asia. Bayesian Change Point analyses also identified increases in lobster landings along the east coast of Peninsular Malaysia in the mid-1980s, with fishing operations expanding from Johor northward through Pahang and Terengganu. Granger-causality tests revealed significant associations between Indian mackerel landings and the number of powered fishing boats in Perlis and Kedah in western Peninsular Malaysia, with varying lag intervals among each state. While these results enhance our understanding of fisheries trends, spatial expansion of fisheries and technological changes complicate the interpretation of fishery trends. Our results suggest that the plateau in global fishery landings since the 1980s may also have already occurred in Southeast Asia.

Keywords: historical ecology; environmental history; fisheries; Southeast Asia; British Malaya

Introduction

Marine capture fisheries are integral to the socio-economic well-being of fishing communities across Southeast Asia, contributing substantially to local and global food production, providing millions of jobs, and generating substantial economic revenue (Teh and Pauly 2018, Costello et al. 2020). Recent studies highlight the vulnerable state of marine fish stocks across the region (Clark-Shen et al. 2021, Dimarchopoulou et al. 2021), emphasizing the need for effective fishery management strategies (Lotze and Milewski 2004, Beller et al. 2020). While the history of fishing in Southeast Asia is not unstudied, there remains a significant gap in our understanding of the historical landing and fishing effort patterns for most of the region (Thurstan 2022, McClenachan et al. 2024). Without adequate knowledge of these historical baselines (Pauly 1995), mismanagement of fish stocks could threaten the long-term survival of fish populations and the local communities reliant on them for subsistence and livelihood (Lotze and Milewski 2004, Campbell et al. 2009, Beller et al. 2020).

While reconstructions of historical fishery landings are useful on their own, they are most informative when combined with a measure of total fishing effort, such as the number of powered fishing vessels and licensed fishermen. Together, landing and fishing effort time series can be used to identify the underlying drivers of harvest trends over time (Anticamara et al. 2011, Rousseau et al. 2019). For example, Bueno-Pardo et al. (2020) showed that declining European pilchard landings in Portugal resulted mainly from reduced fishing effort by commercial purse-seine vessels. Likewise, the decrease in

relative abundance of fish populations in the Mozambique Channel since the early 1970s, excluding Mozambique, was associated with increased motorization of fishing vessels and an increase in fleet size across multiple countries (Zeller et al. 2021). Understanding the specific drivers of fishing effort on species landing patterns in Southeast Asia can help policymakers to develop sustainable management strategies in the region (Alleway et al. 2023, McClenachan et al. 2024).

Colonial documents provide a valuable and relatively underutilized resource for reconstructing marine fishery landings and effort in Southeast Asia. Singapore was established as a British settlement in 1819, followed by Malaysia in 1824, forming the trading colony known as British Malaya. Prior to 1921, fisheries were governed by different authorities, including the Straits Settlements and Federated Malayan States (Maxwell 1921b), with management focused on advancing the economic development of marine capture fisheries. Apart from an annual statement detailing the license fees for various types of sailing boats and fishing gear, there was limited information available on the diversity of harvested species and their biological characteristics (Wilkinson et al. 1904, Maxwell 1921a, Maxwell 1921b, Stead 1923). The establishment of a unified Fisheries Department in late 1923 marked a new beginning for the industry. It resulted in scientific surveys in Malayan waters, experiments in fish rearing within rice fields, and the compilation of basic statistics in annual reports (Choo 2019). The latter provided valuable, albeit imprecise, annual estimates of the number of licensed fishermen, the various types of fishing boats and gears, and species-specific

landings for each state across British Malaya until World War II (WWII). After the war, there was a significant shift in the marine fishing industry marked by a dramatic increase in fish landings. This was driven by advancements in fishing fleets, such as the adoption of diesel-powered engines and new fishing gear (Kesteven 1949, Butcher 2004), as well as the expansion of global seafood trade (Platteau 1989). These innovations enabled fishermen to explore new offshore fishing grounds and sparked intense competition among nations, particularly during the early 1960s, to enhance marine capture fisheries (Abdul *et al.* 1956, Anon 1958, Saharuddin 1995, Butcher 2004).

Although colonial records have the potential to provide valuable historical insights, the compilation of historical and modern records in Malaysia and Singapore has been hampered by the inconsistent use of common names. However, this challenge is not insurmountable; evidence from early naturalist books, archival illustrations, and photographs can all be used to identify targeted species. Qualitative data from these sources can complement quantitative statistics to analyse long-term fishery trends and infer changes in population abundance or community structure (Kittinger *et al.* 2015, Sáenz-Arroyo and Revollo-Fernández 2016). For example, Fortibuoni *et al.* (2010) adapted early naturalist descriptions of fish landings from the Northern Adriatic Sea into a semi-quantitative format to study long-term changes in community structure. The authors reported significant declines in large demersal fishes, alongside increases in small, early maturing fish species over the past two centuries. Therefore, the integration of historical and contemporary data sources can facilitate taxonomically accurate reconstructions of fish landings in Southeast Asia.

Several limitations must be considered when interpreting catch reconstructions. One challenge stems from the spatial expansion of fishing activities, particularly transboundary fishing in Southeast Asia (Butcher 2004), before the establishment of Exclusive Economic Zones (EEZ) under the United Nations Convention on the Law of the Sea (UNCLOS) in 1982. The movement of fishing fleets across states and national waters, compounded by illegal fishing activities, can complicate the attribution of landings to specific states, potentially masking local stock depletion and distorting marine resource assessments (Butcher 2004, Stobutzki *et al.* 2006a, Christensen and Tull 2014, Teh *et al.* 2017, Cardinale *et al.* 2023). For example, Malaysian authorities estimated that 10%–15% of Thailand's annual catches in the late 1970s and 1980s came from Malaysian waters (McDorman and Tasneeyanond 1987), highlighting the challenges in accurately attributing catches across national borders. Additionally, the introduction of new fishing technologies, such as powered boats and advanced fishing gear, referred to as 'technological creep', can further skew historical data by improving catch efficiency without a corresponding increase in fish abundance (Palomares and Pauly 2019, Scherrer and Galbraith 2020). Together, these factors introduce a degree of uncertainty in the assessment of long-term fishery trends.

This manuscript aims to advance our understanding of changes in the marine fishing of Malaysia and Singapore over the past century, with a focus on quantifying changes in landings and metrics of fishing effort. We compiled annual landing data, the number of licensed fishermen, and number of powered and non-powered fishing boats from colonial and contemporary fisheries reports over the past 114 years, from 1907 to 2021. Change point analyses were conducted on landings

and fishing effort time series to detect abrupt changes. Subsequently, Granger-causality tests were used to identify changes in landing data that can be plausibly attributed to changes in each metric of fishing effort.

Materials and methods

Data collection

We compiled historical and contemporary data on species landings and commercial fishing effort metrics (number of licensed fishermen and powered and non-powered fishing boats), from each state in Malaysia and Singapore from 1907 to 2021 (Fig. 1). Historical records were attained from colonial documents in museums, libraries, and national archives of Singapore and the UK (Supplementary Material S1). Contemporary fisheries data from Singapore was obtained from the Fishery Statistical Bulletin by the Southeast Asian Fisheries Development Center (SEAFDEC), accessible at <http://map.seafdec.org/fisherybulletin/>. The statistical data from Malaysia was compiled from annual fishery reports published by the Department of Fisheries Malaysia, available at <https://www.dof.gov.my/en/resources/fisheries-statistics-1/>.

Pre-war estimates of fishermen and boat numbers were documented by the colonial fisheries department for taxation purposes, based on fishing gear types and boat license fees. Landings were estimated from fresh fish and seafood product weights recorded by colonial fishery officers in landing ports across British Malaya (Birtwistle 1931). Pre-war landings were reported in katties (1 katty = 0.60 kg), while post-war landing data were recorded in pikuls (1 pikul = 60 kg) and tonnes, all of which were standardized to tonnes for comparison. In years lacking species-specific data ($n = 19$), total landings were aggregated and reported.

Annual landings were grouped based on their common names (local or historical) to a family level or higher taxonomic groups using species identification guides (Supplementary Material S2). Most tropical fisheries are multispecies fisheries (van Oostenbrugge *et al.* 2002), where species identification and classification are often challenging due to high biodiversity. While there will invariably be a degree of semantic uncertainty (Akçakaya *et al.* 2000, Hey *et al.* 2003) as taxonomies undergo continual refinement (Mace 2004), grouping species into categories allow for the assessment of general trends in species complexes over time (Isaac *et al.* 2004). Although cryptic species and changes in species composition may mask depletion trends within a taxonomic group, using historical and modern identification guides from different time periods can mitigate these uncertainties. References by early naturalists and fishery experts included Cantor (1850); Maxwell (1921a); Stead (1923); Green (1926); Birtwistle (1931); Birtwistle (1937); Birtwistle (1938), alongside modern identification guides from the Malaysian Department of Fisheries and SEAFDEC (2014). All common names were cross-verified with FishBase (Froese and Pauly 2010) to ensure accurate classification within higher taxonomic levels. Freshwater fish, aquaculture fish, and derived seafood products were excluded from statistical analysis to focus on changes in landings of marine fisheries. A comprehensive list of common names and their corresponding taxonomic units is provided in the Supplementary Material S2.

Three case studies were selected from our vast dataset, comprised of landings from 82 taxonomic groups across 16 states, to illustrate changes in landings trends over the past century. The first case example focused on high historical landings

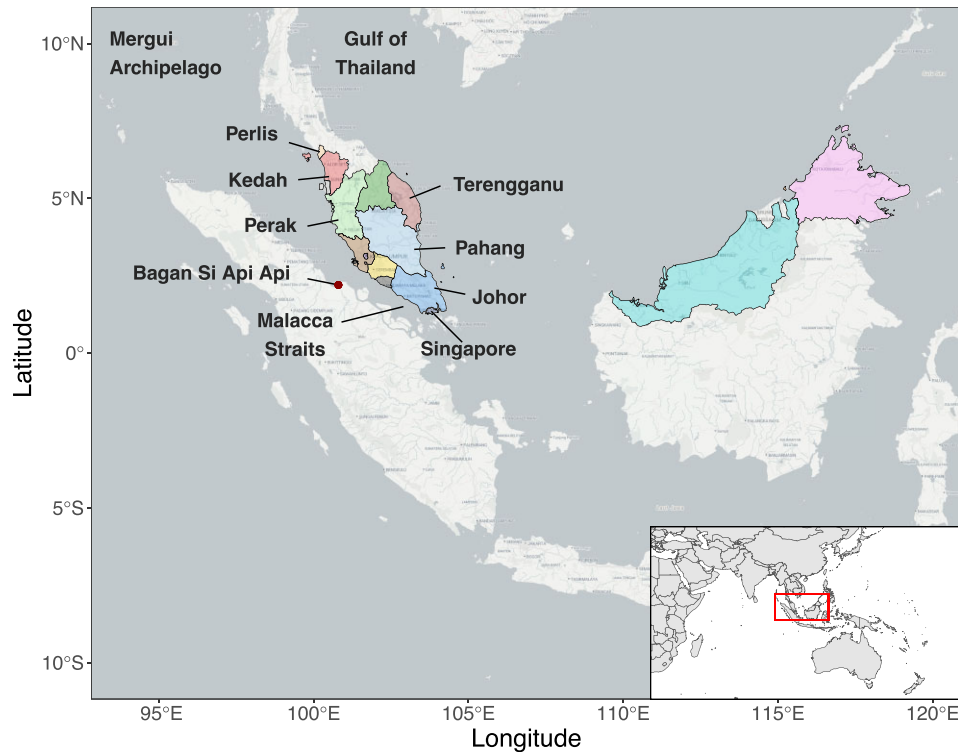


Figure 1. Geographical map of the study regions across Malaysia and Singapore. ‘ggmap’ package version 4.0.0.900 (Kahle and Wickham 2013). Bolded labels refer to study regions in the case studies.

of fusiliers (Caesionidae) in the municipal markets of Singapore to highlight the importance of understanding the nature and spatial context of fishing operations across Southeast Asian waters. The second example identified periods of intense exploitation of lobsters along the east coast of Peninsular Malaysia using Bayesian change point analyses. Finally, the third case study explored the relative importance of powered fishing boats on Indian mackerel landings across states along the western coast of Peninsular Malaysia using Granger-causality tests (Granger 1969). This approach, supported by robust statistical analyses, allowed us to pinpoint periods of abrupt change in the landing data and uncover plausible causal relationships between landings and fishing effort.

Statistical analysis

We analysed each landings time series by species using Bayesian change point analyses to detect abrupt changes in the fishery trends. This method has notable advantages over frequentist approaches, such as its ability to incorporate prior knowledge and uncertainties through a probabilistic framework. A weak prior (mean = 0.05, sd = 0.2) was specified on the intercept-only models due to strong uncertainty about the probability of a change point occurring along each time series. All analyses were based on 11 000 Markov Chain Monte Carlo (MCMC) iterations after a burn-in period of 1000 iterations. Any abrupt changes in fisheries data were detected based on an arbitrary posterior probability threshold of 0.75. All analyses were conducted using the ‘bcp’ package version 4.0.3 (Erdman and Emerson 2008) in R version 4.2.2.

To account for technological creep, we calculated a 2% annual compounded increase in both powered and non-powered fishing boats, reflecting expected improvements in fishing

efficiency over time (Palomares and Pauly 2019). Granger-causality tests were then conducted on each species-specific landing time series to assess directional ‘causality’ among each fishery effort metric based on a truncated dataset, from 1968 to 1997. These tests evaluate whether past values of one variable could predict the future values of another metric, implying a plausible causal relationship (Shojaie and Fox 2022). This method contrasts with standard correlation tests, which measures the strength and direction of a linear relationship between two variables at a specific point in time. Additionally, we evaluated the assumptions of stationarity using the Augmented Dickey–Fuller (ADF) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests using ‘tseries’ package version 0.10–54 (Trapletti et al. 2015). We attained stationarity by calculating the second-order difference in the data. In cases where the assumption of stationarity was violated even after transformation, specifically for landing data from the federal island territory of Labuan, we did not conduct further analyses. The Akaike’s Information Criterion (AIC) was then used to evaluate the model fit between each state-specific landing data and fishery effort metric with different lags. Lowest AIC values indicated the optimal lag period for each species. All Granger-causality tests were performed using the ‘lmtest’ package version 0.9–40 (Hothorn et al. 2015).

Results and discussion

Colonial state of the fishing industry (pre-1950)

Over the past 90 years, there has been a steady increase in landings from Malaysia and Singapore, reaching a peak in 2016 before declining over the last five years (Fig. 2). Before 1950, annual harvest estimates by the fishery department

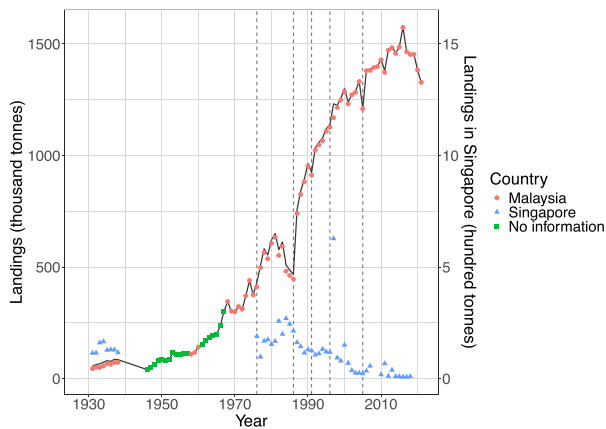


Figure 2. Change in landings from Malaysia (y-axis; thousand tonnes) and Singapore (secondary y-axis; thousand tonnes) over the past 90 years, from 1931 to 2021. Black line denotes the overall trend in landing data. Dashed lines refer to abrupt changes in overall landings based on the Bayesian change point analysis threshold of 0.75. No information represented in the legend refers to landing data (thousand tonnes) without species-specific capture information. Data were not collected from 1939 to 1946 due to World War II.

ranged between 60 000 and 80 000 tonnes, reflecting the early development of the fishing industry in Malaya. Most small-scale fishermen operated within a natural coastal belt, leaving the productive offshore waters untouched (Le Mare 1951, Burdon 1955). However, the onset of the Japanese Occupation of Malaya in 1941 halted the routine collection of fishery statistics. Despite the lack of quantitative landings data during this period, historical records point to a dramatic food shortage during the WWII years, highlighting the profound impact of wartime disruptions on local food supplies and the fishing industry (Shimizu 1997, Huff and Huff 2020). According to newspaper evidence from the early years of WWII, pelagic fish species such as the Spanish mackerel and wolf herring formed part of local fish landings (Anon 1942a, Anon 1942b). Little information exists regarding the state of the fishing industry towards the end of WWII. However, annual fishery reports from the post-war period spanning from 1945 to 1947 indicate a widespread shortage of essential fishing materials, boats, and gears, such as fishhooks and cotton required for making fish nets. Fishermen attempted to innovate by using alternative materials, although these efforts were met with limited success (Le Mare 1946). These essential shortages directly impacted the ability of fishermen to sustain adequate landings and exacerbated regional food shortages during the immediate post-war period.

Rapid technological advancement and fishery expansion (1950–2016)

The critical shortage of food and materials in the aftermath of WWII prompted advancements in fishing methods and technologies (Kesteven 1949). These innovations, adapted from wartime developments (Smith 1994, Holm 2012), not only enabled small-scale fishermen to exploit untapped offshore resources but improved the transportation of fresh fish to markets in a better marketable quality (Abdul et al. 1956, Anon 1958).

The successful introduction of bottom trawling in the late 1950s by Thai vessels in the Gulf of Thailand also prompted

widespread developments in the marine fishing industry of Malaysia, leading to the establishment of a demersal trawl industry along the Malacca Straits (Fig. 1). Successful trawl operations led to a notable increase in species landings, accounting for ~48% of all landings in Malaysia by 1974 (Morgan and Staples 2006). This highlights the vital role new fishing methods and technologies had in marine capture fisheries from Malaysia and Singapore.

Recent decline in fishing industry (2016 to present)

The successful adoption of modern fishing technologies in Malaysia, along with the implementation of multiple national development policies, played a crucial role in enhancing harvest from marine fisheries. Governmental policies—for example, the National Fishery Development Plan in 1985 (NFDP), which provided subsidies for vessel construction and fishing equipment—were crucial for expanding the fishing industry in the 1980s and 1990s (Omar et al. 1992, Yahaya and Abdullah 1993, Christensen and Tull 2014). These policies also extended to marketing infrastructure, resulting in a progressive increase in marine fish landings over the past four decades (Abu Talib et al. 2003). This increase reached a peak in 2016, after which landings started to sharply decline, especially in Peninsular Malaysia, with much of the continued growth in production attributed to commercial landings from Sabah and Sarawak in Eastern Malaysia (Fig. 3; Saharuddin 1995, Butcher 1996a). It is important to note that before the late 1980s, landings data from East Malaysia was sparse, and the historical condition of the marine fishing industry from East Malaysia was not well-documented (Anon, 1945).

In reality, sharp reductions in landings have been observed in certain states across Peninsular Malaysia, particularly in Kelantan, Terengganu, and Perlis (Fig. 3). These declines may be associated with overfishing, as trawlers have actively sought new fishing grounds due to the local depletion of fish populations (Fig. 3, Morgan and Staples 2006). Unlike in Malaysia, commercial landings from Singapore peaked in the mid-1980s, with annual landings hovering around 25 000 tonnes before declining gradually to a minimum (Fig. 3; Corpus 2014). On average, landings from Singapore represented 1.44% of the total landings from both countries. These trends reflect Malaysia's increasing focus on developing its production industry and the diminishing emphasis on marine capture fisheries within Singapore.

The recent decline in landings and fishing effort (Supplementary Material S3 and S4) suggests that commercial stocks in Malaysia and Singapore may be locally depleted. More crucially, the plateau in global landings observed since the mid-1980s (Pauly and Zeller 2016, Hilborn et al. 2020) may also have occurred in Southeast Asia. Although changes in landings can reflect variations in fishing effort, shifts in distribution ranges, and fluctuations in population abundance driven by demographic or climatic factors, as well as the influence of different social and economic variables (Srinivasan et al. 2010, Sethi et al. 2012), the comparison between landings and fishing effort metrics clearly demonstrates an increasing pressure on individual fish stocks (Supplementary Material S3 and S4).

Drawing comparisons with statistical data from the FAO FishStat database (FAO 2024a) revealed that observed landing trends in our study were similar to those in neighbouring Southeast Asian countries, such as Myanmar, Cambodia,

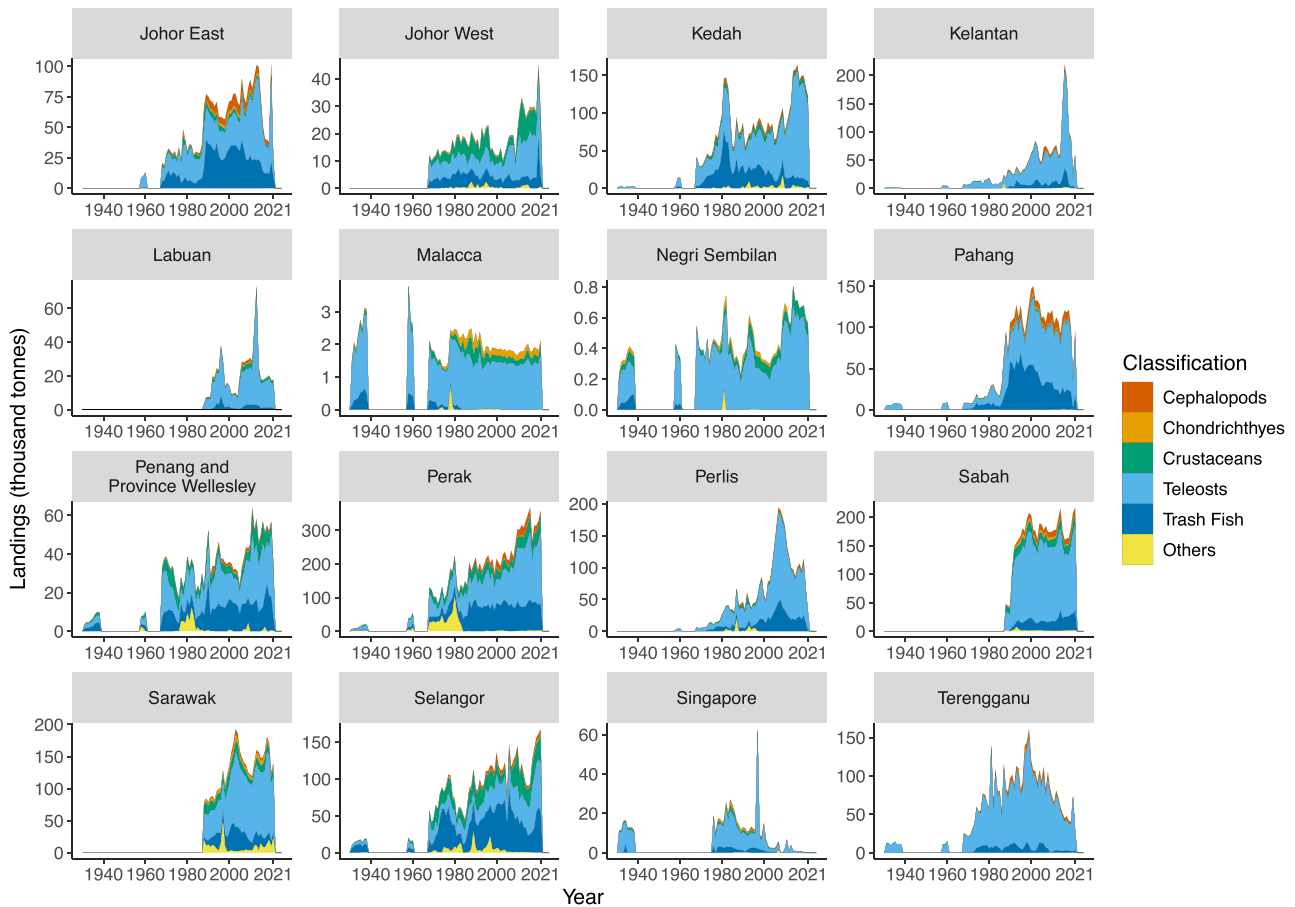


Figure 3. Changes in landings (thousand tonnes) from each state in Malaysia and Singapore over the past 90 years, from 1931 to 2021. Each line denotes a different higher-order taxonomic classification (Supplementary Material S2): cephalopods; chondrichthyes; crustaceans; teleosts; trash fish; others. Trash fish refers to species with little to no commercial value and are usually taken as bycatch.

and the Philippines (Supplementary Material S5). Landings in these countries also showed a gradual increase followed by a decline in recent years. In comparison, marine capture fishery trends in Thailand peaked much earlier in the mid-1990s, and have since declined steadily (Derrick et al. 2017). The decline in commercial landings from Malaysia and Singapore was not apparent when aggregated across all Association of Southeast Asian Nations (ASEAN) countries (Plot L; Supplementary Material S5). This was due to high reported landing data from Indonesia and Vietnam, which have been increasing steadily over the past decades, masking landing reductions observed in other nations. At a global scale, we found that the plateau in global capture fisheries statistics attained in the 1980s in certain major fishing areas, e.g. the Northwest Pacific (Area 61), may have already occurred in Southeast Asia (FAO 2024b). Overall, our results highlight the variability in national fishery trends and underscore the need for more detailed regional and species-specific fishery assessments to accurately evaluate changes in marine resource management.

Case study 1: Disproportionate historical landings highlight the importance of understanding where fishing operations occurred across Malayan waters.

During the early 1920s, Japanese fishermen from Okinawa played a crucial role in the colonial food production in Singapore. These fishermen contributed close to half of the total fish supply in Singapore during the pre-war period (Fig. 4),

primarily targeting fusiliers, also known as Ikan Delah, using a specialized technique known as the muro-ami fishing method (Shimizu 1997). This method involved a diesel-powered fishing boat flanked by smaller non-powered boats, with up to fifty local fishermen swimming in a concerted manner to corral the reef fish into the net while holding a string of weighted streamers (Green 1925, Green 1926, Le Mare 1951). Moving from reef to reef, the fishes were packed on ice to maintain quality and freshness before being transported to Singapore for sale by a parent boat (Birtwistle 1928).

While one might assume that this labour-intensive approach to catching fusiliers was restricted to local waters surrounding Singapore, close investigation of colonial reports documents long-distance expeditions to fringing reefs surrounding islands across Southeast Asia, extending northward to the Gulf of Thailand and the Mergui Archipelago, and eastward to Indonesia (Fig. 1, Le Mare 1951). In contrast, little to no landings were reported from each state along the east and west coasts of Peninsular Malaysia, as well as from Eastern Malaysia (Fig. 4). The high observed landing data from Singapore thus reflect the pre-war exploitation of fusiliers and the significant contribution that these Japanese fishermen made to colonial food production in the region.

Little has been documented about the fishing methods used to harvest fusiliers after WWII and in the present day. However, it is possible that the sharp decrease in fusilier landings reflects their depleted population state in coastal waters around

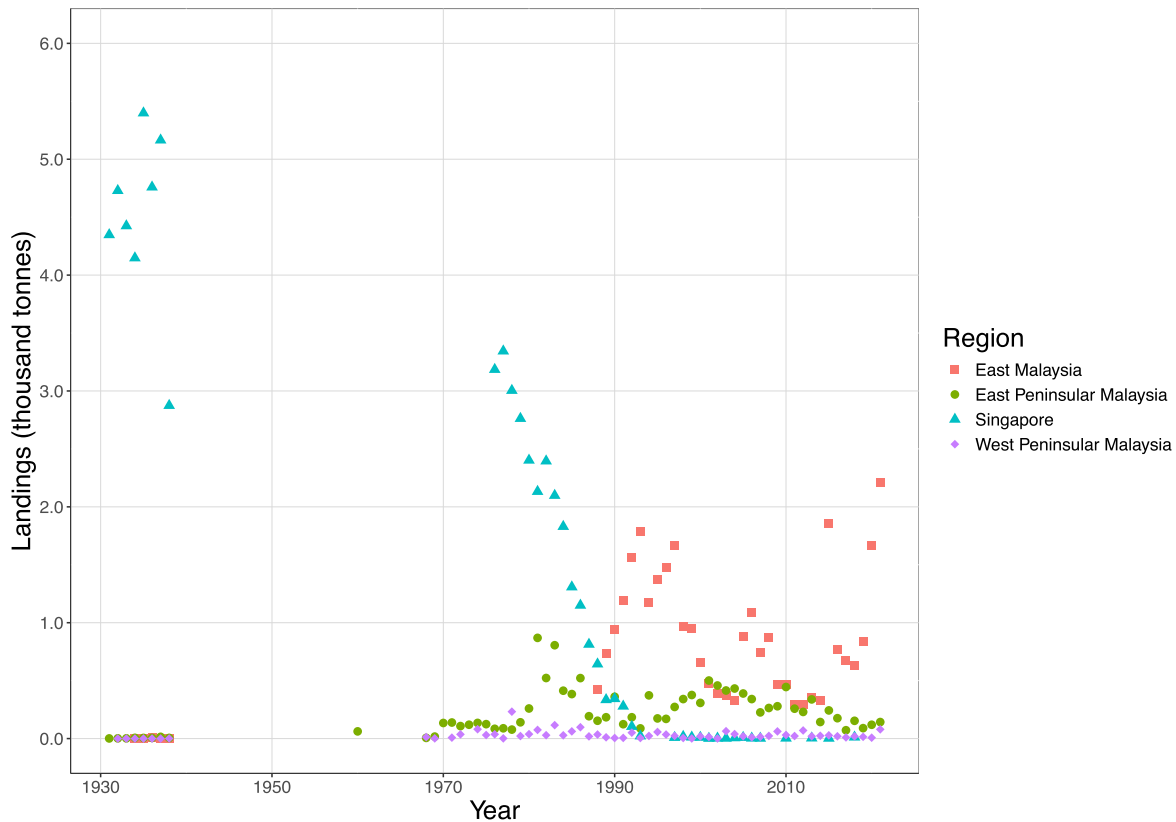


Figure 4. Fusilier landings (thousand tonnes) from Malaysia and Singapore over the past 90 years, from 1931 to 2021. East Malaysia refers to the states of Sabah and Sarawak and the federal island territory of Labuan. East and West Peninsular Malaysia refer to the east and west coasts of Peninsular Malaysia, respectively.

Singapore and along Peninsular Malaysia (Morgan and Staples 2006). Currently, fusilier landings comprise less than half of the maximum recorded landings during the colonial period. Our findings highlight the importance of understanding the spatial context of fishing operations in Malayan waters, as well as the need to account for potential sampling biases that may affect the validity of the data.

Case study 2: Bayesian Change Point analysis identifies intense exploitation of lobsters along the east coast of Peninsular Malaysia.

Since the 1980s, lobster landings along the east coast of Peninsular Malaysia have shown a notable pattern, marked by an initial increase followed by a steady decline starting in the mid-1990s. This decline underscores the intense exploitation of lobster stocks by both local and foreign fishing fleets during the 1980s, resulting in suggested biomass reductions of over 90% from the unexploited state (Ahmad et al. 2003, Stobutzki et al. 2006b). This decrease in lobster landings has been attributed to various anthropogenic factors, including legal overexploitation, illegal fishing activities, habitat destruction, pollution, urban development, and the impacts of climate change (Stobutzki et al. 2006a, Siow et al. 2020, Siang et al. 2022).

Using Bayesian Change Point analysis, we found significant increases in lobster (*Panulirus spp.* and *Thenus orientalis*) landings along the east coast of Peninsular Malaysia (Fig. 5). In Johor, landings doubled from ~90.2 tonnes in

1984 to 182.7 tonnes in the following year (posterior probability = 0.810). Moving northward, we detected a sudden increase in landings from Pahang in 1990 (posterior probability = 0.917), peaking in 1993, before gradually decreasing in recent years. In contrast, Terengganu initially experienced a steady increase in landings, followed by a steep decline from 313 tonnes in 1994 to 169 tonnes in 1995, based on the posterior probability of 0.772. We did not detect any abrupt changes in landings from the northernmost state of Kelantan, where lobster landings remained consistently low throughout the time series.

The varying timing of change points among states is consistent with a potential spatial expansion and subsequent depletion of lobster fishing grounds along the east coast of Peninsular Malaysia, starting in the southernmost state of Johor before moving northward through Pahang and Terengganu. Observed landing patterns mirror recent findings by Cardinale et al. (2023), who documented a sequential spatial depletion of northern shrimp populations in the North Sea, from west to east. Crustacean fisheries are particularly susceptible to spatial depletion, as fishers usually target coastal inshore areas before expanding to deeper offshore waters, driven by advancements in fishing technologies and shifting market demands (Armstrong et al. 1998). While historical and current management practices for lobster fisheries remain poorly documented, it is reasonable to assume that the observed landings are largely from local waters. The lobster fishery primarily targets waters off Johor and southern

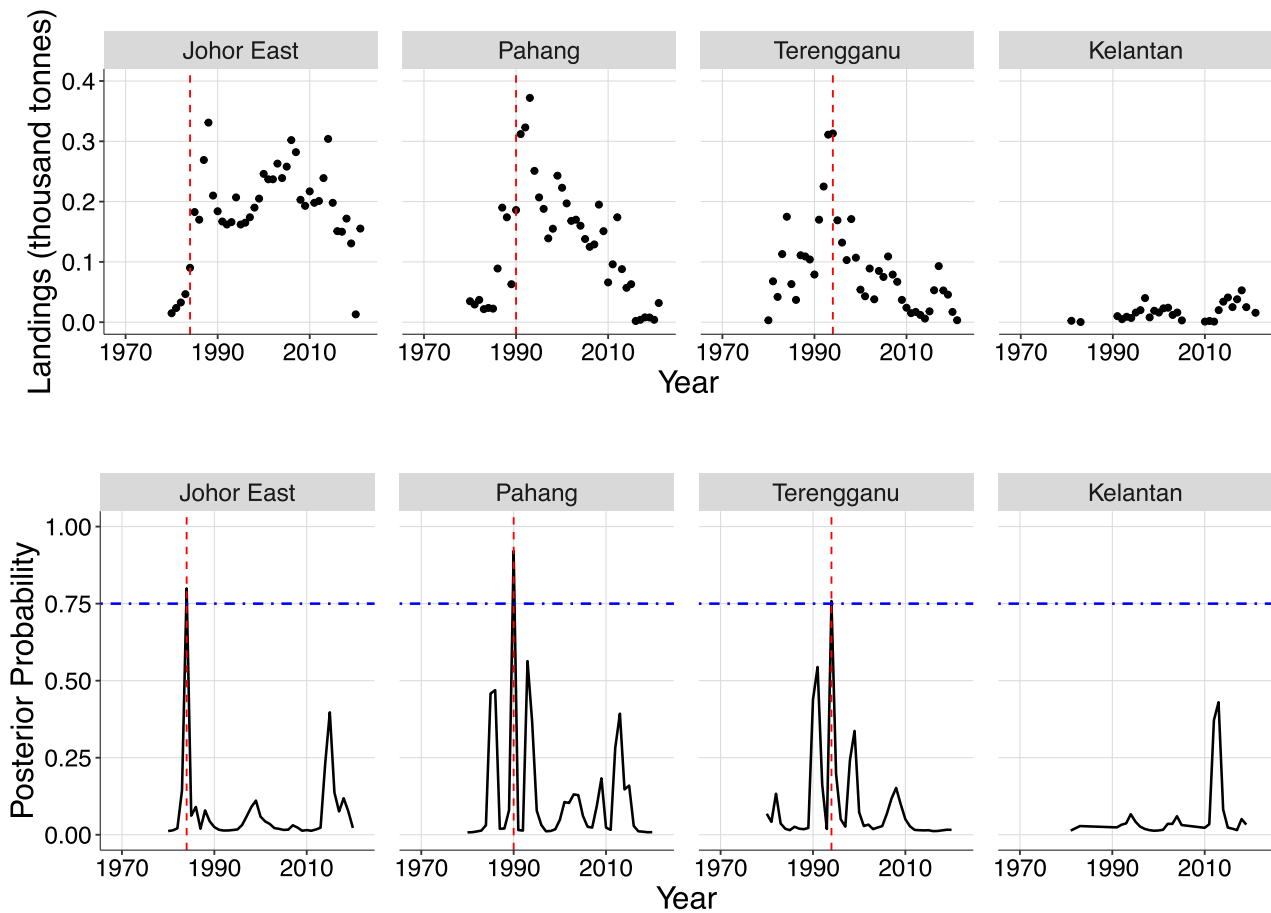


Figure 5. Landings (top row; thousand tonnes) and posterior probability of change points (bottom row) of lobsters among states along the east coast of Peninsular Malaysia, from South to North (left to right). Vertical red dashed lines denote abrupt changes in landing time series based on the Bayesian change point analysis threshold of 0.75, indicated by the horizontal dot-dashed line in the bottom panels.

Pahang, where artisanal fishers use traditional fishing equipment, such as box-like traps and seine nets in nearshore areas, while commercial trawlers occasionally catch adult lobsters as bycatch in bottom trawl nets at deeper depths (Siow et al. 2020). Given that lobsters are preferentially kept alive when sold to intermediaries who then transfer them to dealers, it is likely that they are caught close to their landing sites. This further supports the assumption that they are sourced locally rather than from distant fishing grounds (Siow et al. 2020).

Case Study 3: Varying importance of powered fishing boats on Indian mackerel landings along the west coast of Peninsular Malaysia.

Small pelagic fishes are a major contributor to commercial marine fish production from the west coast of Peninsular Malaysia (Ean 1999). Among these, the Indian mackerels (*Rastrelliger* spp.), also locally known as Ikan Kembong, contribute up to 79% of total pelagic fish landings from Perlis, Kedah, and Perak (Sin and Yew 2016). Traditional and commercial fishermen target Indian mackerels using powered and non-powered fishing boats, making them an ideal case example to examine the underlying drivers of landing patterns (Ean 1999, Lee 2000, Ahmad 2000). We hypothesized that observed increases in Indian mackerel landings were associated with increasing fishing effort resulting from an increase in number of diesel-powered fishing vessels in each state.

Our results revealed variations in Indian mackerel landings and the number of powered fishing boats across two states (Fig. 6). In Perlis, there was a gradual increase in Indian mackerel landings and the number of powered boats, which both reached a plateau in the mid-1980s and were steady thereafter. In Kedah, both landings and the number of powered fishing boats reached a maximum in the early 1980s, followed by a decline in landings to lower levels while the number of powered boats remained high over the past decade. The Granger-causality tests revealed significant causal association between the number of powered fishing boats, which were adjusted for technological creep, and Indian mackerel landings in Perlis and Kedah along the west coast of Peninsular Malaysia (Fig. 6). We did not detect any associations between Indian mackerel landings and other metrics of fishing effort (the number of licensed fishermen and non-powered fishing vessels) across states. In Perlis, the best explanatory model revealed a temporal lag of two years (i.e. landings resulting in a subsequent increase in powered boats) ($F = 8.39$, $df = 18$, $P = 0.003$) across a 26-year time period from 1968 to 1997, excluding years with missing landing data. Similarly, in Kedah, the landings of Indian mackerel were positively associated with the number of powered boats one year later ($F = 6.98$, $df = 25$, $P = 0.014$) over a 29-year period from 1968 to 1997 (Fig. 6). We found no significant evidence for reverse causality (i.e. increase in powered boats resulting in a subsequent increase in

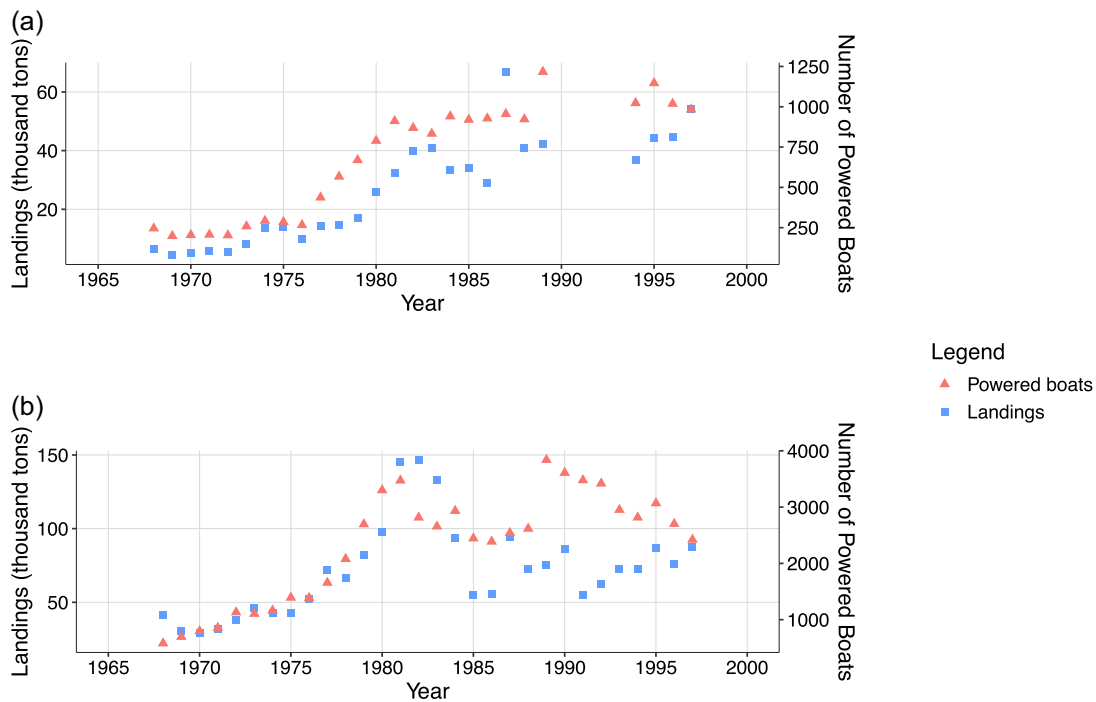


Figure 6. Changes in Indian mackerel landings (y-axis; square symbols; thousand tonnes) and number of powered fishing boats (secondary y-axis; triangle symbols; adjusted for technological creep) from (a) Perlis and (b) Kedah over time.

landings) in Perlis ($F = 0.22$, $df = 18$, $P = 0.802$) and Kedah ($F = 1.43$, $df = 25$, $P = 0.243$).

While diesel-powered engines were introduced to the Malayan Peninsula in the 1920s, most locals were hesitant to use them due to their high operational costs (Green 1927). This reluctance persisted for approximately three decades until the mid-1950s, when engines became more readily accessible after WWII. Consequently, there was a steady transition from sail-powered to diesel-powered boats (Ean 1999). For example, the number of powered fishing boats in Selangor saw a hundredfold increase, from 7 boats in 1953 to 753 powered boats in 1954, with a posterior probability of 0.984. This led to an increase in Indian mackerel landings, with a reported 91 003 tonnes caught from the west coast of Peninsular Malaysia in 1968. Mechanization not only freed the marine capture fishing industry from the vagaries of the weather and facilitated the faster transport of products to markets in better quality, but resulted in the expansion of fishing operations (Morgan and Staples 2006). The widespread use of diesel engines, coupled with the successful introduction of industrial trawling, resulted in a steady increase in pelagic fish landings from Perlis and Kedah.

Nominal catch per unit effort (CPUE) for the Indian mackerel revealed a positive trend in Perlis and a negative pattern in Kedah, from the late 1960s to the late 1990s (Supplementary Material S6). The increase in CPUE in Perlis indicated relatively high mackerel abundance, even as effort increased (Fig. 6). In contrast, the decline in Kedah corresponded with reduced landings, where low abundance persisted despite high fishing effort (Fig. 6). Diminishing fish landings per unit effort reported in the purse seine fishery along the west coast of Peninsular Malaysia, coupled with increasing amounts of non-target ‘trash fish’ landings, reflect the depleted state of local pelagic fish populations, including Indian mackerel (Ean

1999). These trends also corresponded with the introduction of the Fisheries Licensing policy in 1981, which aimed to reduce fishing effort in coastal waters by limiting the number of fishing boats, and minimizing conflicts between small-scale traditional fishermen and large-scale commercial fishermen (Yahaya 1988, Omar et al. 1992, Omar et al. 2000). Similar patterns have been observed in grouper (Serranidae) populations across Malaysia (Mat Piah et al. 2018), where annual estimates of CPUE, a proxy for fish abundance, declined, along with reported increases in landings. The recent increase in grouper landings may be associated with financial subsidies provided by the Malaysian government in 2012 to alleviate rising expenses in the fishing industry (Jamal et al. 2017, Wong and Yong 2020).

Although we observed a significant relationship between the number of powered fishing vessels and Indian mackerel landings in Perlis and Kedah, no detectable relationship was identified in Perak ($P > 0.05$). In Perak, despite the highest levels of fishing effort among the three states, indicated by the total number of licensed fishermen (mean \pm SD: 12138.92 ± 3504.95 ; average across 49 years, from 1968 to 2016; Supplementary Material S3) and powered boats (mean \pm SD: 4637.88 ± 777.00 ; average across 49 years, from 1968 to 2016; Supplementary Material S4), nominal CPUE remained stable (Supplementary Material S6). However, such stability may mask signs of local stock depletion, particularly as pelagic fish populations shift along the coast or fishing effort moves between states, likely reflecting spatial expansion and depletion (Myers and Worm 2005). For instance, previous research by Cardinale et al. (2011) documented sequential exploitation of pelagic fish stocks in the Java Sea, where fishers progressively depleted and abandoned their traditional fishing grounds as they became less profitable. Likewise, observed landing trends in this potentially open-access, unregu-

lated fishery suggest that serial depletion may have occurred. Unfortunately, limited information exists on the management of the pelagic fishing industry along the west coast of Peninsular Malaysia from the late 1960s to 1990s, highlighting the need for further research to better understand long-term trends.

Limitations of the study

While our findings offer valuable insights into the socioeconomic drivers of species landing patterns over the past century, colonial statistics likely underestimate the true landings due to the complexities of the fisheries supply chain in Southeast Asia. Historically, along the east coast of Peninsular Malaysia, landings were marketed at the beach, with a fraction transported inland for sale in local markets (Firth 2006). However, if the landings were insufficient or arrived late in the day, landings were shared among the crew and consumed locally, leading to an underestimation of daily landings (Firth 2006). This contrasts with the west coast of Peninsular Malaysia, where most fishermen operated under a debt system to financiers, known as towkays. These financiers advanced money and purchased fishing equipment in exchange for the fishermen committing to sell all their landings to them, thus ensuring a steady supply of fish for sale at local and municipal markets (Stead 1923, Burdon 1955). At these markets, financiers may understate the weight of their products to evade potential tax penalties imposed by fishery officers (Stead 1923, Burdon 1955). This practice may have resulted in a systematic underreporting of landings, further complicating the accuracy of historical data.

Additionally, fishery products marketed in inland or municipal markets during the pre-war period may not have originated from local waters. Le Mare (1949); Burdon (1955) and Maxwell (1921b) estimated that ~75% of colonial landings sold in the municipal markets of Singapore originated from waters around Indonesia. For example, it was reported that traditional fishermen based in Singapore frequently crossed the Malacca Straits to Bagan Si Api Api during the colonial period (Fig. 1) to fish and process their landings before returning to sell their products locally (Burdon 1950, Butcher 1996b). More recently, prior to the establishment of national waters and EEZs under the UNCLOS, fishermen were permitted to fish in the waters of neighbouring countries (Tickler et al. 2018). While transboundary fishing may have resulted in increased overall landings, it obscured the true origin of fish landings and may have masked signs of local stock depletion (Damasio et al. 2020). Spatial expansion of fisheries and the resulting uncertainty regarding the geographical origin of fish landings may, therefore, complicate the interpretation of CPUE trends, potentially resulting in hyperstability or hyperdepletion of the CPUE vs. abundance relationship (Walters 2003).

Moreover, in both historical and contemporary reports, species landings are often underestimated due to the omission of illegal, unreported, and unregulated (IUU) fishing, lack of recreational fishing statistics, and the amount of bycatch discarded during each fishing trip. While not the focus of our study, previous studies suggest that harvest estimates across Southeast Asia may be underestimated by 29%–48% across countries, fishing sectors, and time periods (see Teh et al. 2011, Pauly and Zeller 2016, Teh and Pauly 2018 for more details). This omission introduces a degree of imprecision in our esti-

mates, potentially complicating our interpretation of species landing trends and masking the true signals of change.

One assumption in the Granger-causality statistical framework was the consistent measurement of data over time intervals without errors in each time series. While we minimized irregular sampling using a truncated species landing dataset specific to the west coast of Peninsular Malaysia, reported landings undoubtedly underestimate the true landings, which include IUU fishing, as well as recreational landings (Pauly and Zeller 2016). Additionally, our bivariate comparisons assumed linear associations between landings and each fishery effort metric. In reality, interactions among time series trends are highly dynamic and non-linear (Zou et al. 2019), which may not be adequately captured in static linear models (Shojaie and Fox 2022).

The lack of reliable fishery data underscores the need for alternative data sources, such as archaeological evidence or indigenous ecological knowledge, to deepen our understanding of the historical state of marine capture fisheries in Southeast Asia (McClenachan et al. 2012, Jessen et al. 2022, Alleyway et al. 2023). For example, Eckert et al. (2018) conducted semi-structured interviews with traditional fishers from First Nations communities in British Columbia to document reductions in the size and abundance of yelloweye rockfish. Similarly, McClenachan (2009) examined historical photographs to reveal significant declines in goliath grouper populations in the Florida Keys. By integrating similar non-traditional data sources, we can gain a more comprehensive understanding of long-term changes in the marine fishing industry from Southeast Asia, which would help policymakers set conservation targets and develop effective management strategies in the face of ongoing climate change (Thurstan et al. 2015).

Conclusions

In this study, we compiled landings data and fishing effort metrics from Malaysia and Singapore over the past 114 years, from 1907 to 2021. Our results indicate a steady increase in landings over the past 90 years, reaching a peak in 2016 before subsequently declining over the last five years. Focusing on the three case examples, our results revealed that colonial landings of fusiliers reported from Singapore were disproportionately high, highlighting the importance of understanding the spatial extent of fishing operations conducted by Japanese fishermen across Southeast Asia. Bayesian Change Point analyses also identified significant increases in lobster landings along the east coast of Peninsular Malaysia in the mid-1980s, with spatial expansion in commercial fishing operations observed from Johor northward through Pahang and Terengganu. Granger-causality tests further revealed a significant association between Indian mackerel landings and the number of powered fishing boats among Perlis and Kedah along the west coast of Peninsular Malaysia, with variations observed across states and over time. These results enhance our understanding of marine capture fisheries in Malaysia and Singapore over the past century and showcase the use of novel statistical tools in advancing our knowledge of fisheries dynamics across an important yet understudied region of the world.

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Author contributions

C.N. contributed with the conceptualization of the manuscript, compilation of the data, statistical analysis, and writing of the manuscript. O.J. and J.O. contributed to the work and provided feedback on the introduction, results, and discussion. All authors reviewed the manuscript.

Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

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Data availability

Fisheries data from Singapore was downloaded from the Fishery Statistical Bulletin by the Southeast Asian Fisheries Development Center (SEAFDEC), accessible at <http://map.seafdec.org/fisherybulletin/>. Fisheries statistics from Malaysia are available at <https://www.dof.gov.my/en/resources/fisheries-statistics-i/>. All data are available in a repository: <https://github.com/clementngzw/Historical-Ecology>.

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