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# Local Fishers' Knowledge of Target and Incidental Seahorse Catch in Southern Vietnam

A. P. Stocks[1] · S. J. Foster[1] · N. K. Bat[2] · N. M. Ha[3] · A. C. J. Vincent[1]

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**Abstract**
Many vulnerable marine species are caught in small-scale fisheries that lack long-term records, thereby limiting the development of effective evidence-based management measures. To uncover recent trends in fish landings and value in the absence of historical data, we interviewed 77 fishers and five buyers on Phu Quoc Island in Southern Vietnam regarding their current and past fishing practices, with a focus on seahorse catches. Seahorses (*Hippocampus spp.*) are caught using multiple gear types (including trawls, crab nets, and compressor diving) and have both cultural and financial value. Most fishers catch seahorses incidentally, though 14 targeted them and made the majority of their income from their sale. Fishers reported that seahorse catch rates decreased by 86–95% from 2004 to 2014, while landed value simultaneously increased by 534%. If these reports are accurate, seahorse fishing on Phu Quoc is unsustainable and requires immediate management controls.

**Keywords** Seahorses · Fisher interviews · Trawling · Diving · Catch decline · Target · Bycatch · Fisheries management · Phu Quoc island · South Vietnam

## Introduction

Fisheries can affect entire ecosystems through biomass removal and habitat degradation (Hutchings and Reynolds 2004; Christensen *et al.* 2014) and thus require informed management measures to effectively mitigate their wider negative impacts (Pauly *et al.* 2002). A variety of complementary tools are needed to ensure fisheries are sustainable (Pauly *et al.* 2005; Botsford and Brumbaugh 2009), especially due to variation in countries' management capacity. Increasingly, fisheries management practices such as gear restrictions and catch quotas are being integrated with spatial approaches like marine reserves (Pauly *et al.* 2003; Hilborn *et al.* 2004). In addition, multilateral agreements such as the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) are being deployed to help enhance fisheries management efforts, especially for vulnerable species (Richards and Maguire 1998; Caddy 1999; Musick *et al.* 2000).

Many fisheries management tools developed for data-rich, well-regulated fisheries prove difficult to apply to small-scale fisheries, which tend to be data-poor and largely unregulated (Berkes *et al.* 2001; Mills *et al.* 2011). Unlike industrial fisheries, which generally use a single gear to target a single or a suite of species, small-scale fisheries use a variety of gears to catch many species often indiscriminately (Chuenpagdee *et al.* 2006). These multi-gear, multi-species fisheries are diffuse in nature, with thousands of boats operating from many small rural villages (Berkes *et al.* 2001), making them challenging to monitor and study (Chuenpagdee *et al.* 2006; McClanahan *et al.* 2009). As a result, the majority of their catch remains undocumented or grossly underestimated (Zeller *et al.* 2006, 2007; Jacquet *et al.* 2010) leading to poorly informed management.

Underestimating the impacts of small-scale fisheries and/or managing them poorly can have global implications. Small-scale fisheries account for anywhere from a third

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✉ A. P. Stocks
ally.stocks@gmail.com

[1] Project Seahorse, Institute for the Oceans and Fisheries, The University of British Columbia, 2202 Main Mall, Vancouver, BC V6T 1Z4, Canada

[2] Research Institute for Marine Fisheries, 224 Lelai, Ngoquyen, Haiphong, Vietnam

[3] Centre for Natural Resources and Environmental Studies, Viet Nam National University, 19 Le Thanh Tong, Hanoi, Vietnam

(Chuenpagdee *et al.* 2006) to over half (Berkes 2003) of the world's fish catches by weight. They also employ 50.5 million of the world's 51 million fishers, some 95% of whom are in developing countries (Berkes *et al.* 2001; FAO 2004). Small-scale fishing provides a critical contribution to the livelihoods and food security of many rural people in these developing countries (Béné *et al.* 2007). Unchecked, these fisheries have the capacity to cause immense damage to habitats, fish stocks, and vulnerable marine species (Alfaro-Shigueto *et al.* 2010), and thus require greater attention from fisheries policy-makers than they have received to date. Yet they remain low on the research and policy agendas for both national and multilateral organizations (Salas *et al.* 2007).

Given the lack of long-term record keeping in most small-scale fisheries, working directly with fishers can fill gaps in our scientific understanding of these systems. Because they are intricately connected to and reliant upon their native ecosystems, local resource users often understand them best (Menzies 2006). Local knowledge has therefore proven useful in developing effective and collaborative fisheries management (Berkes *et al.* 2000; Silvano and Valbo-Jørgensen 2008). This approach is not without its drawbacks, for example, certain studies have documented the inaccuracies of fisher narratives (O'Donnell *et al.* 2012; Tesfamichael *et al.* 2014). However, interviews can provide reliable information on trends and fluctuations, enabling quick tracking of relative changes in fisheries (Tesfamichael *et al.* 2014). Furthermore, local knowledge has been used in a variety of fisheries contexts to supplement scientific knowledge and enhance management strategies (Mackinson 2001; Silvano and Valbo-Jørgensen 2008; Moreno-Baez *et al.* 2010). Fisher interviews are a particularly useful tool in data-poor situations where conservation concerns exist (Aylesworth *et al.* 2017).

Fisher knowledge is especially useful for understanding genera that have historically been of low to no priority for fisheries management but are now receiving conservation attention (Aylesworth *et al.* 2017). Among the most charismatic and notable of these species are seahorses (*Hippocampus* spp.). An estimated 37 million seahorses are caught annually (Lawson *et al.* 2017), yet virtually none appear in formal fisheries records. The large-scale global trade in seahorses for traditional Chinese medicine, ornamental display, and trinkets led to all species being listed on CITES Appendix II in 2002 (as reviewed in Vincent *et al.* 2011; see also Giles *et al.* 2006; Foster *et al.* 2017)). Member countries must now ensure that international trade does not harm wild populations and that specimens are legally acquired (CITES 2016). Such responsibilities can be extremely challenging, since many exporting countries lack biological and trade data on seahorses and/or the capacity to implement CITES regulations (Vincent *et al.* 2013). In those countries, local fishers are the first and best information source for seahorse management and conservation (Giles *et al.* 2006; O'Donnell *et al.* 2010, 2012).

In Vietnam, a CITES-imposed ban on exports of one seahorse species, *Hippocampus kuda*, highlighted the need to access local fishers' biological, fisheries and trade data. Seahorses are fished throughout Vietnam and exported as well as consumed within Vietnam for various purposes including tonics to promote kidney health and increased sexual potency (Giles *et al.* 2006). There is evidence that the exploitation of seahorses in Vietnam, combined with damaged and degraded habitats, is causing declines in their populations (Van Long and Hoang, 1998; Giles *et al.* 2006; Stocks *et al.* 2017). Poor monitoring and documentation of seahorse fisheries led to the CITES export ban on *H. kuda*, and a clear requirement that Vietnam develop adaptive management measures to lift the ban (CITES 2013a). The ban was lifted in 2018 when Vietnam confirmed an end to seahorse exports until it can be ensured that they comply with CITES requirements for sustainable sourcing (CITES 2018).

The overall goal of this study was to increase our understanding of seahorse fishing, trade, and domestic use in southern Vietnam in support of conservation and management planning. Our specific objectives were to determine historical changes in seahorse catch, fishing effort, and seahorse price to establish the level of exploitation that has occurred in the area. In addition we explored changes in gear use, seahorse size, and other indications of fishing pressure. These data can provide an indication of the sustainability of the fisheries and the pressures faced by seahorse populations. We chose to study active seahorse fishing grounds at Phu Quoc Island and the An Thoi Islands in southern Vietnam (CITES 2013b), a notable hotspot of seahorse fishing that has attracted conservation concerns (Ut and Tam 2012; Stocks *et al.* 2017). This research will help to guide monitoring and management efforts for seahorse fisheries, trade, and conservation, and assist Vietnam in meeting its obligations under CITES.

## Materials and Methods

### Study Site

Our research focused on fishers operating in waters surrounding the Phu Quoc District, Kien Giang province in Southern Vietnam (from 9.45–10.30° N to 103.55–104.05° E, Fig. 1). The area, collectively known as Phu Quoc, contains Vietnam's largest island, Phu Quoc Island, and 21 smaller islands known as the An Thoi Islands. The waters surrounding the islands are relatively shallow (less than 40 m) and lie within 50 km of the coast (Pomeroy *et al.* 2009), making them easily accessible for inshore fishers. Phu Quoc has a monsoonal sub-equatorial climate, experiencing a rainy season from May to October and a dry season from November to April. During the rainy season, precipitation occurs up to 19–21 days per month, usually accompanied by high winds and rough seas.

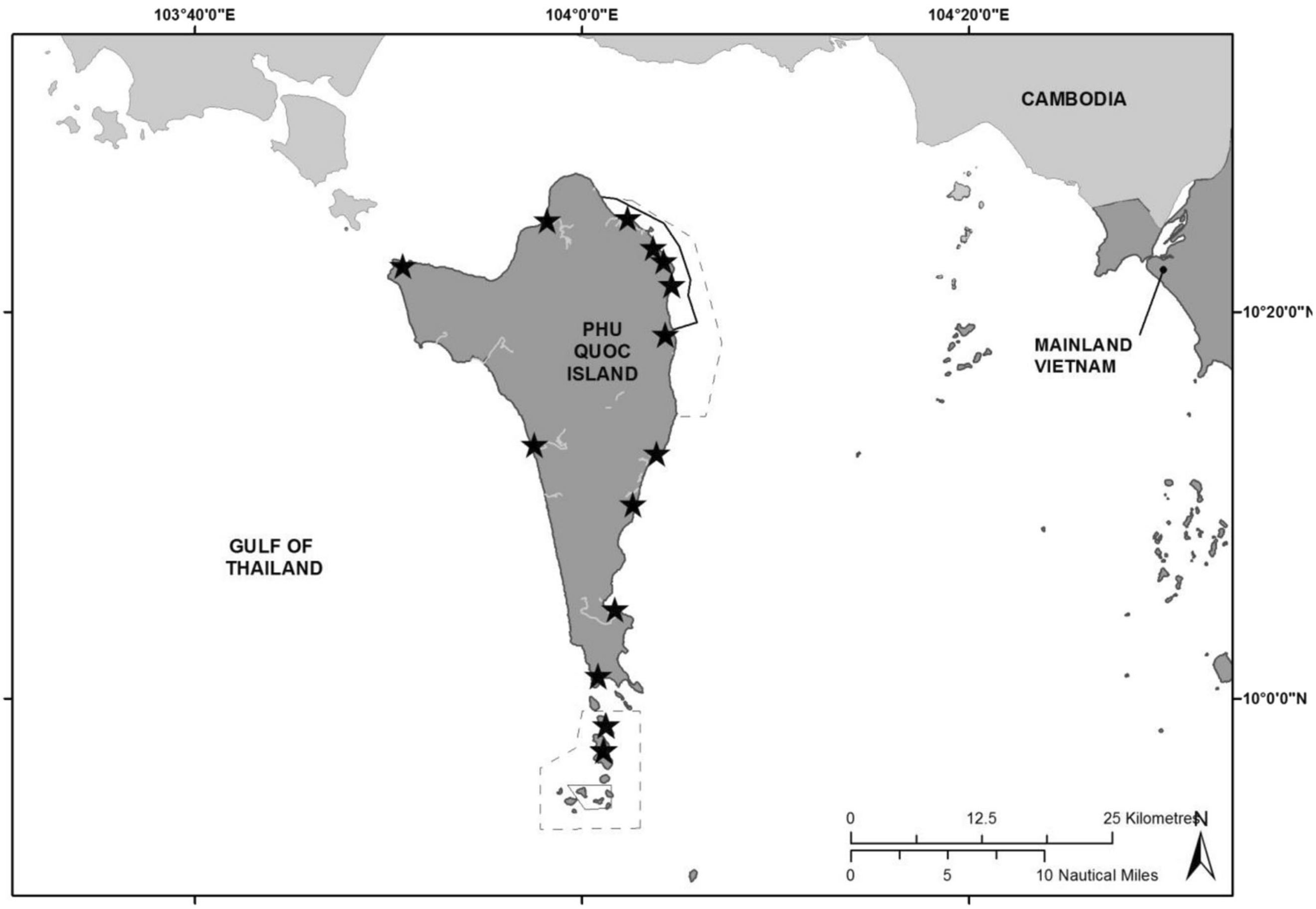


**Fig. 1** Map of study location in Southern Vietnam showing Phu Quoc Island and the 13 An Thoi Islands, as well as mainland Vietnam (dark grey) and Cambodia (light grey). Stars indicate sites where fishers and buyers were interviewed, clockwise from centre left: Duong Dong, Ganh Dau, Rach Tram, Da Bac, Xa Luc, Bai No, Da Chong, Bai Bon, Cay Sao, Ham Ninh port and village, Vinh Dam, An Thoi, Hon Thom, and Hon Roi. The area contains two MPAs designated under statute 1297/2007 QD-UBND. Solid lines denote areas designated for full protection (2195 ha of seagrass in the north, 757 ha of coral reef in the south). Dashed lines denote the designated buffer zone around the protected areas (4630 ha in the north and 8962 ha in the south)

## Interviews and Respondents

From April to July 2014, we conducted semi-structured interviews to document fisher and buyer understanding of the biology, fishery, trade, conservation, and management of local seahorse populations. Interviews were conducted in ports and villages across Phu Quoc Island, as well as two of the southern islands: Hon Thom and Hon Roi (Fig. 1). All interviews followed an ethics protocol approved by the UBC Behavioural Research Ethics Board (H12–02731). We used a combination of purposive and snowball sampling methods to find participants; we approached potential interviewees at fish landing sites and asked them to suggest others who might be appropriate for the study (Bryman 2012). We briefly explained our research (interpreted into Vietnamese by research assistants), assuring the participant that interview data were confidential before obtaining written or oral consent to begin the interview.

The questionnaire used to guide the interview consisted mostly of short questions about fishers' practices, gear use, and catch of seahorses (both past and present), followed by more open-ended questions about the future of seahorse fishing (Appendix). The interviews were designed to take less than 30 min to complete, ideal for collecting specific, quantitative information (Huntington 2000). Not every fisher answered every question, and fishers sometimes addressed only a subset of the questions because of their time limitations, therefore sample sizes ($n$) vary throughout the text.

## Data Standardization and Analysis

We used analysis of variance (ANOVA) tests to compare fishing effort among gear types, seahorse catch per unit of fishing effort (CPUE) among gear types, and the mean size of seahorses reported by gear types (all met the necessary assumptions for ANOVA). Where ANOVA results were significant, we used post hoc group comparisons (pairwise t-tests and Tukey Honest Significant Differences) to determine which pairs were significantly different. All statistical analyses were carried out in the R statistical platform (R Development Core Team; www.r-project.org).

We standardized seahorse catch rates reported by fishers to seahorses per boat per day (meaning a 24-h period). If fishers reported their catch in mass (grams or kilograms), we converted it to number of individual seahorses using a ratio of 165 individuals per kg of wet seahorses (1 seahorse = 6.1 g, Stocks *et al.* 2017), or 350 individuals per kg of dried seahorses (1 seahorse = 2.9 g, *Giles et al.* 2006). If fishers reported their catch by month, we converted it to a daily estimate by dividing their reported catch volume by the highest and lowest number of days they reported fishing per month. If no estimate of days fished per month was given, 10 and 20 fishing days per month were used for maximum and minimum catch respectively, based on other fishers' effort.

We combined all gear types to analyze trends in catch rates through time, assuming that changes in the seahorse CPUE would be consistent among gear types. We calculated the mean seahorse CPUE for each year and applied linear models to plot the regression.

Fishers reported landed values of seahorses in Vietnamese Dong (VND) per kilogram of live seahorses, VND per kilogram of fresh dead seahorses, VND per kilogram of dried seahorses, and VND per individual fresh or dried seahorse. These values were then converted to USD using an exchange rate of 21,200 VND: 1USD (IMF 2015). We used the price of live seahorses to reconstruct a time series and converted historical prices to 2014 VND equivalents using interest rates provided by the International Monetary Fund, then converted to USD (IMF 2015).

# Results

## Study Participants

We conducted interviews with 77 fishers, each from different fishing boats, and with at least 1 year of experience using the gear type under discussion. Based on our estimates of the number of boats on the island, we spoke with representatives from over 25% of the roughly 300 small-scale fishing vessels based in Phu Quoc. Respondents ranged in age from 24 to 59 years old (39.1 ± 8 years; $n = 69$) and had spent 3 to 34 years (13.4 ± 8 years; $n = 74$) fishing off Phu Quoc using the same gear type. Only one respondent was female, reflecting the fact that very few females participated in active fishing; less than 1% of fishers we observed were women.

In addition to the fisher interviews, we conducted brief interviews with five seahorse buyers who had been purchasing seahorses for 6 to 20 years (10.9 ± 6, $n = 5$). Most fishers sold their catch to two or three buyers ($n = 24/39$), while the total number of buyers on Phu Quoc is likely around ten ($n = 15/39$).

## Description of Fisheries: Gear Types, Habitat, Target Species, and Effort

Fishers employed at least ten fishing gears in the waters surrounding Phu Quoc to catch a variety of species. We focused on five that caught seahorses regularly (Table 1): otter trawl nets ($n = 55$ fishers), compressor diving equipment ($n = 10$ fishers), crab nets ($n = 6$ fishers), beam trawl nets ($n = 4$ fishers), and pair trawl nets ($n = 2$ fishers). Working alone or in groups of up to 12, fishers operated motorized boats ranging in size from 6 to 20 m long (10.1 ± 4 m, $n = 71$). They fished in coastal substrates made up of sand, mud, seagrass, and coral reef up at depths up to 60 m (Table 1). When asked what they fished for, most fishers said they targeted particular species such as shrimp or squid, but some would keep whatever they caught ($n = 14/74$).

Fishing effort was very similar for otter trawls, beam trawls, divers, and crab nets, although we lack data for pair trawlers (Table 2). These gear types were deployed for similar number of days per month, with about 15–16 days minimum and 22–24 days maximum. There was no significant difference in the time fishers spent travelling to their fishing location ($F = 0.77$, $df = 4$, $P > 0.5$). For the time spent actively fishing, there was significant variation among gear types ($F = 16.23$, $df = 4$, $P < 0.05$). A post hoc Tukey test showed that the active fishing time of crab fishers and otter trawls were significant ($P < 0.05$), spending the longest time actively fishing (though crab fishers returned to shore while their nets remained deployed at sea). There was a significant difference in the fuel consumed by the different gear types ($F = 8.04$, $df = 4$, $P < 0.05$). Otter trawls consumed a significantly higher volume of fuel based on a post hoc Tukey test ($P < 0.05$).

## Seahorse Catches

All interview respondents caught seahorses, either incidentally ($n = 52/77$) or on purpose ($n = 25/77$). Those that caught them incidentally used otter trawls ($n = 36/52$), compressor diving equipment ($n = 8/52$), crab nets ($n = 6/52$), and pair trawls ($n = 2/52$). Those that included them in a list of species they targeted used otter trawls ($n = 19/25$), beam trawls ($n = 4/25$), and compressor diving equipment ($n = 2/25$). Fourteen fishers considered seahorses to comprise greater than 70% of their income ($n = 14/46$); four used beam trawls and ten used otter trawls. Most fishers made less than 30% of their income from seahorses ($n = 30/46$).

Seahorse catch rates were significantly different among fishing gears ($F = 10.13$, $df = 4$, $P < 0.05$, Fig. 2a; $F = 10.91$, $df = 4$, $P < 0.05$, Fig. 2b). Based on post hoc Tukey tests, seahorse CPUE was consistent amongst compressor divers, crab nets, and otter trawls that did not target seahorses ($P > 0.05$), while beam trawls and otter trawls that targeted seahorses had higher seahorse catch rates ($P < 0.05$).

**Table 1** Description of some of the fishing gears and boats used in Phu Quoc, Vietnam, based on interviews with local fishers. Targeted organisms and habitats are listed in order of most common to least common response

| Fishing gear | *N* | Targets | Gear description | Method of operation | Habitat | Depth | Mesh diameter | Boat | Number of crew |
|---|---|---|---|---|---|---|---|---|---|
| Otter trawl | 55 | Shrimp, finfish, squid, seahorses, octopus | Cone-shaped net consisting of a body made from 2 to 4 panels, closed by one codend and with lateral wings extending forward from the opening. Kept open horizontally by two otter boards and weighted with a metal chain. Towed from the stern of one boat. | Net dragged along the bottom as boat travels along the surface. Net hauled up and emptied 3–4 times per day. | Sand, mud, seagrass, small rocks | 3–40 m | 1–6 cm | 6-20 m long with 10–90 hp. engine | 1–5 |
| Pair trawl | 2 | All species including seahorses | As above, but larger net towed from the stern of two boats. | As above, but two boats operating. | Sand, mud, seagrass, small rocks | 2-60 m | 1–6 cm | 12-20 m long with 56–110 hp. engine | 7–12 |
| Beam trawl | 4 | Seahorses, shrimp, squid | Cone-shaped net, whose horizontal opening is provided by a 5-6 m long beam made of wood or metal. Towed from the stern of one boat. | The beam disturbs species on the ocean floor as the boat travels along the surface. Net hauled up and emptied 3–4 times per day. | Seagrass, sand, small rocks | 2-12 m | 2–3 cm | 6-10 m long with 15-22 hp. engine | 1–2 |
| Compressor (hookah) divers | 10 | Mollusks, grouper, crab, seahorses | Divers wear masks and weight belts and are supplied with air pumped from the ocean surface through a 300 m-long plastic hose held by the divers' teeth. | Collect organisms by hand and store them in mesh bags, return to the boat 2–3 times per day to empty bags and rest. | Coral reef, sand, small rocks, seagrass | 2-30 m | N/A | 6-10 m long with 8-24 hp. engine | 1–4 |
| Crab net | 6 | Swimming crab, mud crab | Stationary net 1-2 m high and 1-6 km long weighted with cement blocks. | Weighted nets left in the water and checked daily. | Sand, mud, small rocks | 2-30 m | 3–10 cm | 7-8 m long with 8–24 hp. engine | 2–3 |

**Table 2** Fishing effort of four fishing gears used in Phu Quoc, Vietnam, based on interviews with local fishers

| Fishing gear | Minimum number of fishing days (days/month ± S.D.) | Maximum number of fishing days (days/month ± S.D.) | Time spent travelling to fishing site (hours ± S.D.) | Active fishing time (hours ± S.D.) | Fuel use (L/day ± S.D.) |
|---|---|---|---|---|---|
| Otter trawl | 14.8 ± 6 (*n* = 24) | 24.2 ± 4 (*n* = 45) | 1.0 ± 0.6 (*n* = 33) | 10.2 ± 2 (*n* = 53) | 40.4 ± 29 (*n* = 52) |
| Beam trawl | 16.5 ± 9 (*n* = 2) | 24 ± 5 (*n* = 4) | 0.5 ± 0.3 (*n* = 4) | 7.3 ± 2 (*n* = 4) | 11.5 ± 2 (*n* = 4) |
| Compressor Diver | 15.5 ± 2 (*n* = 4) | 21.9 ± 5 (*n* = 8) | 1.25 ± 1.7 (*n* = 7) | 7.1 ± 1 (*n* = 9) | 10 ± 6 (*n* = 7) |
| Crab net | 16.3 ± 6 (*n* = 3) | 23.3 ± 4 (*n* = 4) | 1.0 ± 0.7 (*n* = 2) | 12.8 ± 2 (*n* = 6) | 10.2 ± 6 (*n* = 5) |

Fishers estimated the height of seahorses they caught by gesturing roughly with their hands. The mean height of seahorses reportedly caught did not vary by gear type (though the sample sizes for pair trawls were not large enough to include in this analysis). There was no significant difference in the height of seahorses caught by fishers using beam trawls, otter trawls, compressor diving equipment, or crab nets (Fig. 3, F = 0.87, df = 4, $P > 0.05$).

Fishers reported seasonal variations in fishing effort and seahorse catch. During monsoon season, most fishers reported fishing fewer days than in dry season due to rough conditions (*n* = 23/33). Despite these distinct wet and dry seasons, there was no clear high and low season for seahorse catch. Some fishers reported a high season from February to March (*n* = 23/50), while others reported a high season from May to June (*n* = 17/50). There was also no agreement on a low season; responses spanned all months.

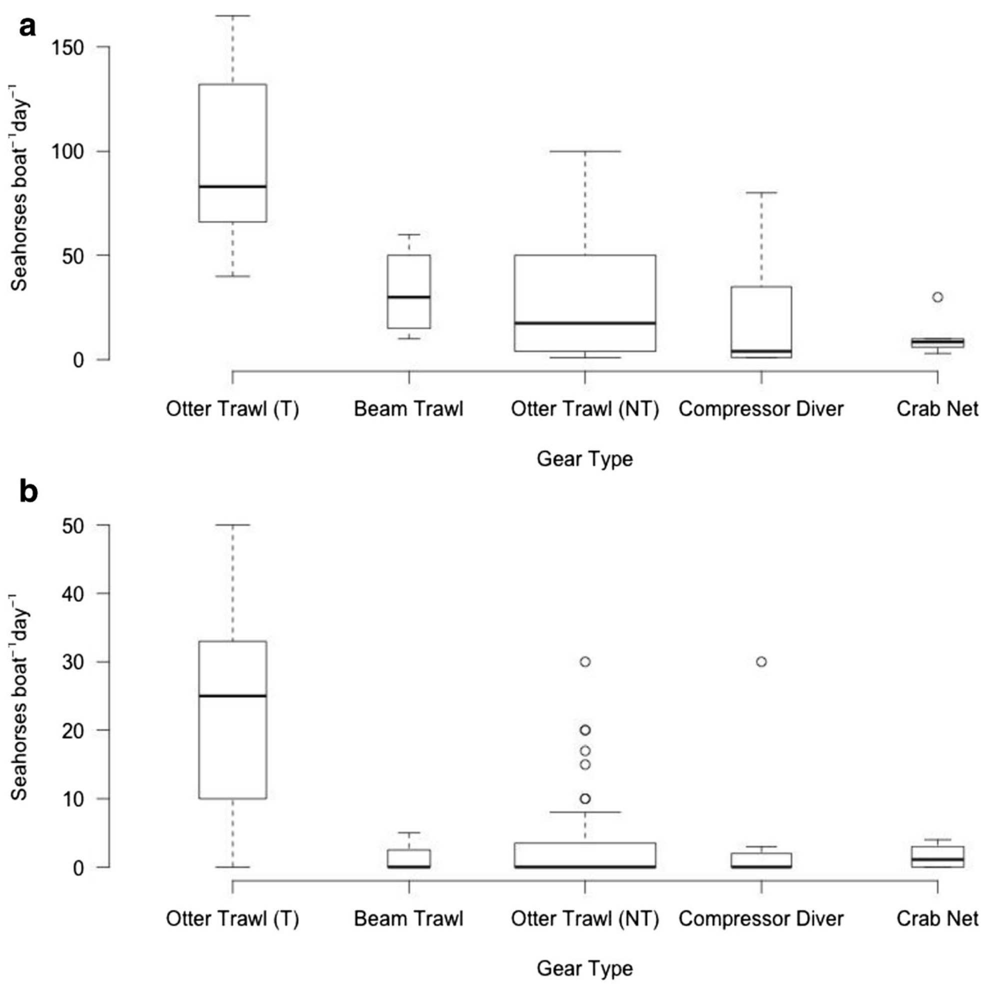


**Fig. 2** *A. maximum* CPUE estimated by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets in Phu Quoc, Vietnam. Width of boxplots is proportional to sample size (*n* = fishers interviewed). Median number of seahorses caught per boat per day by target otter trawls = 83, *n* = 10; beam trawls = 30, *n* = 4; non-target otter trawls = 17.5, *n* = 44; compressor divers = 4, *n* = 8, crab nets = 8.5, *n* = 6. Width of boxplots is proportional to sample size. *b*. Minimum CPUE estimated by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets in Phu Quoc, Vietnam. Median number of seahorses caught per boat per day by target otter trawls = 25, *n* = 10; beam trawls = 0, *n* = 4; non-target otter trawls = 0, *n* = 44; compressor divers = 0, *n* = 8, crab nets = 1.1, *n* = 6. Width of boxplots is proportional to sample size

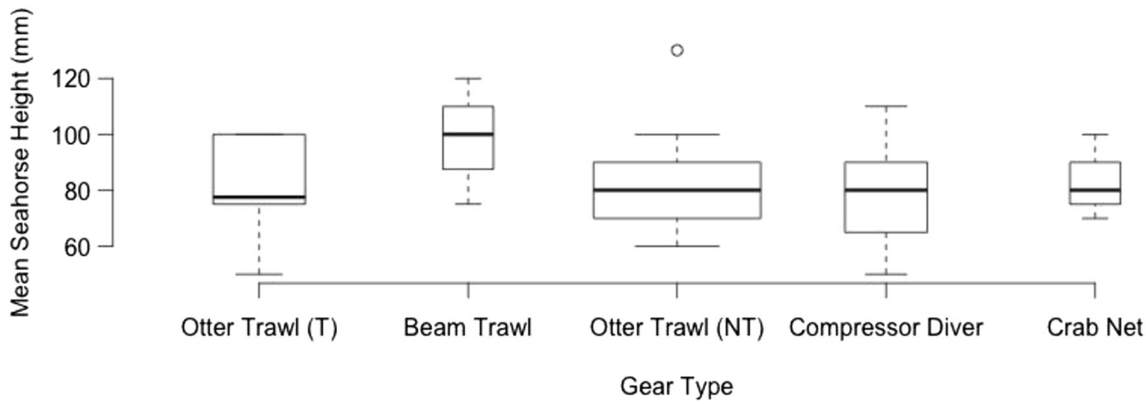


**Fig. 3** Estimated mean height of seahorses caught by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets in Phu Quoc, Vietnam. Median of mean seahorse height for target otter trawls = 77.5, $n = 10$; beam trawls = 100, $n = 3$; non-target otter trawls = 80, $n = 33$; compressor divers = 80, $n = 8$, crab nets = 80, $n = 3$. Width of boxplots is proportional to sample size

## Value of Seahorses

Fishers described catching many different types of seahorses: spiny, smooth, black, yellow, white, and "buffalo," the local name for *Hippocampus kuda*. When fishers caught seahorses, they would only throw them back in the water if they were still alive and too small to be sold ($n = 35/67$), usually judged to be less than 30 mm ($n = 23/35$). Many fishers, however, would keep seahorses regardless of their size to give as gifts or to make seahorse "wine" by combining them with alcohol ($n = 32/67$).

Nearly half of fishers attempted to keep seahorses alive on the boat ($n = 27/57$) by storing them in buckets filled with seawater and either switching the water regularly ($n = 11/27$) or using a small battery powered aerator to keep the water oxygenated ($n = 16/27$). Other fishers left the seahorses to dry in the sun ($n = 14/57$) or put them directly on ice ($n = 22/57$). Once landed, fishers sold seahorses ($n = 64/67$) and/or kept them for personal use or gifts ($n = 32/67$). Fishers were aware of the value of seahorses and had been selling them for between 2 and 20 years (mean 8.6 ± 5 years, $n = 48$).

Fishers reported a range of landed prices of seahorses from April to July 2014. Live seahorses were most valuable at 1.4–2.3 USD per seahorse ($n = 23$) while fresh dead seahorses sold for 0.8–1.1 USD per seahorse ($n = 21$). Dried seahorses sold for 0.5–1.8 USD per seahorse ($n = 11$).

## Changes over Time

Fishers reported declines in seahorse CPUE, decreased mean height of seahorses, and increased ex-vessel price from 2004 to 2014. Seahorse CPUE reported from 2004 onward suggests a yearly decline of 10 seahorses boat$^{-1}$ day$^{-1}$ for minimums and 27 seahorses boat$^{-1}$ day$^{-1}$ for maximums (Fig. 4). This suggests a cumulative decline of 95% from 2004 to 2014 based on minimum CPUE ($r^2 = 0.39$, $P < 0.05$) and 86% based on maximum CPUE ($r^2 = 0.16$, $P < 0.05$). When asked whether they noticed a change in the body size of seahorses being caught over the past 10 years, most fishers said no ($n = 34/40$), although the rest noted that they had decreased in size ($n = 6/40$). Fishers reported an exponential increase in the ex-vessel price of live seahorses from $44 USD per kilogram of live seahorses in 2004 to $279 USD in 2014 ($r^2 = 0.72$, $P < 0.05$, Fig. 5).

## Perceptions of Sustainability

Most respondents were concerned about the future of the fishery, with 63% alluding to a fishery that was not sustainable ($n = 35/56$). We did not define sustainability explicitly, but asked fishers to consider the future of catching seahorses and the factors driving this future About half of those that suggested the fishery was unsustainable reflected on changes in seahorse numbers; 54% cited drastic declines in catch ($n = 19/35$). Fishers blamed too many boats fishing ($n = 5/26$), destructive trawling ($n = 4/26$), catching small and/or pregnant seahorses ($n = 2/26$), and the long life cycle of seahorses ($n = 1/26$) as reasons for perceived declines. Thirty-seven percent of fishers reported that seahorse fishing was sustainable ($n = 21/56$). About half of those considered the fishery to be sustainable in economic terms; 12 fishers thought it was sustainable because they could still make a profit from seahorses (mostly from increasing prices as supply dwindled; $n = 12/17$). Others suggested that seahorse fishing was sustainable because seahorses have many young ($n = 3$), grow quickly ($n = 2$), it's impossible to catch them all ($n = 2$), and they can't go extinct ($n = 2$).

We asked fishers what could be done to improve the future of fishing where they operate. Sixteen fishers responded to this question, and suggestions included the following: placing a moratorium on trawl fishing and rake fishing ($n = 5/16$); throwing back small or pregnant seahorses ($n = 4/16$); increasing the production of seahorses through aquaculture ($n = 3/16$); creating no-fishing zones ($n = 3/16$); encouraging the use

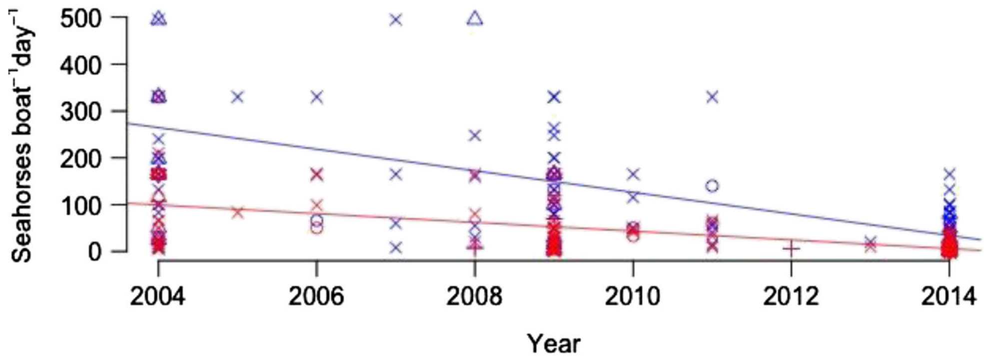


**Fig. 4** Declines in seahorse CPUE from 2004 to 2014 as reported by fishers from Phu Quoc, Vietnam. Estimates of maximum past catches in blue ($y = -23.12x + 46{,}600.34$; $r^2 = 0.16$, $P < 0.05$), estimates of minimum past catches in red ($y = -9.392 + 18{,}920.545$, $r^2 = 0.39$, $P < 0.05$). Symbols indicate gear type (triangle: compressor divers, plus: crab nets, cross: otter trawl, circle: beam trawl); not all data points are displayed, as maximum estimates were as high as 1600 seahorses per boat per day

of large mesh sizes ($n = 1/16$); or enforcing seasonal closures of all fisheries ($n = 1/16$). One fisher mentioned that he'd like to leave behind pregnant males, but knew that if he did, another boat would catch them. Two fishers stated that, even if the government tried to ban seahorse fishing, it could not monitor the whole island and fishing would continue.

## Seahorse Supply Chain and Sustainability According to Buyers

Once obtained from fishers, buyers sold live seahorses to vendors at the market in Ham Ninh where seahorses were kept in tanks to be sold to Vietnamese tourists. Dead seahorses were sent to the mainland (either to Ham Ninh or Rach Gia if still fresh; or Ho Chi Minh or Hai Phong if dried), from where they would eventually be sent to China. Some buyers operated opportunistically, only purchasing seahorses during peak months of local tourism, when demand for seahorse products was high. Others, however, bought seahorses year-round and consistently sent bags of hundreds of dried seahorses to mainland Vietnam.

Buyers noted changes in the number and size of seahorses they had purchased over the past 10 years. During the interview period, each buyer purchased seahorses from about 1–6 boats on a daily or weekly basis ($n = 5$). In 2004, they would buy from up to 20 boats daily ($n = 3$). Five years ago, they would purchase 2–10 kg of fresh seahorses per day, to a maximum of 100 kg in 1 day, according to one major buyer. Now they can obtain less than 1 kg of seahorses per day ($n = 4$). Only one buyer commented on the change in height of

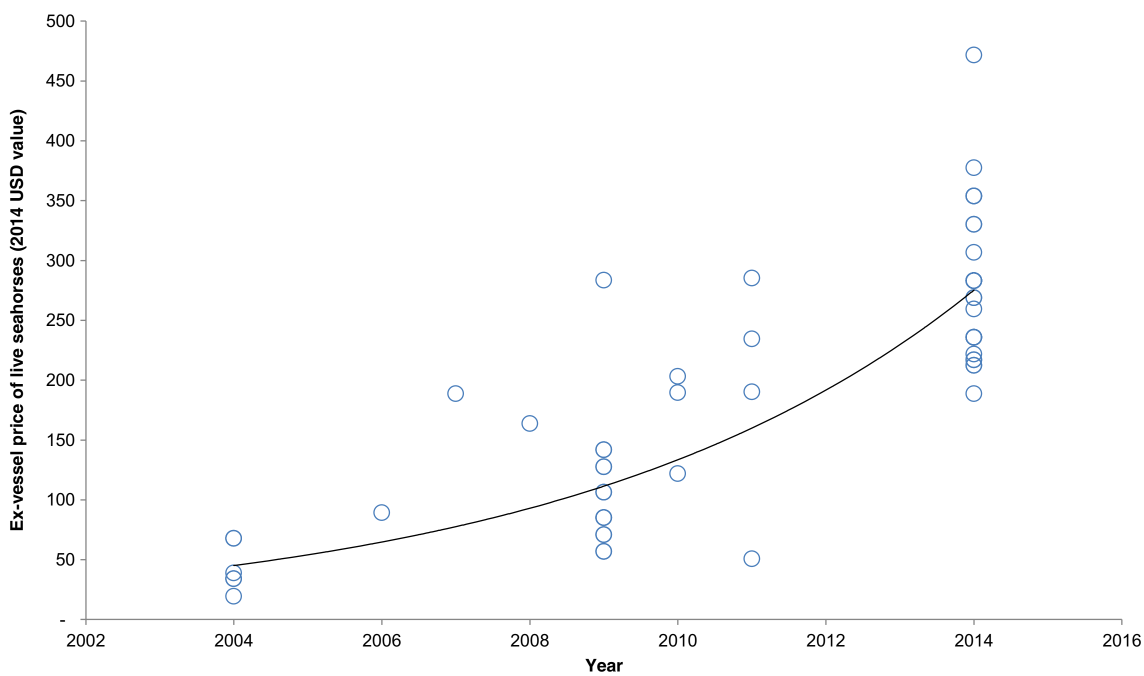


**Fig. 5** Increase in ex-vessel price of live seahorses from 2004 to 2014 as reported by fishers from Phu Quoc, Vietnam, adjusted for inflation. $y = 2\text{E-}156e^{0.1808x}$, $R^2 = 0.72$, $P < 0.05$

seahorses. He noted that seahorses >12 cm used to constitute 90% of his trade 10 years ago, 70% of his trade 5 years ago, and only 50% of his trade now. The two buyers who responded to our question about sustainability felt that seahorse fishing was unsustainable and suggested protecting a spawning area.

## Discussion

Our study revealed that while most Phu Quoc fishers catch seahorses incidentally, some have made the transition to deliberately targeting seahorses using otter trawls and beam trawls. All told, fishers in the region used five different gears (both indiscriminate and targeted) to catch seahorses at rates of 1–90 seahorses per boat per day. Reported declines in catch rates of up to 95% between 2004 and 2014, together with a 534% increase in ex-vessel price of seahorses, suggest unsustainable levels of exploitation. While fish stocks commonly decline under fishing pressure, aspects of seahorse life history (e.g., intense male parental care, long-term pair bonding, and site fidelity) mean that these fishes are particularly vulnerable to high levels of exploitation (Foster and Vincent 2004; Lawson *et al.* 2014). Vietnam is the world's leading reported exporter of live wild seahorses (UNEP-WCMC 2014) yet seahorses are also consumed domestically and exported illegally, both to an extent that is not fully appreciated (Foster *et al.* 2017). Add in the persistent global demand for seahorses and it is clear that these fishes are still much sought after, and their fisheries and trades must be well regulated and managed.

Ours is a rare example where active gears – specifically beam and otter trawls – are deliberately employed to catch seahorses, resulting in higher catch rates than documented for other Southeast Asian seahorse fisheries (Lawson *et al.* 2017). Many gear types throughout the world catch seahorses incidentally, with most caught by destructive gears such as bottom trawls (Vincent *et al.* 2011; Lawson *et al.* 2017). Targeted seahorse fishing is well documented only in the Philippines, where seahorses are caught by hand along with many other species (Vincent *et al.* 2007). Targeted seahorse fishing using trawl nets was historically noted in Thailand and Malaysia but these fisheries were not analyzed quantitatively (Perry *et al.* 2010), nor documented in more recent surveys of Thailand (Kuo *et al.* 2018). Fishers in our study reported mean catch rates near Phu Quoc that were three times higher than reported for other parts of Asia, where documented seahorse catch rates ranged from 0.1 to 10 seahorses $boat^{-1}$ $day^{-1}$ (Salin and Yohannan 2005; Giles *et al.* 2006; Meeuwig *et al.* 2006; Vincent *et al.* 2007; Perry *et al.* 2010). Obtaining information on the existence and nature of other seahorse target fisheries will improve our understanding of the global nature of seahorse fishing.

Fisher interviews provided a reasonable estimate of some seahorse fishing parameters – CPUE and seahorse size, in particular – indicating their utility to generate information for conservation and fisheries management purposes. According to actual fisheries landings in the Phu Quoc area (Ut and Tam 2012; Stocks *et al.* 2017), mean CPUE was very similar to the minimum catch range reported by Phu Quoc fishers in our study (though the maximum catches reported by fishers are not unheard of; landings of over 80 seahorses $boat^{-1}$ $day^{-1}$ have been recorded in the area (Stocks *et al.* 2017)). Based on the comparison to landings data, minimum catches reported by fishers may be a reasonable estimate for average landings; similar to what has been documented in other seahorse fisheries (O'Donnell *et al.* 2012). Fishers' estimates of general seahorse height were below the 10 cm recommended minimum size limit (CITES 2004), but landings surveys conducted on Phu Quoc found median seahorse height to be between 10 and 13 cm (Stocks *et al.* 2017), and most fish caught were mature. These findings suggest that fisher interviews, when interpreted cautiously, might provide useful information for conservation purposes, especially for developing precautionary fisheries management where data are limited, such as in this case of seahorse fisheries. Nevertheless, consistent monitoring is needed to better determine the accuracy of fishers' estimates.

The declines in seahorse CPUE reported in our study – of about 90% over 2004 to 2014 – echo the magnitude of decline documented in recent trade surveys across Vietnam (Foster *et al.* 2017) and other investigations of historical seahorse fishing (Pajaro *et al.* 1997; Giles *et al.* 2006; Ut and Tam 2012). Other studies of seahorse fishing have shown stable CPUE, albeit perhaps after previous declines (Meeuwig *et al.* 2006; O'Donnell *et al.* 2012). While fluctuations in CPUE are expected in a fishery, significant reductions can indicate declining population health and fisheries sustainability (Harley *et al.* 2001).

The fisher-reported trend in seahorse catches indicates a need for precautionary conservation of seahorse populations in Vietnam, but also the need for robust catch monitoring systems to confirm the ongoing rate and magnitude of the reported decline. Previous studies have documented that fisher interviews are reliable for discerning trends but that fishers' recall is seldom entirely accurate (Tesfamichael *et al.* 2014). For seahorses specifically, some fishers in the central Philippines reported CPUE values that were double the actual values (O'Donnell *et al.* 2012). Changes in the size of the Phu Quoc fishing fleet would also influence the true magnitude of decline in seahorse catch rates. The number of vessels operating in the area appears not to have changed according to available data (Department of Capture Fisheries & Resource Exploitation and Protection, unpublished data), although undocumented and/or illegal fishing may be occurring and could potentially account for some of this decline in CPUE. Finally, changes in seahorse size and species composition from 2004 to 2014 would have affected our calculation of changes in CPUE. Taken together, these factors introduce uncertainty around the specific magnitude and rate of population decline over time, but the trend itself suggests a situation of great conservation concern.

The decrease in seahorse catch rates and increase in ex-vessel price reported by fishers indicate a fishery where demand outstrips supply. The demand for traditional Chinese medicine (TCM) has increased with growing human population and rising affluence (Chen *et al.* 2007; Lin *et al.* 2018), placing higher pressure on rare species used medicinally (Still 2003). As the demand for seahorses rises, many areas where seahorses are caught have experienced similar declines in catch (Pajaro *et al.* 1997; Giles *et al.* 2006). Fishers on Phu Quoc have identified that seahorse fishing is increasingly unsustainable, yet many will continue to fish these vulnerable species until they are gone. These fishers are aware of the high demand and high price for seahorses, and rely on them – in some cases completely – for their livelihoods. Curbing the national and international demand for seahorses might influence the fishers that target seahorses, but would not change the fate of seahorses captured incidentally (i.e., in trawl nets). Increased efforts are required to improve the sustainability of all seahorse-fishing methods.

This study gives plenty of warnings that the Phu Quoc exploitation of seahorses is probably unsustainable, and that management is urgently needed. In order to reduce pressure on seahorse populations, management will be required for both fishers targeting seahorses and those catching them incidentally. Management interventions may be more straightforward for targeted fisheries, but is also necessary to reduce the cumulative impact of the large trawl fleet, which is consistently catching seahorses while simultaneously destroying habitat (Stocks *et al.* 2017; Foster *et al.* 2018). Current management in the Phu Quoc area (for all fisheries and not for seahorses in particular) includes occasional surveys at major ports by border guards and fisheries surveillance officers, and two minimally enforced marine reserves located on the northeastern and southern side of the islands. It is essential that the marine reserves, at least, be well implemented and respected but seahorses and other species would also benefit from reductions in effort, whether seasonally or permanently (Foster and Vincent 2016). Any such measures will need to be developed with fishers if there is to be co-operation and compliance (Pomeroy and Berkes 1997; Pomeroy *et al.* 2007).

Our study findings contribute to the overall effort to ensure sustainable seahorse fisheries and trade in Vietnam. Under CITES, Vietnam remains responsible for ensuring any exports of the six species found in national waters (*Hippocampus comes*, *H. histrix*, *H. kelloggi*, *H. mohnikei*, *H. spinosissimus*, and *H. trimaculatu;* Giles *et al.* 2006) are legal and do not damage wild populations. In that context, it must establish long term monitoring of CPUE for all seahorse species at various sentinel locations in Vietnam, with Phu Quoc being among the foremost. Only then can the country demonstrate the efficacy of its fisheries and trade management and move toward reinstating legal seahorse exports under the CITES framework. We would hope that such efforts to track seahorse CPUE will be in the context of more comprehensive monitoring of small species in bycatch and small-scale target fisheries. Seahorses are certainly not the only species at risk even if they are the only species in small-scale fisheries in Vietnam to enjoy CITES support.

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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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