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Quantifying non-target seahorse fisheries and domestic traditional medicine-based trade in Malaysia

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ABSTRACT

Seahorses (*Hippocampus* spp.) are sold primarily for traditional medicine (TM) uses in Southeast Asia. Although Malaysia is reportedly an important global seahorse exporter, documentation on the current extent of seahorse catch and trade of seahorse-based TM within the country is limited. This study aimed to quantify patterns of seahorse bycatch, gear-specific biological parameters of caught seahorses, and trade characteristics in Malaysia. Questionnaire-based fisher and TM surveys were administered nationwide from March 2021 to March 2023. Seventy-one percent of fisher respondents (612 out of 860) reported catching seahorses, with gill or drift net fishers (73 %) more likely to have caught seahorses than trawlers (12 %). Significant spatial differences in species composition was observed between Peninsular Malaysia and Malaysian Borneo (Sabah state). The total estimated annual seahorse catch within Malaysia was approximately 3376 kg per year, with 77 % of the catch attributed to gill or drift nets and 23 % to trawling operations. Almost half (40 %) of traditional Chinese medicine (TCM) practitioners/ traders (*n* = 138), 3 % of Malay TM practitioners (*n* = 3), and 88 % of other TM traders (*n* = 7) reported selling seahorse species. This study is one of the first to quantify the often overlooked but critical contribution of small-scale fisheries, especially gill and drift nets, towards seahorse bycatch. The current supply volume and selling price of seahorses were observed to be relatively high, while the present-day demand was reportedly low. Almost half of TCM practitioners/ traders interviewed were still actively selling seahorses, indicating that there is still considerable demand. To ensure the sustainability of seahorse populations in Malaysia, efforts in both small-scale and trawl fisheries must be reduced while strictly enforcing seahorse trade regulations.

1. Introduction

Fisheries bycatch, or the incidental capture of non-target organisms, poses a significant threat to many marine species, and its management remains a critical priority for ensuring sustainable fisheries. The growing recognition of bycatch as a threat highlights its detrimental impact on wild populations and their habitats (Dias et al., 2020; Omar et al., 2020; Gilman et al., 2023). It is important for the impacts of fisheries on non-target species to be considered when addressing biodiversity and conservation concerns in the practice of ecosystem-based fisheries management (Dimarchopoulou et al., 2023). However, most bycatch studies disproportionately focus on charismatic vertebrates, such as marine mammals, turtles, and seabirds (Lin et al., 2023; Putman et al., 2023; Ramírez et al., 2024), while other species receive comparatively less attention.

Seahorses (*Hippocampus* spp.) represent a marine group that, while rare, constitute a significant component of bycatch. These small, bony fishes belong to the family Syngnathidae (Fricke et al., 2024) and inhabit

tropical and temperate shallow waters, including seaweed beds, seagrass meadows, coral reefs, estuaries, and mangroves (Choo and Liew, 2003; Salin et al., 2005). They are closely associated with bottom habitats, slow swimmers, have low density, low fecundity, display traits of mate and site fidelity, and obligate parental care (Vincent and Sadler, 1995; Perante et al., 2002; Foster and Vincent, 2004). These biological and ecological characteristics render them particularly vulnerable to being captured as bycatch (Vincent, 1996; Otero-Ferrer et al., 2017). Heavy fisheries exploitation have shown to have resulted in declines of seahorse populations in Latin America (Marín et al., 2021), and in Vietnam (Stocks, 2015). Seahorse bycatch globally is primarily attributed to the use of trawl nets, particularly large-scale operations. However, seahorses are also caught using other types of fishing gear, albeit at varying levels (Perry et al., 2010; Lawson et al., 2017; Stocks et al., 2017).

An estimated 10 million wild-caught seahorses have been sold annually across among 80 countries for use in traditional medicine (TM), curiosities, and the aquarium trade since the start of the trade in the 1980s (Lawson et al., 2017). Trade Records Analysis of Flora and Fauna in Commerce (TRAFFIC) reported that Malaysia was one of the top five countries globally, which contributed 2 % (equivalent to 225, 182 individuals) of the total global exports of dried seahorses (Louw and Bürgener, 2020). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Trade Database indicated that Malaysia was among the key countries of origin, contributing 2 % (approximately 830 kg) of the 95 % of dried seahorses imported by Hong Kong over a decade, from 2008 to 2018 (Louw and Bürgener, 2020). Despite Malaysia featuring prominently in the global seahorse trade, not much is known on the current status and extent of local seahorse trade.

Out of the 46 seahorse species found globally (Lourie et al., 2017), 12 Indo-Pacific species have been recorded in Malaysian waters. These species include *H. barbouri*, *H. comes*, *H. histrix*, *H. spinosissimus*, *H. kelloggi*, *H. kuda*, *H. trimaculatus*, *H. mohnikei*, *H. denise*, *H. bargibanti*, *H. satomiae*, and *H. pontohi* (Lim et al., 2011; Aylesworth et al., 2016; Short et al., 2020). Based on previous studies, eight non-pygmy species out of the 12 seahorse species are commonly sold within the country (Lim et al., 2011; Aylesworth et al., 2016). Seahorses are not legally protected under the federal Fisheries Act 1985 [Act 317] (Lim et al., 2011; IUCN, 2021), although most of the known occurring species in Malaysia are listed as Vulnerable under the IUCN Red List of Threatened Species, (IUCN, 2021). In line with global trends, the majority of seahorses sold in Malaysia were reportedly used in traditional Chinese medicine (TCM) (Perry et al., 2010). In addition to the Chinese community, Malay communities in Malaysia also consume seahorses for various health benefits (Choo and Liew, 2005; Halim et al., 2017; Salleh et al., 2020). The use of TM has historically been, and reportedly remains, widespread for the treatment of diseases among Malaysian communities (Halim et al., 2017). Assessing the prevalence of seahorse trade in relation to ethnic-based traditional medicine practices is crucial, given the significant ethnic-driven demand for seahorses (Ng et al., in press).

Seahorse catch profile and volume has been shown to differ as a function of gear types and spatial locations (Lawson et al., 2017). The estimated total annual number of seahorse bycatch in trawls in Malaysian waters from 1998 to 2001 was 1165,979 individuals (Lawson et al., 2017). A local survey conducted in 2001 estimated that the total number of seahorses caught as bycatch by trawlers operating in waters 5–8 nautical miles off the coastline of Peninsular Malaysia was approximately 565,640 individuals (Choo and Liew, 2005). A follow-up study, conducted through interviews, found that the largest estimated annual seahorse catch per trawl vessel was between 0 and 50 seahorses per 8–10-day trip on the east coast of Peninsular Malaysia, followed by the west coast and Sabah (Perry et al., 2010). However, these past studies are relatively outdated, and the current volumes of seahorse bycatch from trawlers, in relation to other fishing methods, remain unknown.

The use of fishers' knowledge obtained through interviews is becoming more prominent in fisheries research particularly when conventional quantitative fisheries methods could not be applied (Silas et al., 2023). Interview-based approach has been used successfully to characterise the nature of high bycatch rates of marine mammals and sea turtles in small-scale fisheries (Lin et al., 2023). Interviews also captured unreported catches that were not included in many data-recording systems, including official statistics (Silas et al., 2023). Additionally, interviews are considered a feasible and time-saving approach to rapidly assess the use of marine fisheries resources (Garmendia et al., 2021). Information gathered from fishers is valuable, as they are often the first group to handle seahorses, placing them at the initial stage of the trade (Vincent et al., 1996; Silas et al., 2023). In addition to fishers, traders are an important group to interview, as they provide first-hand insights on both seahorse fisheries and trade (Winter et al., 2011; Lam et al., 2014). However, the last comprehensive interview conducted was over two decades ago (Perry et al., 2010) and lacked documentation on the contribution of small-scale fisheries to seahorse bycatch and ethnic-based TM trade.

In response to the aforementioned knowledge gaps, the aim of this study was to quantify recent patterns of seahorse bycatch, examine gear-specific biological parameters (species and size) of caught seahorses, and assess the prevalence and characteristics of seahorse trade in relation to ethnic-based traditional medicine practices in Malaysia. A questionnaire-based survey of local fishers was used to determine the prevalence of seahorse bycatch, catch profile (species and size) of seahorses caught in trawls and other small-scale fishing gears, sales volume and price of both live and dried seahorses. The questionnaire was modified to survey TM practitioners/ traders for information on supply and sales volume, selling price, species, size, and source of dried seahorses, which were used to examine current trade levels. We hypothesized that (1) current seahorse catch profiles vary between regions, (2) seahorse bycatch volume in other gears is similar to that from trawls, and (3) seahorse catch and trade volume is perceived to have declined over time.

2. Methods

2.1. Study area and fisheries profile

Malaysia, consisting of Peninsular Malaysia and Malaysian Borneo, is located at the center of the Indo-Pacific seahorse trade. The country is surrounded by extensive territorial waters, which serve as crucial habitats for seahorses (Vincent, 1996; Choo and Liew, 2005). Fisheries operations are zoned by distance from shore (Zones A, B, and C) to reduce encroachment from large-scale trawlers into nearshore waters. Small-scale fishers, defined by vessel size limit <40 GRT and by gear types (gill or drift nets, hooks and lines, portable traps, and traditional anchovy purse seines), primarily operate in Zone A (within 5 nm from shore for most states, and within 8 nm for the states of Perlis, Kedah, Penang, Perak, and Selangor) (DOFM, 2020). On the other hand, large-scale fishers, including smaller and large-scale trawl operators, can only operate in Zones B and beyond. Lawson et al. (2017) found that catch per unit effort of seahorse bycatch was greater for gill/ entangling nets in Malaysia than trawl nets (1998–2001).

The geographical scope of the study encompasses nine key fishing states along both coasts of Peninsular Malaysia, as well as the state of Sabah in Malaysian Borneo. Peninsular Malaysia's fleet of over 15,000 trawlers and Sabah's fleet of almost 6000 trawlers target shrimps and demersal fishes in the Strait of Malacca, South China Sea, Sulu Sea, and Celebes Sea (DOFM, 2020, 2021). Seahorse species occurrence and relative distribution differ between various regions - out of the 12 species known to occur in Malaysia, the common and abundant species in west Peninsular Malaysia are *H. trimaculatus*, *H. spinosissimus*, *H. kuda*, *H. mohnikei*, *H. comes*, *H. kelloggi*, and *H. histrix*, while those in east Peninsular Malaysia are *H. trimaculatus*, *H. spinosissimus*, and *H. comes*. Common species in Sabah are *H. trimaculatus*, *H. spinosissimus*, *H. kelloggi*, *H. kuda*, *H. barbouri*, *H. comes*, and *H. histrix*, while

H. bargibanti, H. denise, H. pontohi, and *H. satomiae* are known to occur in the region (Chen et al., 2021).

2.2. Questionnaire-based data collection

Questionnaire-based interviews were conducted with two focal groups, specifically fishers and TM practitioners/ traders, across Malaysia. The fisher and TM interview surveys in Peninsular Malaysia were conducted from March 2021 to April 2022 while the surveys in Sabah were conducted from January to March 2023. These surveys were administered either through the phone (during the period of COVID-19 pandemic lockdown) or face to face during post-lockdown field visits. Fisher contacts were obtained from initial respondents, local fisher associations, and fishmongers, using haphazard and snowball sampling. Contacts of TM practitioners/ traders were identified through search engines and social media platforms (Google, Google Maps, and Facebook) using the search terms of 'traditional medicine shop' and localities in both English and local languages. For this study, TCM practitioners/ traders refer to practitioners/ traders who were practicing or selling TCM, who are typically of Chinese ethnicity themselves. Similarly, Malay TM practitioners are generally those of Malay ethnicity practicing or selling Malay traditional medicine, while Indian TM practitioners are usually Indians practicing or selling Indian traditional medicine. Other TM traders refer to those of other ethnicities practicing or selling their own forms of TM.

The fisher and TM questionnaires consisted of nine sections with 52 questions (Material S1) and seven sections with 52 questions (Material S2), respectively. Six questionnaire sections common to both surveys included seahorse trade, usage of seahorses, valuableness of seahorses, biological and threat awareness, personal information, and additional biodiversity data. Demographic characteristics such as gender, age, ethnicity, location they live in (state), location they grew up in (state), and education level of respondents were collected. The questionnaires were adapted from literature review related to seahorse fisheries and trade (Rosa et al., 2005, 2011; Halim et al., 2017; Mat et al., 2017; Salleh et al., 2020) and with the guidance of field experts, i.e., second and third authors. Questions were phrased to minimise use of technical jargons. Each set of questionnaires took approximately 10–15 minutes to complete.

2.2.1. Seahorse fisheries and trade

In the fisher survey, catch estimates, fishing gears used, frequency and duration of fishing operations, and fate of caught seahorses were recorded. Fishers' perceptions of how seahorse populations have changed since they began fishing were also documented.

In both fisher and TM surveys, the retail sales volume, selling price, and difference in price or usage between types of sold seahorses by fishers and TM practitioners/ traders were recorded. All three questions were included for understanding both historical and current trade. For the fisher survey, the retail sales volume was first recorded in units commonly used by respondents such as individuals per year or per month for live seahorses and individuals per week or per month for dried seahorses. The selling prices were recorded by individuals for live seahorses and by weight or individuals for dried seahorses. For the TM survey, the retail sales volume was first recorded in units commonly used by respondents such as number of individuals per week or kg per month. The retail sales volume estimates for defined lengths of time (e.g., daily, weekly) were determined by estimating the quantities of seahorse imports and exports based on respondents' reported trade volumes. The selling price of seahorses was reported by weight.

For the traditional medicine (TM) survey, data on the supply volume of seahorses were collected. Additionally, information was gathered on whether the seahorses sold were sourced locally or imported, along with the specific countries or regions of origin. The questions on supply volume and source of sold seahorses were also included for both historical and current trade. Besides that, the perception of TM practitioners/ traders on the nature of seahorse trade regulations in Malaysia was gathered.

2.2.2. Biological assessment

During field interviews with fishers and TM practitioners, permission was obtained to examine and photograph seahorses that were captured at landing sites or sold in TM shops. These seahorses were identified to species level by examining morphological characteristics using Lourie et al. (2004) as reference (Fig. S1). In the event of no direct seahorse encounters, fishers and TM practitioners/ traders were asked to identify historically captured or sold species using a photographic guide (Fig. S1). Where necessary, clarification questions on presence or absence of key morphological characteristics were asked. In the case of phone interviews, seahorses were identified based on photos that were shared willingly by respondents via follow up using a phone messaging app.

2.3. Research ethics

The surveys were restricted to coastal fishers and TM practitioners/ traders of Malaysian nationality 18 years old and above, and residents of Malaysia. Before conducting the surveys, the questionnaire was tested and refined with test groups by conducting mock interviews to ensure its comprehensibility regardless of the respondents' background. The University of Malaya Research Ethics Committee (UMREC) approved the questionnaire and issued an ethical permit (UM.TNC2/UMREC - 1225). The Sabah Biodiversity Centre (SaBC) also issued an Access License (JKM/MBS.1000–2/2 JLD. 16 (89)). In accordance with the approved ethics protocol, the project objectives were disclosed by the interviewer, informed consent from each respondent was plainly requested, participation was voluntary and anonymous, and assurance were given that the interviewee could terminate the survey at any time. Contact details of the research investigators for enquiries, transparency regarding the organizations involved in the research, namely Universiti Malaya and a local NGO, Save Our Seahorses (SOS) Malaysia, and information on how survey responses would be used were also included.

2.4. Sample size calculation

Estimation of sample size of respondents would ideally be based on area-specific proportions of fishers who catch seahorses, which are unknown. Using the Australian Bureau of Statistics sample size calculator and relevant fishery statistics (see Table S1 for details), the expected minimum sample sizes of 173 fishers in the west coast of Peninsular Malaysia, 106 fishers in the east coast of Peninsular Malaysia, and 104 fishers in Sabah were obtained. Based on an online search on the number of TM shops and TM practitioners/ lecturers from local universities that offer TM courses (see Table S2 for details), the expected minimum sample sizes of 210 TM practitioners/ traders in Peninsular Malaysia and 16 TM practitioners/ traders in Sabah were obtained.

2.5. Data analysis

Responses for the fisher survey were compiled and analyzed according to three main regions: the east and west coasts of Peninsular Malaysia, and Sabah, to account for the differences in distribution of gear types across these regions. Responses from the TM survey were analyzed based on two main regions, i.e. Peninsular Malaysia and Sabah, due to similarity in responses between east and west coasts of Peninsular Malaysia. To characterise local seahorse fisheries profiles, seahorse capture history and species of captured seahorses were summarized by fishing gear types, including hand collection. The size and fate of caught seahorses were summarized using percentages. Estimated catch by individual fishers were averaged to calculate the mean catch per unit effort (number of seahorses per gear per year) and were multiplied by the reported number of gears operating in each region (DOFM, 2021),

and by the percentage of fishers that catch seahorses by gear type, to obtain a rough estimate of total annual seahorse landings in Malaysia. These were calculated for only gill or drift nets and trawls, and only for the ten states in which interviews were conducted. Seahorse numbers were converted to kilograms based on previously estimated mean weight of seahorses caught by Malaysian gears, i.e., 3.18 g per seahorse, considering the low annual catch (Perry et al., 2010).

To characterise the current extent of the seahorse trade, estimates of supply volume, retail sales volume and selling price of dried and live seahorses (per individual or kilogram) sold by fishers and TM practitioners/ traders were analysed. Estimated retail sales volume of dried and live seahorses by fishers recorded for defined lengths of time were averaged and multiplied by the reported number of gears operating in each region (DOFM, 2021), and by the percentage of fishers that do sell seahorses, to obtain an estimate of total seahorse sales. Estimated supply and retail sales volume of dried seahorses recorded for defined lengths of time were averaged, standardised to annual quantities, and multiplied by the total estimated number of surveyed TM shops that reported selling seahorses. The resulting volume quantities were converted to kilograms, using the mean seahorse size of 3.18 g per seahorse. The selling price of dried and live seahorses were reported per individual or per kilogram on average in Malaysian Ringgit (MYR) and converted into United States dollars (USD) using the exchange rate of 1 MYR = 0.22 USD. The current annual supply volume, annual retail sales volume, and selling price of dried seahorse were calculated. Due to the lack of sufficient reliable historical trade estimates, comparison between historical and current (supply volume, retail sales volume, and selling price) was not carried out. The percentage of the TM practitioners/ traders who (1) were currently selling seahorses, (2) previously sold but no longer do, and (3) never sold, as well as the percentage of species and size of dried seahorses sold for TM were calculated. The percentages of shops with locally and/ or internationally sourced dried seahorse supplies were calculated, and the source locations were summarized. Data from the present study as well as data on seahorse usage (Ng et al., in press) were summarized graphically to provide an overview of the trade.

The midpoint (+/– one standard deviation) for any range of values provided by respondents was used in calculations. Ranks of seahorse catch composition between regions and between small-large scale fisheries were analysed using the Wilcoxon Rank Sum Test. Seahorse trade status was analysed using the Chi-square Test of Independence and Fisher's exact test. All statistical analyses were undertaken using the R computing language version 4.3.0 (R Core Team, 2023). For all comparisons, p-values less than 0.05 were considered significant.

3. Results

3.1. Seahorse fisheries profile

Out of 860 fishers interviewed across Malaysia (Fig. 1), 71 % have previously caught seahorses. Among those, only 3 % (n = 17) specifically targeted seahorse capture. A fisher in Negeri Sembilan, Peninsular Malaysia reported intentionally collecting seahorses via diving in shallow (< 3 m) coastal habitats, where he was able to catch 20–30 seahorses at a time in a year. In Peninsular Malaysia, majority of the
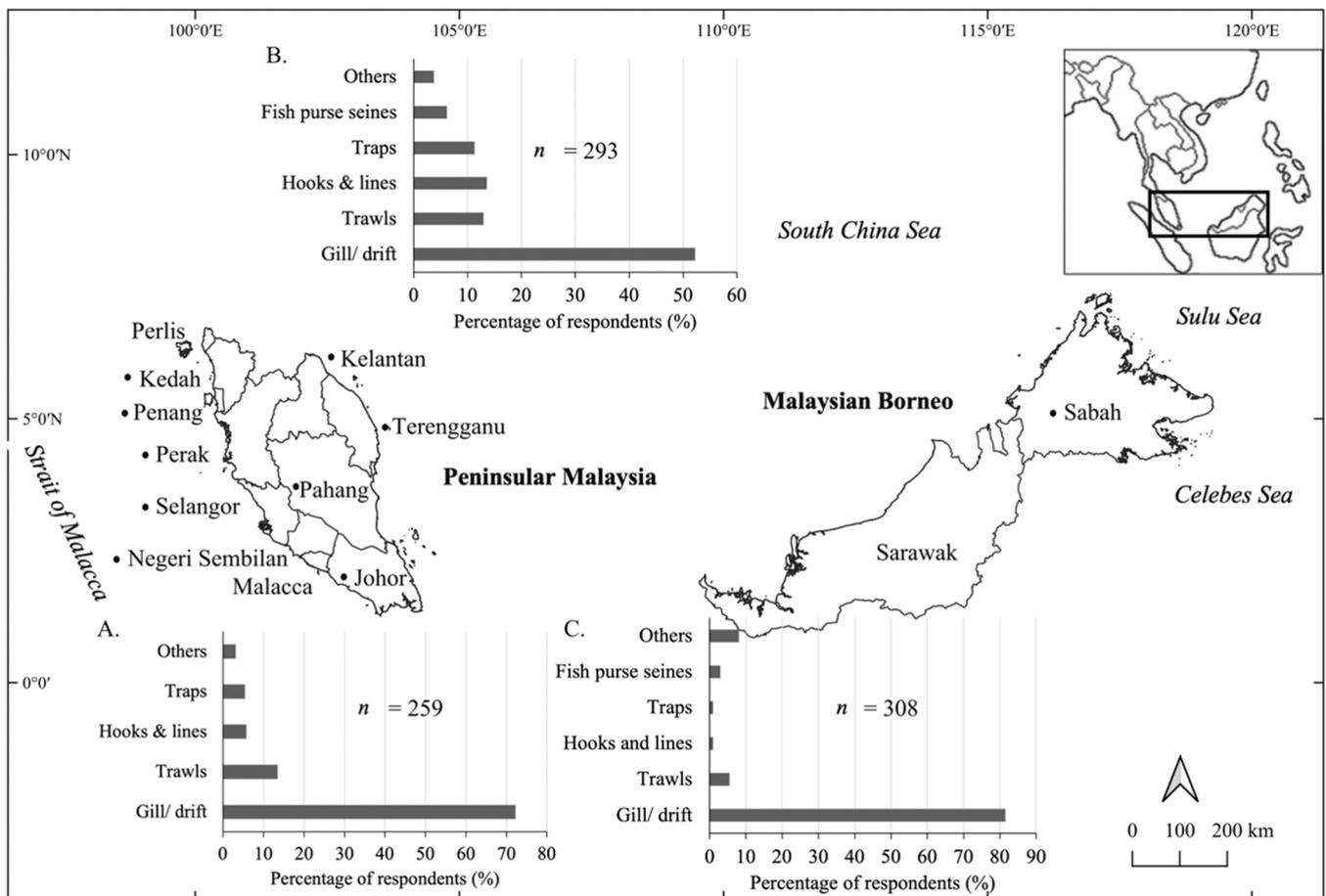

Fig. 1. Map of study sites (●) across Malaysia by state. Inset map shows the study area within Southeast Asia. Bar charts indicate the composition of fishing gears used by 860 fisher respondents from (A) the west coast, (B) east coast of Peninsular Malaysia, and (C) Sabah. Fishing gears categorized as 'others' in the west coast included cast nets (*jala*), portable gears, lift nets, hand collection (sea), and other seines, that of in the east coast included hand collection (intertidal areas), dredges/ scoops, and other seines, while that of in Sabah included lift nets (*bagang*) and hand collection.

respondents using gill or drift nets (85 %), trawls (86 %), fish purse seines (61 %), crab traps (57 %), portable traps (64 %), or other methods (40 %) had caught seahorses (Fig. 2A). Similarly, in Sabah, most respondents using gill or drift nets (63 %), trawls (65 %), fish purse seines (67 %), and crab traps (67 %), as well as hand collection (89 %) had caught seahorses (Fig. 2B). For gill and drift net fisheries that had previously caught seahorses, fishing operations typically occurred 10–30 days per month at depths of up to 60 m, using mesh sizes ranging from 1 to 8 in. Trawling operations that had caught seahorses typically occurred at depths of up to 40 m during the night, with vessels returning to port every few days. For example, trawl vessels of size class C would go out for 7–10 days at a time. The mesh size of trawls is typically no more than 5 m mesh at the mouth (for zone B trawl boats) and no more than 38 mm mesh in the cod end.

In terms of species catch profile, eight species were caught in Peninsular Malaysia while nine species were caught in Sabah. The three most common species caught in Peninsular Malaysia were *H. trimaculatus* ($n = 38$ fishers), *H. spinosissimus* ($n = 30$), and *H. kuda* ($n = 19$) whereas that of in Sabah were *H. kuda* ($n = 123$), *H. spinosissimus* ($n = 111$), and *H. comes* ($n = 81$). The rank of caught seahorse species was different between regions (W = 10, p < 0.05). Small-scale and large-scale fishing gears reportedly caught nine species each. Out of the nine species captured, *H. kuda* ($n = 131$), *H. spinosissimus* ($n = 120$), and *H. comes* ($n = 78$) were the three most common species caught by small-scale fishing gears whereas *H. spinosissimus* ($n = 21$), *H. trimaculatus* ($n = 17$), and *H. kuda* ($n = 11$) were the most common species caught by large-scale fishing gears. The rank of seahorse species was different between gear types (W = 70, p < 0.05) (Fig. 3).

The average seahorse catch per gear for gill or drift nets ($n = 361$) was 49±9.5 seahorses per year and that for trawls ($n = 54$) was 99±26.4

Fig. 2. Seahorse catch history of (A) 552 fisher respondents in Peninsular Malaysia and (B) 308 in Sabah, based on fishing gear types. Fishing gears categorized as 'others' in (A) include anchovy purse seines, cast nets (*jala*), hooks and lines, dredges/ scoops, lift nets, hand collection, other seines, and other traps. *Bagang* is the local name for a kind of lift net. Sample size (*n*) of each fishing gear indicated at the end of each bar.

seahorses per year (Table S3). The largest estimated annual seahorse catch per gill or drift net was 1825 seahorses in both Sabah and eastern Peninsular Malaysia. Gill or drift net fishers (73 %) were more likely to have caught seahorses than trawlers (12 %). The estimated annual seahorse catch by gill or drift netters in Malaysia was 813,883 individuals (2589 kg/ year) with a higher quantity in Sabah (56 %), followed by the east coast (23 %), and the west coast (21 %) of Peninsular Malaysia (Fig. 4; see Table S4 for calculation). The total estimated annual trawl catch of seahorses in Malaysia was 247,382 individuals (787 kg/ year) with a higher quantity in the east coast (46 %), followed by the west coast (42 %) of Peninsular Malaysia, and Sabah (12 %) (Fig. 4; see Table S5 for calculation). The total annual seahorse catch for both gears was 3376 kg/ year with 77 % contributed by gill or drift nets and 23 % by trawls.

3.1.1. Fisher perception

Of the 860 respondents, 72 % perceived a decline in seahorse populations compared to when they first started fishing. Regarding the fate of captured seahorses, 72 % of respondents reported releasing them back into the water. Of those who released the seahorses, some respondents retained them (33 %), selling some or all (3 %), and giving them away to their families or friends upon requests (2 %). Almost half of the respondents who caught seahorses retained them (45 %), some of which also reported selling some or all (4 %) and giving to others (3 %). Only a minority reported selling some or all (8 %), discarding them (7 %) or giving to others (4 %). Reasons given by fishers who had either released or discarded caught seahorses included concerns for their survival, no demand for seahorses, do not use seahorses in any way, and undesirable condition(s) of seahorse (dead, pregnant, small-sized, or smooth in appearance).

3.2. Seahorse-based traditional medicine trade status

Out of the 458 TM practitioners/ traders interviewed across Malaysia, 32 % were currently selling seahorses, 25 % previously sold, and 43 % had never sold them. Among the 419 respondents in Peninsular Malaysia, many of them (42 %) had never sold any form of seahorses, 31 % were currently selling them, and 27 % previously sold. Out of the 39 respondents in Sabah, majority of them (51 %) never sold any form of seahorses, 44 % were currently selling them, and 5 % previously sold. The seahorse trade status was dependent on regions; hence we rejected the hypothesis that traditional medicine sale practices are the same between regions ($X^2 = 8.95$, $df = 2$, p < 0.05).

With regard to ethnic-specific TM practices, the status of seahorse trade varied between TCM, Malay TM, Indian TM, and other TM. Among the 348 TCM practitioners/ traders interviewed, 40 % of respondents were currently selling either dried seahorses, capsules containing seahorse extracts or both, 32 % no longer sell them, and 28 % had never sold them. Out of the 92 Malay TM practitioners interviewed, majority of them (96 %) have never sold any form of seahorses, 3 % were currently selling them, and 1 % no longer sell them; five reported that they were using seahorses in their treatments but had never sold them. All Indian TM practitioners interviewed have never sold any form of seahorses as their practices are entirely plant-based. Out of the eight other TM traders (Suluk, Bajau, Jawa, and Sino Kadazan), majority of them (88 %) were currently selling dried seahorses while 12 % no longer sell them (Fig. 5). Across all ethnicities, the TM practitioners/ traders who previously sold seahorses indicated that the last seahorse retail sales took place between four months to more than 30 years ago. The seahorse trade status was dependent on ethnic-based TM practices (two-tailed p < 0.05).

Half of the respondents across Malaysia (52 %, $n = 70$) were unsure of the current supply volume of their dried seahorses due to irregularity in both volume and frequency of supply, e.g., approximately less than 100 g (or a few dried individuals) to 1 kg at irregular intervals. Based on available estimates, the current annual supply volume of dried seahorses
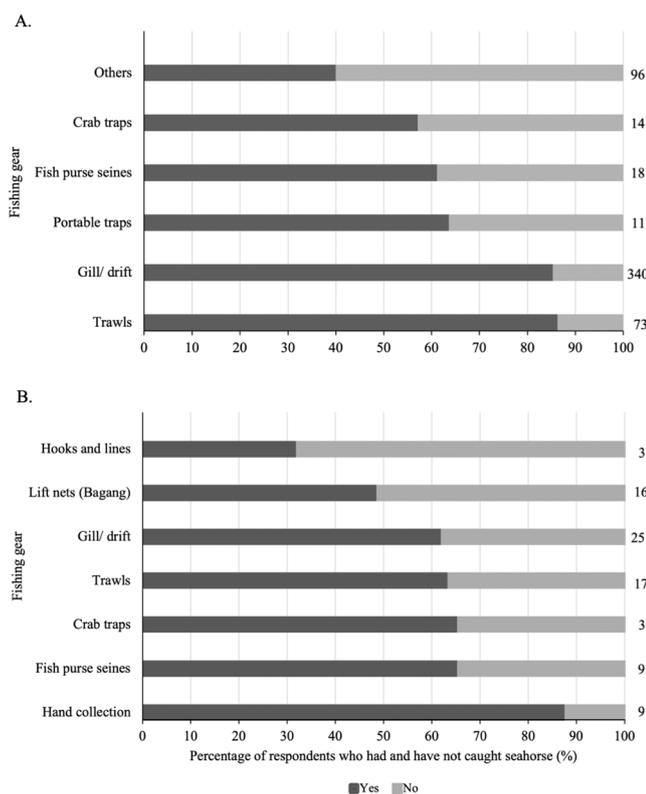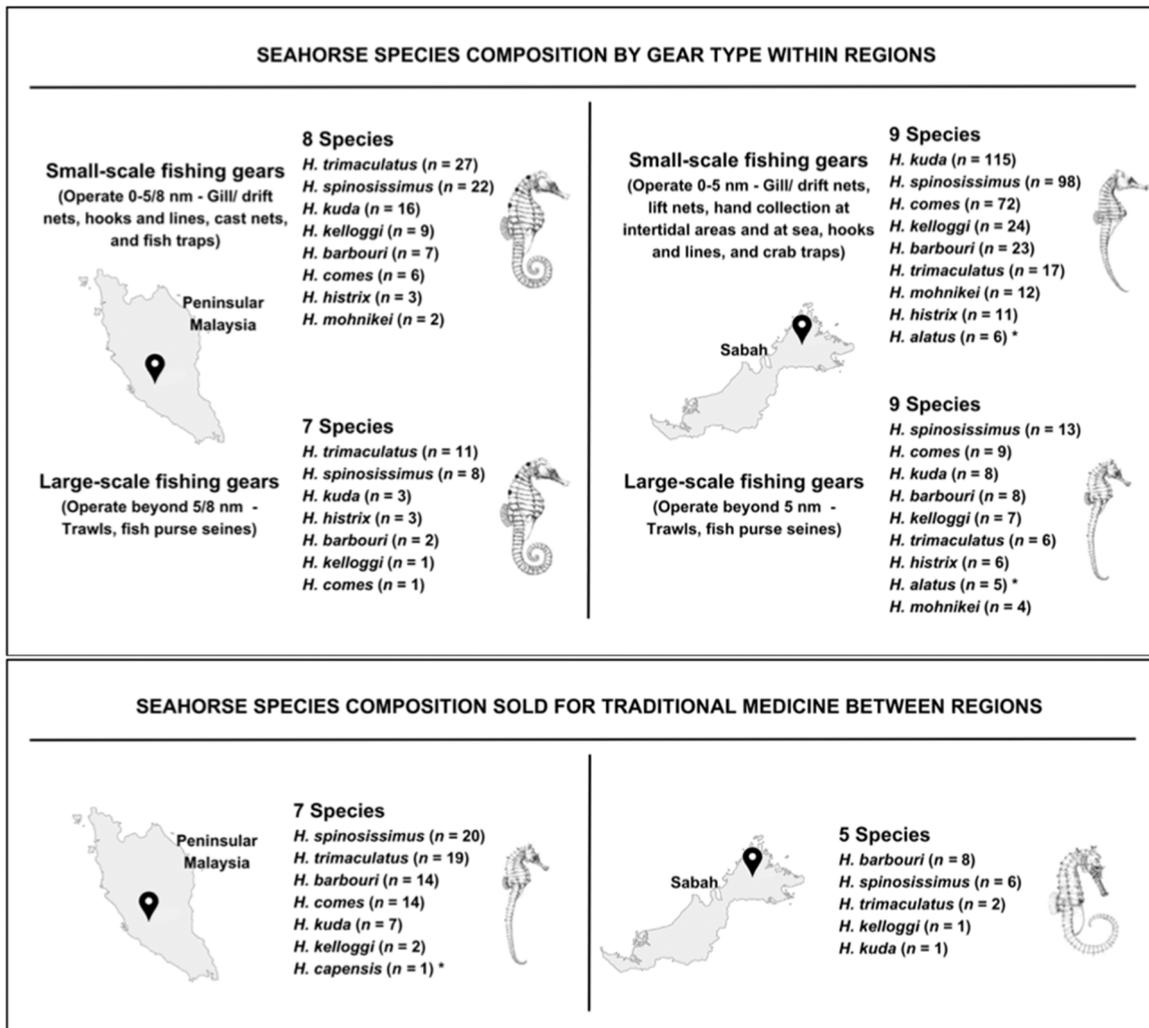
Fig. 3. Seahorse species (*Hippocampus* spp.) composition by gear type (small-scale vs large-scale fishing gears) within Peninsular Malaysia and Sabah as well as seahorse species composition sold for TM between these regions. Sample sizes (*n*) indicate numbers of respondents that caught and sold each species. Seahorse images represent the most common species caught in each gear type and sold in each region. * represents the species that are foreign to Malaysia.
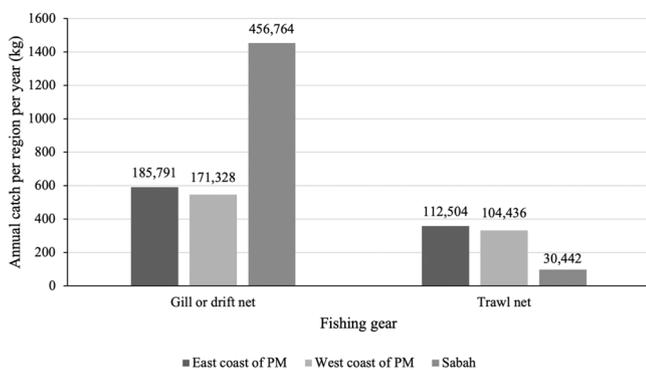

Fig. 4. Estimated annual catches of seahorses (in kilograms) by fishing gear and region in Malaysia. Annual catch per region is the estimated average catch (based on interview surveys) multiplied by the reported number of gears operating in each region (Source: DOFM, 2021), and the percentage of fishers that catch seahorses by gear type. Conversions of number to weight of seahorses were based on a mean of 3.18 g per seahorse. Sample size (*n*) of each region indicated at the top of each bar.
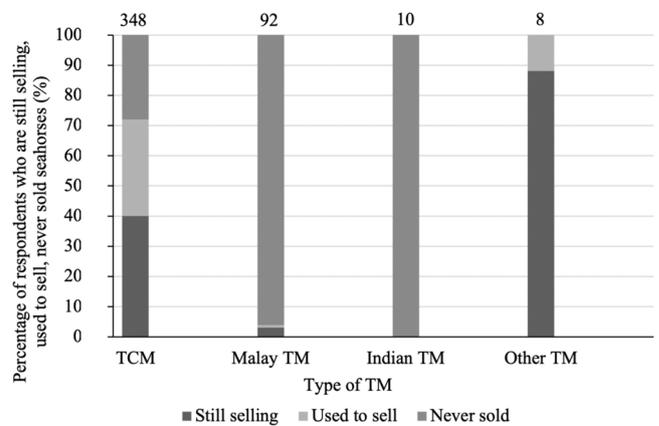

Fig. 5. Status of seahorse trade (dried seahorses and seahorse capsules) among 348 TCM practitioners/ traders, 92 Malay TM practitioners, 10 Indian TM practitioners, and eight other TM traders (Suluk, Bajau, Jawa, and Sino Kadazan) interviewed in Peninsular Malaysia and Sabah. Sample size (*n*) of each type of TM indicated at the top of each bar.
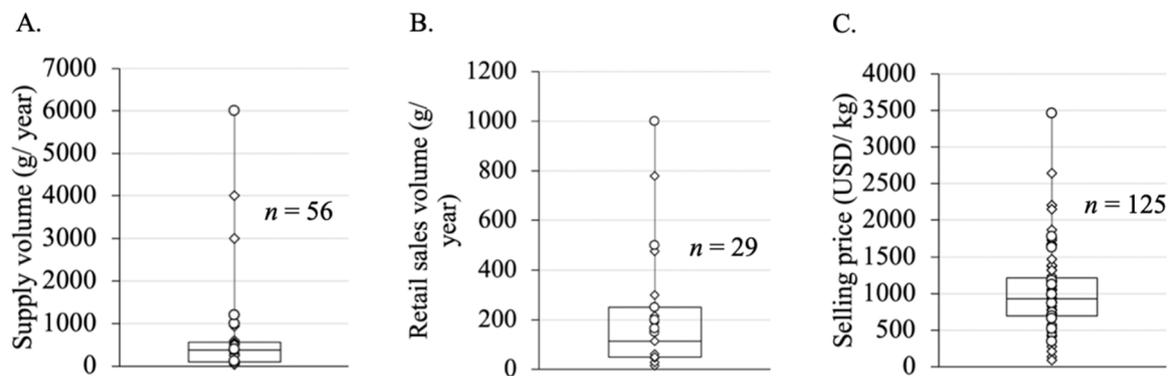
Fig. 6. Current (A) annual supply volume, (B) annual retail sales volume, and (C) selling price of dried seahorses in Peninsular Malaysia and Sabah. Conversions of prices were based on an exchange rate of 1 MYR = 0.22 USD. Sample sizes (*n*) indicate numbers of estimates from respondents. Data points indicate individual data of Peninsular Malaysia (◇) and Sabah (○), respectively.

on average was 625 g/ year (*n* = 56 practitioners/ traders; Fig. 6A; see Table S6 for difference between regions). After considering the total estimated number of surveyed TM shops that reported selling seahorses, the estimated current annual supply volume was 93 kg/ year (Table S7). Eight respondents (6 % of current sellers) reported that they would not renew their supplies, i.e., would stop selling seahorses, after exhausting current inventory.

Due to irregular sales resulting from lack of consumer demand, most TM practitioners/ traders (*n* = 95) were similarly uncertain of the current retail sales volume of their dried seahorses. Among the respondents who were currently selling dried seahorses (*n* = 29), mean annual retail sales volume of 205 g/ year was estimated (Fig. 6B; see Table S6 for difference between regions). After considering the total estimated number of surveyed TM shops that reported selling seahorses, the current annual retail sales volume was 30 kg/ year (Table S7). Other respondents (*n* = 10) reported no recent sale transactions of dried seahorse for up to the past four years. Despite that, most respondents who previously sold dried seahorses (*n* = 103) still value seahorse in terms of health to treat skin conditions, heatiness, kidney disorders, asthma, facilitate blood-cleansing, tonify kidneys, detox, strengthen the lower back, and as an aphrodisiac.

The current mean selling price of dried seahorses was USD 1052/ kg (*n* = 125 practitioners/ traders) (Fig. 6C; see Table S6 for difference between regions). Nine respondents were unsure of the prices of their dried seahorses but had indicated that they were expensive. One of these nine respondents was a Malay TM practitioner who sold dried seahorses not at a fixed price but rather by the amount his patients are willing to pay. Prices of dried seahorses varied with seahorse size, texture, and colour. Bigger seahorses were sold at a higher price than smaller ones. Four respondents reported selling smooth or light-coloured seahorses (e. g., white) at higher prices compared to spiny or dark-coloured seahorses (e.g., green, black).

3.2.1. Species profile and sources of sold seahorses

Based on survey of the current trade, commonly sold species of dried seahorses for local TM in Peninsular Malaysia were consistent with the profile of locally captured species with *H. spinosissimus* being the most commonly sold (*n* = 20 practitioners/ traders) followed by *H. trimaculatus* (*n* = 19), *H. barbouri* (*n* = 14), *H. comes* (*n* = 14), *H. kuda* (*n* = 7), and *H. kelloggi* (*n* = 2) (Fig. 3). The exceptions were *H. histrix* and *H. mohnikei* that were captured relatively often but not seen during the survey. One of the TCM shops also reported selling *H. capensis*, a non-native species (Fig. 3). However, only five of the captured species – *H. barbouri* (*n* = 8 practitioners/ traders), *H. spinosissimus* (*n* = 6), *H. trimaculatus* (*n* = 2), *H. kelloggi* (*n* = 1), and *H. kuda* (*n* = 1) were being sold in TCM and other TM in Sabah (Fig. 3). Information on species of dried seahorse that were historically sold in Peninsular Malaysia were limited but included *H. barbouri* (n = 2 practitioners/ traders), *H. kuda*

(n = 1), and *H. trimaculatus* (n = 1) whereas those sold historically in Sabah could not be identified.

Less than one-third (26 %) of practitioners/ traders based in Peninsular Malaysia (*n* = 28) had sourced their dried seahorses locally within Malaysia, namely Peninsular Malaysia (e.g., Pulau Ketam; Hutan Melintang; Taiping; Teluk Intan; Ipoh; Kuala Lumpur; Penang; Johor; Pahang; Terengganu), Sabah, and Sarawak. Species of dried seahorses that were sourced locally included *H. spinosissimus*, *H. trimaculatus*, *H. barbouri*, *H. kuda*, *H. comes*, and *H. kelloggi*. About a third of the respondents in Peninsular Malaysia (39 %) had obtained fully imported supply of dried seahorses that originated from China (*n* = 26), Indonesia (*n* = 7), the Philippines (*n* = 3), Thailand (*n* = 3), Vietnam (*n* = 3), Hong Kong (*n* = 1), India (*n* = 1), and South Africa (*n* = 1). The rest of the respondents had either obtained their dried seahorses from both Malaysia and other countries (3 %) or were unsure of the source (32 %). On the other hand, 70 % of respondents from Sabah (*n* = 12) had sourced their dried seahorses locally within Peninsular Malaysia, Sabah, and Labuan. Only 12 % of respondents in Sabah had solely imported their dried seahorses from China (*n* = 1) and the Philippines (*n* = 1). The rest had either obtained their dried seahorses from both Malaysia (*n* = 2) and other countries, namely Taiwan (*n* = 1) and the Philippines (*n* = 1) (12 %) or were unsure of the source (*n* = 1) (6 %).

3.2.2. Perception of trade regulation

For context on existing trade regulations, all known seahorse species are listed on Appendix II of CITES since 2002, and the listing has been implemented since 2004 (Vincent et al., 2011). The CITES listing regulates international trade but has no regulatory power over domestic fishing, sale, or trade of seahorses within Malaysia (Foster, 2023). Most of the domestic seahorse trade is also not monitored by any local agency as seahorses are not listed in any local laws and regulations, except the Wildlife Protection Ordinance 1998 in Sarawak (Foster, 2023). The CITES Enforcement Authorities (EAs) only conduct general monitoring at entry and exit points of the country that is not specific to seahorses (Foster, 2023).

According to some of the traditional Chinese medicine (TCM) practitioners and traders interviewed, the use and trade of seahorses are regulated by the Malaysian government. The reported nature of these regulations varied among respondents. The use and trade of seahorses in TCM were said to have become either controlled or illegal as far back as five years ago, reportedly due to the protection of seahorses that were on the verge of extinction. One respondent mentioned that the retail sales of small-sized spiny seahorses were permissible, but not the large ones. Another respondent highlighted that the current dried seahorse inventory in the shop was purchased before the supposed seahorse trade ban. Retail sales of seahorse derivatives in capsules were also said to be illegal by some respondents. Some respondents (*n* = 3) said that dried seahorses can be sold for medicinal purposes provided that a license is

obtained from the Department of Wildlife and National Parks of Peninsular Malaysia. Another respondent mentioned that current retail sales of dried seahorses in TM require an Approved Permit which is an import and export license issued by the Permit Issuing Agencies under the Customs Act 1967. On the other hand, some respondents mentioned that selling dried seahorses was permissible. A modern Chinese medicine practitioner (also a lecturer in the field) indicated that dried seahorse is banned under the National Pharmaceutical Regulatory Agency as it is an animal product, but it is not illegal to practice Chinese medicine using seahorses. Another respondent said that although seahorse trade is regulated under the Wildlife Conservation Act 2010 [Act 716] and the Protection of Wildlife Act 1972 (No. 76 of 1972), no enforcement action had been taken by the government thus far.

4. Discussion

Our study reveals that a majority of Malaysian fishers had previously caught seahorses, primarily as bycatch. One key finding is that gill or drift nets (accounting for 23 % of marine fish landings; DOFM, 2022) appear to be responsible for a higher estimated annual seahorse catch in Malaysia, specifically three times more than trawls, even though trawlers account for 45 % of total marine fish landings (DOFM, 2022). Large-scale trawlers had often been the main fishing gear held responsible for bycatch of marine species and the sole focus in fisheries management to mitigate this issue (Perry et al., 2010; Lawson et al., 2017; Stocks et al., 2017). However, our findings suggest that small-scale fisheries, using gill or drift nets, cannot be overlooked when addressing issues of seahorse bycatch within Malaysia, and likely elsewhere within the Indo Pacific region as well (Lawson et al., 2017).

The estimated total number of present-day seahorse bycatch landed by trawlers in Peninsular Malaysia and Sabah from our study is less than half of the previously reported amount in a previous survey conducted in 1998–1999 by Perry et al. (2010), who employed a different approach of calculation than ours. A comparison of fishing effort statistics revealed that the number of registered trawl boats in Malaysian waters during the late 1990s (c.a. 5900) was similar to that in 2005 (c.a. 6300) but dropped more recently in 2022 (c.a. 5300). The trend of bycatch decline could therefore be partially explained by the more recent decrease in trawling effort but is congruent with the perception of fishers who similarly reported decline in seahorse bycatch driven by high fishing pressure. The reported seahorse bycatch decline is not a recent phenomenon but something that had been attributed to overfishing by earlier studies. From interviews with local fishers, Choo and Liew (2005) reported that the declines were rapid in areas with heavy fishing pressure or where trawlers commonly operate such as in the Kedah–Langkawi waters and other areas on the west and east coasts of Peninsular Malaysia.

The interview approach with fishers revealed spatial differences in seahorse composition. We found that seahorse species richness within small-scale, nearshore fisheries is similar to that of large-scale, offshore fisheries (trawls and fish purse seines), and is slightly higher in Sabah than in Peninsular Malaysia (Lim et al., 2011). The reported species composition in these fisheries, however, varies by region. *H. trimaculatus* is reported to be the most commonly caught seahorse in Peninsular Malaysia, while *H. kuda* and *H. spinosissimus* are more commonly caught in Sabah. These findings are supported by species composition profiles from field surveys conducted by Lim et al. (2011) and Lawson et al. (2015). Overall, *H. kuda*, *H. spinosissimus*, *H. comes*, and *H. trimaculatus* are the most common species as they are widely distributed across both regions of Peninsular Malaysia and Sabah (Choo and Liew, 2005, Chen et al., 2021). Trawlers in the east coast of Peninsular Malaysia appear to catch more seahorses than those in the west coast, consistent with previous findings by Perry et al. (2010). This suggests that the deeper, offshore waters of southern South China Sea also serve as important habitat for some seahorse species (Foster, 2023).

Contrary to the geographic differences of species richness observed

in seahorse catches, our study reveals that the species richness of seahorses sold in TCM trade is higher in Peninsular Malaysia compared to Sabah. Common seahorse species sold in TCM trade likewise do not directly correspond to dominant species in fisheries catch; we found that *H. spinosissimus, H. trimaculatus* and *H. barbouri* are common species sold in TCM, which is similar to findings of Choo and Liew (2005). This may not be surprising given that the local TCM trade relies on both locally sourced as well as imported seahorses, the latter from countries that significantly contribute to the global seahorse export, including China, the Philippines, Thailand, Indonesia, India and Vietnam (Vincent, 1996; Choo and Liew, 2005; Perry et al., 2010; Louw and Bürgener, 2020). South Africa had also been identified by some respondents as a source country of sold dried seahorses in Malaysia, reflecting the reported recent surge in imports of dried seahorses from Africa to Asia (Louw and Bürgener, 2020).

Our interview surveys with traditional Chinese medicine (TCM) practitioners revealed that the prices of dried seahorses can vary widely depending on several factors. Size and color-specific differences were found to be important, consistent with previous studies, where larger or light-colored seahorses (e.g., yellow) were more expensive and highly valued compared to smaller or dark-colored seahorses (e.g., black) (Choo and Liew, 2005; Perry et al., 2010). Some respondents indicated that smooth seahorses are sold at a higher price than spiny seahorses, a finding which was reported earlier by Vincent (1996). We had difficulty in obtaining sufficient reliable estimates of historical price; however, the traders reported dramatic increase in current prices of dried seahorses compared to historical prices, which could be due to the rarity of encountering seahorses in the wild and perceived uniqueness of the marine fish.

The effect of declining seahorse bycatch, coupled with higher current selling price, is reflected in both the reportedly reduced sales volume and irregular current supply volume of dried seahorses in local TM shops. Reduced sales volume is consistent with declining level of interest among current and potential buyers, especially with the low prevalence of medicinal use of seahorses reported in recent years (Perry et al., 2010; Ng et al., in press) and fueled further by unfavorable high prices. The decline in retail sales could also be explained by the uncertainty of the Malaysian public members (51 %) and fishers (59 %) regarding the value of seahorses with respect to health benefits (Ng et al., in press). Many respondents perceived the current supply to be considerably lower than historical supplies, although most had difficulty providing estimates of historical supplies. This limitation is not surprising given that seahorses are not as common as other TM species. Additionally, we found that the historical inventories of supply and sales are rarely maintained by TM practitioners/ traders. Some TM shops that previously sold seahorses are also now run by new owners or descendants of previous owners who often have little to no knowledge of the historical seahorse trade. Despite the historical data gaps, our study provides cohesive evidence supporting declining seahorse fisheries catch and TM-based domestic trade within Malaysia.

On the other hand, multiple reports depict Malaysia as an important global seahorse supplier. A recent report by TRAFFIC based on the CITES Trade Database revealed that Thailand (71 %), mainland China (15 %), Senegal (10 %), Malaysia (2 %), and Hong Kong (1 %) were the top five countries/ territories accounting for 99 % of the reported global dried seahorse exports between 2008 and 2018 (Louw and Bürgener, 2020). Peninsular Malaysia alone contributes notably to the global seahorse market (Choo and Liew, 2005). Based on import records, Malaysia was a major contributor of dried seahorses to Hong Kong and Taiwan (Perry et al., 2010). High and consistent overseas demand with advantage of currency exchange may be an important factor favoring Malaysia's seahorses as export commodities rather than for domestic trade (Vincent, 1996; Choo and Liew, 2005; Perry et al., 2010; Louw and Bürgener, 2020). Collectively, the decline in both domestic supply and demand is shaped by inter-linked factors of declining wild population, increased price of seahorse and shifting values of seahorse among TM
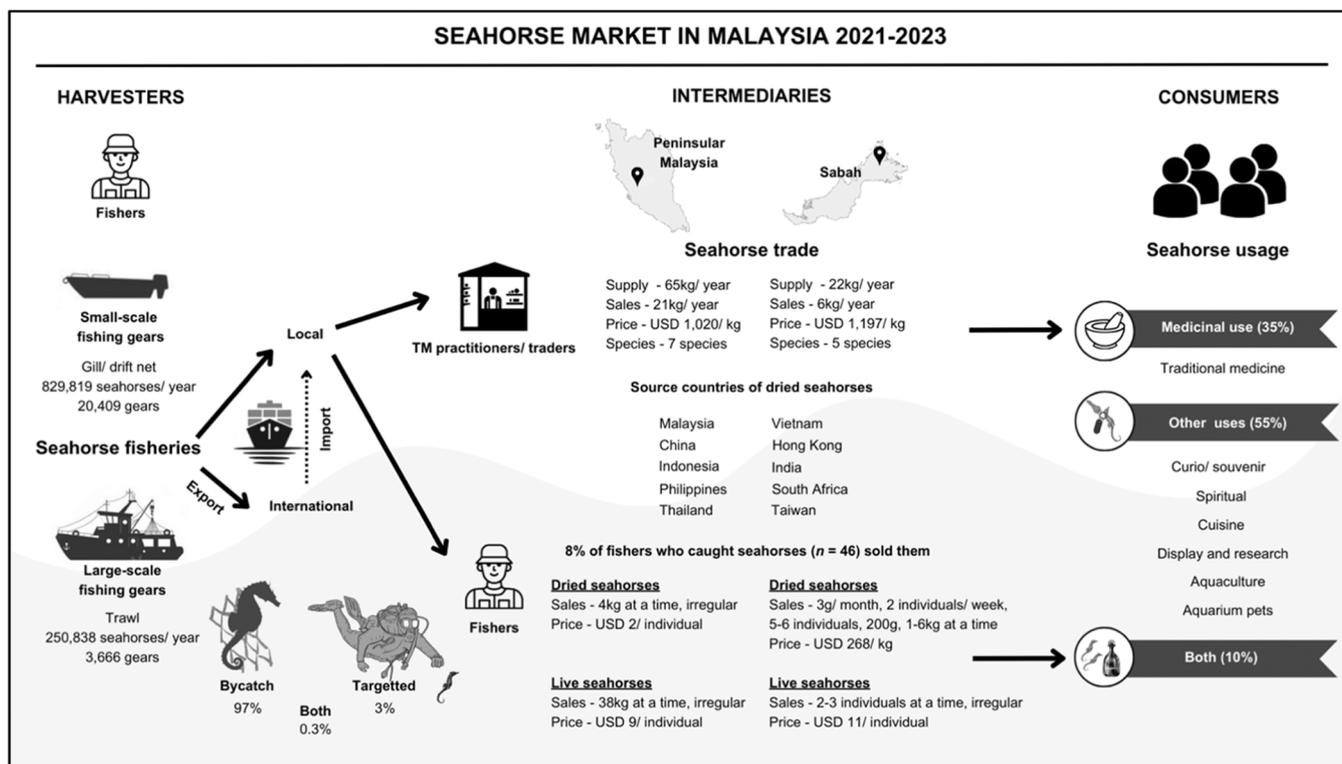
Fig. 7. Current seahorse market in Malaysia (2021–2023) showing the nature of seahorse fisheries and trade based on the present study, as well as usage from Ng et al. (in press).

practitioners and users (see also Ng et al., in press), along with international trade forces. A summary of the seahorse trade market in Malaysia is presented in Fig. 7 (with reference to Tables S6 and S8).

4.1. Way forward

The total estimated annual seahorse catch for Malaysia does not account for all fishing gears involved in seahorse capture, nor does it include seahorse catch from Sarawak. Although the contribution of seahorse bycatch by other gears is unlikely to be significant, Sarawak had shown a wide seahorse distribution and large-scale trawl catch, which would likely contribute significantly to the catch estimates (Perry et al., 2010). Therefore, future seahorse fisheries studies should include investigation of species composition of seahorse catch and annual seahorse catch by gear types within the state. Efforts on surveying Sarawak should also include documentation of ethnic-based trade and uses among coastal-associated ethnic groups.

Aside from the TM trade, seahorses are also sold in the curio and aquarium trade. Based on a poll survey of the Malaysian public, the majority of respondents that buy seahorses reported utilising them for non-medicinal purposes, with retaining them as curios and aquarium fishes being common use types (Ng et al., in press). Seahorse curios were the second most common type of seahorse trade on online market platforms in Malaysia based on a preliminary study (Aminuddin et al., unpublished results). Additionally, the capture of live seahorses for the aquarium trade became more prominent with the development of technology for rearing marine aquarium species (Vincent, 2006; Foster et al., 2021, 2022). Hence, the curio and aquarium-based commercial trade should be investigated in future studies to ensure that these key trade elements are taken into account when evaluating the extent of seahorse use and trade.

5. Conclusions

Overall, this study found that seahorses are not only landed as trawl bycatch, but are also vulnerable to being captured by small-scale fishing gears such as gill or drift nets. Fishers in Malaysia, as the supply chain start point, describe a decrease in seahorse bycatch volume, which raises concerns about the status of seahorse populations in recent years. As long-term data on seahorse populations in Malaysia are limited and the exact status and population trend is difficult to determine, declining catch rates estimated by fishers in the region should be considered as the best available evidence to emphasize the need for precautionary fisheries management measures. The current findings also point towards the prevalence of seahorse trade that is reportedly more common among the TCM practitioners/ traders than the Malay TM practitioners and other TM traders, though demand generally appears to have decreased while selling prices have increased. However, the findings may not accurately reflect the level of seahorse exploitation in Malaysia, considering the significant involvement of Malaysia in seahorse exportation from independent data sources (Louw and Bürgener, 2020). Even if domestic demand for seahorses is low, this may not necessarily reduce fishing pressure on seahorse populations, given the considerable quantities caught incidentally by non-selective fishing gears each year. Furthermore, if seahorse market values continue to rise, the practice of targeted seahorse fisheries could potentially increase. Management actions to reduce efforts of both trawl and small-scale fisheries as well as enforcement of existing seahorse trade laws should be prioritized to promote sustainable local seahorse fisheries and trade.

CRediT authorship contribution statement

Reana May Yen Ng: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization, Project administration, Funding acquisition. **Adam Chee Ooi Lim:** Conceptualization, Methodology, Validation,

Investigation, Resources, Supervision, Project administration, Funding acquisition. **Chin Nurhiqwanalina Binti Henry Chin Siew Lee:** Investigation. **Norazliana Binti Abdul Majib:** Investigation. **Muhammad Ali Syed Hussein:** Validation, Resources, Supervision. **Amy Yee-Hui Then:** Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2024.107188.

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