Fisheries Research 196 (2017) 27–33

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Short communication

Catch as catch can: Targeted and indiscriminate small-scale fishing of seahorses in Vietnam

Allison P. Stocks[a,*], Sarah J. Foster[a], Nguyen K. Bat[b], Amanda C.J. Vincent[a]

[a] Project Seahorse, Institute for the Oceans and Fisheries, The University of British Columbia, 2202 Main Mall, Vancouver, BC, V6T 1Z4, Canada
[b] Research Institute for Marine Fisheries, 224 Lelai, Ngoquyen, Haiphong, Viet Nam

ARTICLE INFO

Handled by B Arara

Keywords:
Compressor diving
Trawl
Hippocampus
Target
Bycatch
Catch-per-unit-effort

ABSTRACT

Serial depletions and the use of indiscriminate gears have led to increased fishing pressure on many previously untargeted species. A largely unregulated global extraction of seahorses (*Hippocampus* spp.) has emerged, of which Vietnam is one of the main sources. Quantifying this extraction is a major empirical and enforcement challenge. Using catch landings surveys of small-scale fishing boats, we determined the fishing pressure on seahorse populations around Phu Quoc Island – a major source of seahorses in Vietnam's trade – from April to July 2014. We focused on two fishing methods, bottom trawling and compressor diving, that either targeted seahorses or caught them incidentally along with a multitude of other species. The seahorse catch consisted of three species – *H. kuda, H. spinosissimus* and *H. trimaculatus* – with relative proportions varying by gear type and fishing ground. Fishers that targeted seahorses caught mean rates of 23 and 32 seahorses per boat per day by bottom trawling and diving, respectively. Trawls and divers that did not target seahorses caught mean rates of 1 and 3 seahorses per day respectively, and caught higher proportions of juvenile seahorses. The total catch from the island was approximately 127,000–269,000 seahorses per year from a fleet of 124 trawl boats and 46 compressor diver vessels. This is up to four times higher than the catch of similarly sized fisheries that obtain seahorses and is likely placing high pressure on local seahorse populations. Our research emphasizes the need to monitor these fisheries and develop effective management efforts for sustainable seahorse populations.

1. Introduction

Seahorses (genus *Hippocampus*) are economically valuable species that are readily extracted by fishers using many gears (Vincent et al., 2011; Lawson et al., 2017). Inhabiting mostly shallow, tropical and temperate waters, seahorses are easily accessible to inshore fisheries (Foster and Vincent, 2004). Used predominantly in traditional medicine, aquarium displays and curiosity shops, millions of seahorses are caught and traded globally each year (Vincent et al., 2011). Certain fishers target seahorses directly – mostly by hand – as in India, Malaysia, Thailand, Brazil, and the Philippines (Marichamy and Lipton, 1993; Rosa et al., 2005, 2011; Vincent et al., 2007; Perry et al., 2010). However, the majority of seahorses are caught as bycatch in non-selective gears such as trawl nets and purse seines (Lawson et al., 2017). Fishers worldwide have reported declines in seahorse populations (Vincent et al., 2011), and this global exploitation is considered unsustainable and in need of informed management. In addition to the livelihood they provide, seahorses are important predators on bottom-dwelling organisms and have an extraordinary life history wherein the male becomes pregnant (Foster and Vincent, 2004). Seahorses are particularly susceptible to overfishing, habitat loss, and other human pressures due to their extreme parental care (Foster and Vincent, 2004).

Complex and largely unmonitored multi-gear fisheries, like those for seahorses, require a suite of complementary tools to ensure their sustainability. These include typical fisheries management measures (e.g. seasonal closures, minimum size limits), the impetus for which may be enhanced by multilateral environmental agreements (Vincent et al., 2013). All seahorse species were added to Appendix II of Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) in 2002, which requires the 182 signatory countries to ensure that their exports are legally acquired and do not damage wild populations. Such responsibilities require that member countries make non-detriment findings (NDFs), which amount to adaptive management plans for the sustainable exploitation of wild populations (Rosser and Haywood, 2002; Foster and Vincent, 2016). Suggested management options for seahorse fisheries include minimum size limits, spatial restrictions on trawling, and fully protected areas, inter alia (Foster and Vincent, 2016). Getting started with NDFs requires a basic

* Corresponding author.
E-mail address: ally.stocks@gmail.com (A.P. Stocks).

http://dx.doi.org/10.1016/j.fishres.2017.07.021
Received 15 December 2016; Received in revised form 15 July 2017; Accepted 22 July 2017

understanding of wild seahorse populations or fisheries, starting with an understanding of the pressures facing seahorse populations (Foster and Vincent, 2016).

In Vietnam, seahorses are caught in vast quantities for global export and domestic consumption, but this extraction is not regulated (Giles et al., 2006). According to CITES reports, the number of seahorses exported from Vietnam per year was between 20,000 and 90,000 for the years 2004 through 2011 (UNEP-WCMC, 2012). This is likely an underestimation – historic data from pre-CITES trade surveys in Vietnam suggested 2.2 million seahorses were caught annually in trawl bycatch from just five of Vietnam's 29 coastal provinces (Giles et al., 2006), and CITES data are known to suffer from errors and/or omissions (e.g. Foster et al., 2016). Not only are seahorses exported in vast quantities, but they are also consumed within Vietnam as tonics to promote kidney health and increase sexual potency (Giles et al., 2006). Survey data of seahorse fisheries in Vietnam are out of date, and may have underestimated seahorse catch volumes by focusing on just one type of gear that caught seahorses incidentally.

There is evidence that the exploitation of seahorses is causing declines in wild populations in Vietnam (Long and Van Hoang, 1998; Giles et al., 2006), of up to 95% (Stocks, 2015). Despite these declines, Vietnam has no official management measures in place to regulate seahorse exploitation. The consequence of Vietnam's lack of data and of capacity was a decision by CITES to suspend all trade of one species (*Hippocampus kuda*) from Vietnam as of March 2013 (CITES, 2013). This is the first export ban ever imposed for any fully marine fish species under a multilateral environmental agreement. It highlights an urgent need to collect fisheries and biological data in Vietnam since *H. kuda* may still be traded domestically, and all other seahorse species in Vietnam may still be traded domestically and internationally.

A region in southern Vietnam reported as a hot spot for seahorse fisheries (Ut and Tam, 2012) was chosen for an in-depth study of different fishing strategies and how they affect seahorses. The objectives of this study were to: 1) quantify the rate of seahorse extraction by various fishing gears standardized to effort; 2) identify the seahorse species caught and their life history states; 3) determine the overall seahorse catch; 4) evaluate an indicator of fisheries sustainability; and 5) evaluate the utility of the CITES recommended 10 cm size limit as one component of an adaptive management plan for seahorse fisheries in southern Vietnam.

2. Materials and methods

2.1. Study site

The location of this study was the Phu Quoc District, Vietnam, in the Gulf of Thailand (from 9.45 −10.30° N to 103.55–104.05° E, Fig. 1). In a large study of Vietnamese seahorse bycatch and trade, Kien Giang province in South Western Vietnam was shown to have the highest seahorse catch rates in the country (Giles et al., 2006). Within this region, anecdotal fishing reports identified Phu Quoc as an area where seahorses were caught in multiple fishing gears. It is also an area of conservation concern, with fishers noting declines of up to 95% in seahorse catch between 2004 and 2014, despite reportedly consistent effort (Stocks, 2015). The area collectively known as Phu Quoc contains Vietnam's largest island, Phu Quoc Island, and 21 smaller islets known as the An Thoi Islands (land area: 593 km^2). Fishing grounds between the island and the mainland are greater than 5000 km^2. Maximum water depth to the east of Phu Quoc is approximately 10 m and the substrate is predominantly soft-bottom (sand or mud) and seagrass (Otero-Villanueva et al., 2007). The north and east coasts of Phu Quoc Island face inshore to mainland Cambodia (within 10 km) and Vietnam (40 km), while the west coast and southern An Thoi islands are more exposed to the Gulf of Thailand.

Surveys were focused on ports along the east coast of Phu Quoc, where fishers operated in shallow (mostly < 10 m deep) fishing grounds and caught seahorses. Fishing grounds were grouped into three regions: north, central, and south (Fig. 1). Each area contained one large, government-operated port, as well as many smaller fishing villages or beaches where seahorses were landed. The northern region, closest to Cambodia, was characterized by sandy, soft-bottom habitat and occasional reefs. The central region contained soft-bottom habitat and patchy seagrass beds. The southern region contained the 13 smaller An Thoi islands, surrounded by reefs and sandy bottom. The northern and southern regions contain designated marine protected areas (MPAs) (Fig. 1). Fishing activity is prohibited within the MPA core zones, and should be regulated in the buffer zones, but enforcement of the MPAs is extremely limited and unregulated fishing still occurs.

2.2. Fisheries-dependent surveys

From April to July 2014, catches were surveyed for *Hippocampus* spp. at nine landing sites along the east coast of the islands (Fig. 1): six were small fishing villages or beaches and three were large, government-operated ports. The local fishing fleet used a variety of gear types including compressor diving equipment, trawl nets, crab nets, hook and line, gill nets, and purse seines. While all gear types caught seahorses at least occasionally, we focused on compressor divers and bottom trawlers, gear types that regularly catch and land higher volumes of seahorses (Stocks, 2015). Compressor 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, collecting organisms by hand. The bottom trawlers operate 6–12 m boats with up to 60HP engines, and drag single nets along the ocean floor that are kept open either by otter boards (otter trawls) or a 5–6 m long wooden or metal beam (beam trawls). These fishing gears were then categorized by whether they targeted seahorses or caught them incidentally (referred to hereafter as: targeted divers, indiscriminate divers, target trawls, and indiscriminate trawls).

Sites were visited in the mornings and evenings on a near daily-basis in order to record catch from boats that fished at night or during the day. Landings were sampled from a total of 305 fishing trips (and about 100 different boats); 134 trips used compressor diving gear and 171 used trawl gear. The spatial distribution of sampled fishing trips across gear types was as follows (for targeted dive, indiscriminate dive, target trawl, and indiscriminate trawl, respectively): northern region: 2, 61, 9, 73; central region: 13, 54, 20, 37; southern region: 0, 4, 13, 13. Sampling was opportunistic and did not necessarily reflect actual fishing effort at each site, but this was accounted for in analyses.

For each fishing trip documented for this study, fishers were asked for information regarding fishing effort (gear type, trip length, active fishing time, distance from shore, fishing depth, and fuel use), location, and bottom habitat. When seahorses were landed the total number of individuals and/or total mass of the catch was recorded; only mass was recorded for live seahorses. Whenever fishers allowed, the species, sex, height, mass, and reproductive state of each seahorse in the landings were recorded. Seahorses were identified using standard seahorse taxonomy (Lourie et al., 2004). Seahorse height was measured as the length from the tip of the coronet to the tip of the outstretched tail (Lourie et al., 1999). Male seahorses were identified by the presence of a brood pouch or, for juvenile males, the presence of a darkened oval zone where a brood pouch was developing; females were identified by the lack of such features or by the presence of an ovipositor (Boisseau, 1967). Males were considered mature where the brood pouch was distended or recently emptied (Vincent, 1994). Females were assumed to mature at the same size as males, as female maturity state can only be determined by dissecting ovaries in freshly dead or preserved specimens (Foster and Vincent, 2004).

2.3. Data analyses: fisheries catch and effort

All catch analyses were carried out using number of individual

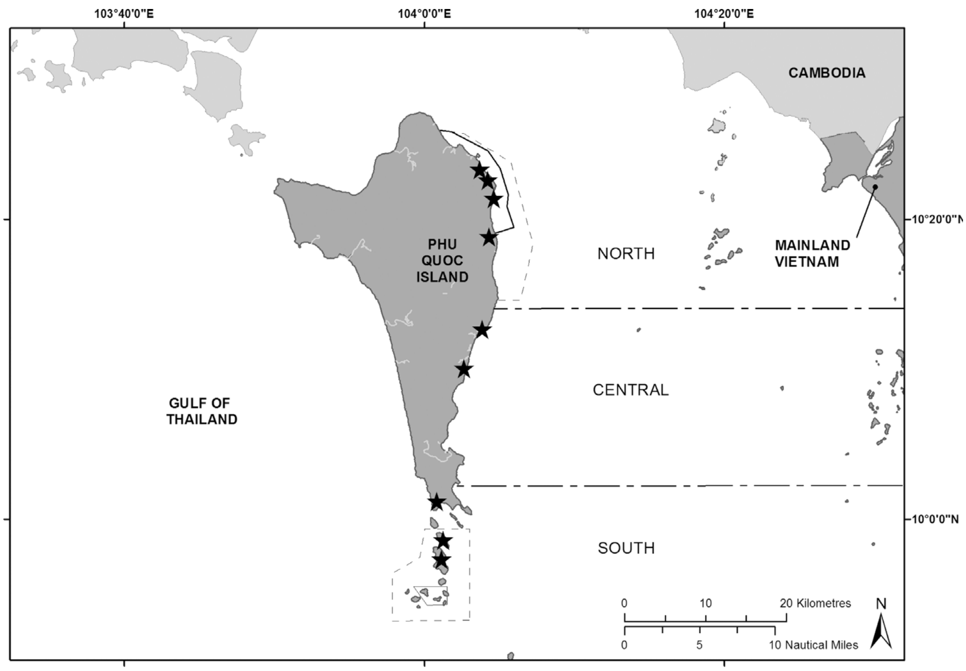

Fig. 1. Map of study location in southern Vietnam showing Phu Quoc Island and the thirteen An Thoi Islands, as well as mainland Vietnam (dark grey) and Cambodia (light grey). Stars indicate sites sampled for fisheries data (from north to south): Xa Luc, Bai No, Da Chong, Bai Bon, Ham Ninh port, Ham Ninh village, An Thoi, Hon Thom, and Hon Roi. The area contains two MPAs; solid lines denote areas designated for full protection, dashed lines denote the designated buffer zone around the protected areas. Dot-dash lines denote fishing areas (north, central, and south).

seahorses. For nearly all catch landings, both the total number and total mass of the seahorse catch were recorded. These data were used to calculate a conversion from mass to number of individuals, using a general linear model. This conversion was subsequently used to convert kilograms of seahorses to number of individuals for catches where only mass was recorded.

Landings and trip durations were used to calculate seahorse catch per unit effort (CPUE); measures of effort were compared using generalized linear models to study their influence on catch rates at sites for each gear. Analysis of variance (ANOVA) tests were used to examine mean CPUE by fishery and fishing location (data met assumptions of ANOVA tests for normality of errors and equal variance). Where ANOVA results were significant, we used post hoc group comparisons (Tukey Honest Significant Differences) to determine which pairs were significantly different.

Total annual seahorse catch was estimated by multiplying mean CPUE of each fishery (pooled for the entire study area) by the number of boats reportedly operating each gear type (DECAFIREP, 2015) and a measure of annual vessel effort based on weather, rest days and gear rotation (150 fishing days per year for divers and 200 for trawlers; Stocks, 2015). Total annual catch was also calculated for each fishing location, using mean CPUE of each fishery specific to that location, extrapolated by the fleet size operating in that area and the same measures of fishing effort. All statistical analyses were carried out in the R statistical platform (R Development Core Team; www.r-project.org).

2.3.1. Catch composition, seahorse maturity and height

A grouped chi-squared test was used to determine whether the proportion of each species caught varied by gear type and location. These proportions were then scaled to total annual landings.

Most seahorses were collected directly from catch landings (85%, $n = 1319$). Supplementary specimens were collected from buyers at their market stalls, or from fishers' seahorse collections at home ($n = 227$), but were only used to calculate species height at maturity (see below). Nearly all seahorses were measured by hand, but a few specimens were photographed and digitally measured using ImageJ (U. S. National Institutes of Health, Bethesda, Maryland, USA). All digitally measured heights (DMH) were converted to hand-measured heights (HMH) using a conversion of $\text{HMH} = 2.1869(\text{DMH})^{\wedge 0.8297}$ (Stocks, 2015). After mathematical conversion, digitally measured sample heights were not significantly different from hand-measured sample heights (Mann–Whitney U-test for *H. spinosissimus*: $W = 2724$, $p = 0.23$; *H. trimaculatus*: $W = 1846$, $p = 0.21$). There was no significant difference in mean height between dry and wet samples (Mann–Whitney U-test for *H. spinosissimus*: $W = 17\,428$, $p = 0.61$; *H. trimaculatus*: $W = 10\,014$, $p = 0.06$) so all samples were pooled in subsequent analysis.

Height at physical maturity (H_M), the point at which 50% of male seahorses are reproductively mature (but not necessarily reproductively active – see Lawson et al., 2014), was determined by fitting a general linear model to a binary classification of males as immature (0) or mature (1) and calculating the inflection point. Using this modeled H_M for each species, fish were assigned to juvenile or adult in order to calculate the sex ratio (the number of mature males to the number of mature females of a species). A chi-square test was used to identify if the ratios were significantly different from unity for each fishery.

The indicator of catch sustainability used in this study was the proportion of the catch that was less than H_M (Froese, 2004), which was calculated for each species and each fishery. Finally, the H_M for each species was compared to 10 cm in order to determine the biological protection conferred by the CITES recommended 10 cm MSL (CITES, 2004), and the proportion of seahorse catch by divers or trawlers below 10 cm was calculated to assess how the size limit would reduce catches if enforced.

3. Results

3.1. Description of fisheries

An estimated 124 bottom trawl boats and 46 compressor diving boats operated from the islands and regularly caught seahorses. Of this total, six dive boats and 24 trawl boats (a mix of otter and beam trawls) sought out seahorses specifically. Most boats, however, fished indiscriminately (40 dive boats and 100 trawl boats), not targeting anything specifically, but catching seahorses along with a vast number of other species. Divers that targeted seahorses fished in areas that were sandy or a mix of sand and debris. Trawl boats that targeted seahorses operated closer to shore in seagrass beds and sandy-coarse substrate. Divers that did not target seahorses fished in areas of sand or coral reef, while trawls that fished indiscriminately operated in open, sandy areas.

Table 1
Mean catch-per-unit-effort of seahorses ± standard error (seahorses boat^{-1} day^{-1}) and estimated total landings per annum for the trawl and compressor diver fishing fleets of Phu Quoc Island, Vietnam. n = number of fishing trips sampled.

Fishery	n	Mean CPUE (± S.E.)	Fleet Size*	Estimated fishing days per annum*	Annual landings (seahorses year^{-1})		
					Mean	Lower 95% CI	Upper 95% CI
Target divers	15	31.8 (± 5.6)	6	150	28,620	18,742	38,498
Indiscriminate divers	117	1.3 (± 0.2)	40	150	7800	5448	10,152
Target trawls	42	23.3 (± 2.9)	24	200	111,840	84,557	139,123
Indiscriminate trawls	123	2.5 (± 0.8)	100	200	50,000	18,640	81,360
				Total	**198,260**	**127,386**	**269,134**

* Estimates of fleet size and number of days fished are based on interviews with fishers in communities across Phu Quoc Island (Stocks, 2015) and consultations with Vietnamese fisheries officials.

3.2. Catch per unit effort (CPUE)

Fishing trips that targeted seahorses had a higher likelihood of catching them in any given trip than did trips that fished primarily for other species. About 93% of target diving trips caught at least one seahorse (n = 14/15), while only 36% of indiscriminate dive trips caught at least one seahorse (n = 43/119). Similarly, 95% of target trawl trips caught at least one seahorse (n = 40/42), while only about 50% of the indiscriminate trawl trips caught at least one seahorse (n = 61/123).

The catch per unit effort (CPUE, seahorses boat^{-1} day^{-1}) was significantly different among target divers, indiscriminate divers, target trawls, and indiscriminate trawls (ANOVA, F = 98.25, df = 3, $p < 0.001$). A post hoc Tukey test showed that target fishing was significantly different from non-target fishing ($p < 0.001$), but within target and non-target fishing (i.e. target divers and target trawls, and non-target divers and non-target trawls) there was no significant difference ($p > 0.05$). Target divers had the highest CPUE, followed by target trawls (Table 1). In contrast, the CPUE from indiscriminate trawls was much lower, while indiscriminate divers had the lowest CPUE (Table 1). Seahorse catch rates also varied regionally (F = 34.18, df = 2, $p < 0.001$), with each group being significantly different based on a post hoc Tukey test ($p < 0.001$). The highest CPUE for target divers was in the central region while indiscriminate divers had a slightly higher CPUE in the north than the central region (Table 2). CPUE was highest in the south for both target trawls and indiscriminate trawls (Table 2).

3.3. Extrapolation of total seahorse catch per annum

We estimated that seahorse landings were between 127,000–269,000 individuals year^{-1} with the majority (82%) coming from the target and indiscriminate trawl fisheries (Table 1). These numbers represent 1200–1800 kg year^{-1} based on an estimated 165 live seahorses kg^{-1}. Estimated total annual catches varied significantly based on the area in which boats fished; the highest volumes of seahorses were caught in the north and south by target trawls, followed by target divers that fished in the central region (Table 2).

3.4. Seahorse landings and size at maturity by species

Three species of seahorses were identified in landings, whose proportions in catch varied by gear and location: the common seahorse *Hippocampus kuda* Bleeker 1852, the hedgehog seahorse *Hippocampus spinosissimus* Weber 1913, and the three-spot seahorse *Hippocampus trimaculatus* Leach 1814. Catch composition varied by gear type: target divers caught the highest proportion of *H. spinosissimus* (n = 371/996), while indiscriminate trawls and target trawls caught the highest proportion of *H. trimaculatus* (n = 121/181) and *H. kuda* (n = 244/289) respectively (x^2 = 494, d.f. = 6, $p < 0.001$). *Hippocampus spinosissimus* dominated diver catches by number of individuals (91.4% c.f., 8.4% *H. trimaculatus* and 0.2% *H. kuda* for target divers; 70.8% c.f., 10.2% *H. trimaculatus* and 19.0% *H. kuda* for indiscriminate divers). On the other hand, trawl catches varied in their species composition: the relative proportion of *H. spinosissimus, H. trimaculatus* and *H. kuda* by number of individuals for target trawls was 56.8, 2.0, and 41.2%, respectively, and for indiscriminate trawls was 58.0, 36.6, and 5.4%, respectively. When scaled to annual catch number by fleet size, target trawls caught the greatest number of *H. spinosissimus* and *H. kuda*, while indiscriminate trawls caught the most *H. trimaculatus* (Fig. 2).

Catch composition also varied regionally (x^2 = 184, d.f. = 4, $p < 0.001$). Catch in the north comprised 81.3% *H. spinosissimus* (n = 295), 10.2% *H. trimaculatus* (n = 37), 8.5% *H. kuda* (n = 31); central catch: 58.0% *H. spinosissimus* (n = 467), 10.0% *H. trimaculatus* (n = 81), and 32.0% *H. kuda* (n = 258); southern catch: 78.7% *H. spinosissimus* (n = 236), 21.3% *H. trimaculatus* (n = 64), and no *H. kuda* (n = 0). When scaled to annual catch number by fleet size, the vast majority of *H. kuda* were caught in the central region (70.2%, n = 258), while the majority of *H. trimaculatus* and *H. spinosissimus* were caught in the south (83.5% n = 64, and 56.7, n = 236, respectively).

For all gear types and species, median height of captured seahorses was remarkably similar (Fig. 3). There was no difference among mean

Table 2
Mean catch-per-unit-effort of seahorses ± standard error (seahorses boat^{-1} day^{-1}) of each fishery by region fished and estimated total landings per annum (seahorses year^{-1}) for Phu Quoc Island, Vietnam. n = number of fishing trips sampled.

	North				Central				South			
	n	Mean CPUE (± S.E.)	Fleet Size	Annual landings	n	Mean CPUE (± S.E.)	Fleet Size	Annual landings	n	Mean CPUE (± S.E.)	Fleet Size	Annual landings
Target divers	2	14.5 (± 3.5)	1	2175	13	34.5 (± 6.1)	5	25,875	0	NA	0	NA
Indiscriminate divers	59	1.4 (± 0.3)	15	3150	54	1.2 (± 0.4)	10	1800	4	0.5 (± 0.5)	15	1125
Target trawls	9	18.1 (± 6.3)	12	43,440	20	14.7 (± 2.3)	4	11,760	13	40.1 (± 5.4)	8	64,160
Indiscriminate trawls	73	1.7 (± 0.6)	30	10,200	37	3.2 (± 2.2)	10	6400	13	5.2 (± 1.9)	60	62,400
Total				58,965	**Total**			45,835	**Total**			127,685

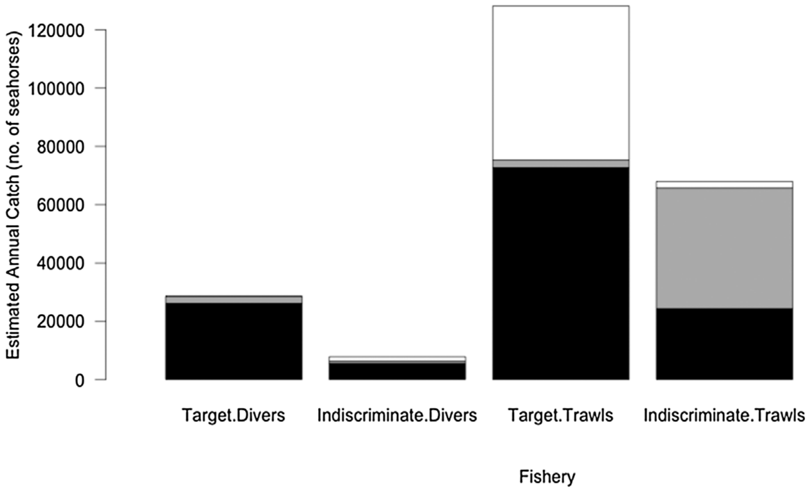

Fig. 2. Estimated annual catch of seahorses (*Hippocampus* spp.) by target and indiscriminate dive and trawl fisheries operating across three fishing grounds on Phu Quoc Island, Vietnam (*H. spinosissimus* in black, *H. trimaculatus* in grey, and *H. kuda* in white).

height of *H. kuda* or *H. trimaculatus* caught across the four fisheries (F = 2.0, df = 3, p = 0.14; F = 0.2, df = 3, p = 0.90, respectively). Mean heights of *H. spinosissimus* did differ among the four different fisheries (F = 9.75, df = 3, $p < 0.001$), with the smallest seahorses caught by target divers (post hoc Tukey test $p < 0.001$).

Species differed minimally in height at 50% male physical maturity (H_M); H_M was 98.5 mm for *H. spinosissimus* (95% C.I. = 96.2–100.8 mm, n = 324), 108.8 mm for *H. trimaculatus* (95% C.I. = 103.4–114.2 mm, n = 130) and 106.1 mm for *H. kuda* (95% C.I. = 96.2–116.1 mm, n = 26) (Fig. 3).

In nearly all fisheries, there was an equal sex ratio for *H. kuda, H. spinosissimus* and *H. trimaculatus*. Male to female ratios of *H. kuda, H. spinosissimus* and *H. trimaculatus* for target divers were: 0:1, 114:100 (p = 0.34), and 15:15 (p = 1); for indiscriminate divers were 9:11 (p = 0.65), 32:22 (p = 0.17), and 7:2 (p = 0.1); for target trawls were 64:55 (p = 0.41), 22:33 (p = 0.14) and 2:2 (p = 1); and for indiscriminate trawls were 9:8 (p = 0.81), 67:43 (p = 0.02), and 41:44 (p = 0.74). Only *H. spinosissimus* caught incidentally in trawl nets showed a skewed sex ratio, with more mature males sampled than mature females (61% males, X^2 = 5.24, df = 1, p = 0.02).

3.5. Indicators of catch sustainability

Indiscriminate divers and indiscriminate trawls caught the highest proportions of immature seahorses, together catching up to three times more juveniles than target fishers. The only case where indiscriminate fishing resulted in a lower proportion of juveniles was for *H. kuda* caught in trawl nets. The proportion of juvenile *H. kuda, H. spinosissimus* and *H. trimaculatus* was: 0, 33 and 12%, respectively, for target divers; 5, 40 and 40%, respectively, for indiscriminate divers; 9, 17 and 0%, respectively, for target trawls; and 6, 31 and 29%, respectively, for indiscriminate trawls.

The proportion of catches of *H. kuda, H. spinosissimus* and *H. trimaculatus* less than 10 cm height (the recommended minimum size limit) was 6, 39 and 0%, respectively, for divers, and 10, 32 and 11%, respectively, for trawls.

4. Discussion

This is the first quantitative comparison of targeted and incidental seahorse capture by two fishing methods: bottom trawling and compressor diving. We demonstrate that, while divers caught seahorses at

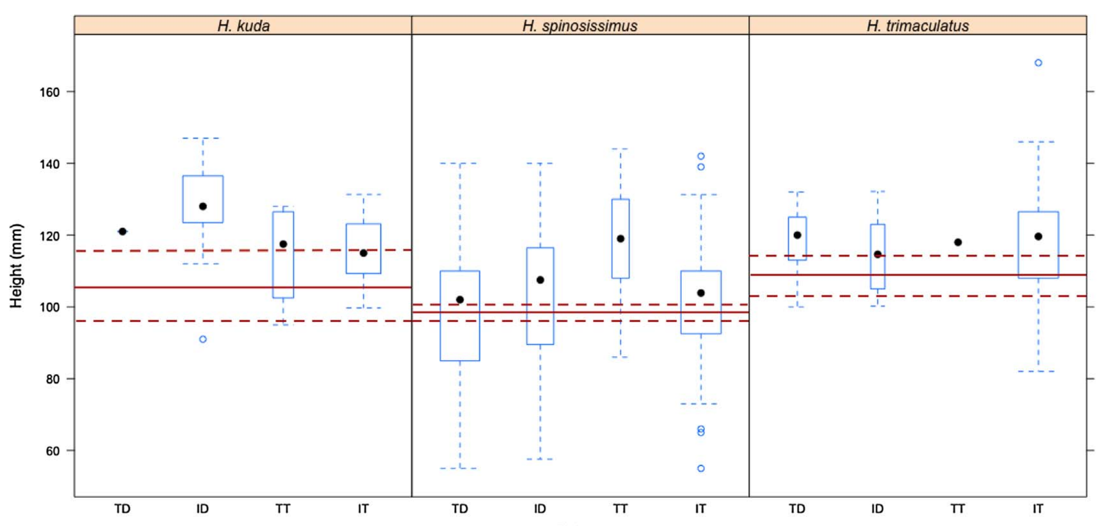

Fig. 3. Comparison of the size of seahorses caught by target and indiscriminate dive and trawl fisheries of Phu Quoc Island, Vietnam. Median height of *H. kuda* caught by indiscriminate divers (ID) = 128 mm, n = 15; target trawls (TT) = 118 mm, n = 4; indiscriminate trawls (IT) = 115 mm, n = 11; the one *H. kuda* measured from target divers (TD) was 121 mm height. Median height of *H. spinosissimus* caught by TD = 102 mm, n = 145; ID = 108 mm, n = 68; TT = 119 mm, n = 28; IT = 104 mm, n = 152. Median height of *H. trimaculatus* caught by TD = 120 mm, n = 22; ID = 114 mm, n = 14; the one *H. trimaculatus* measured from target trawls was 118 mm height; IT = 120 mm, n = 112. Width of boxplots is proportional to sample size. Solid horizontal lines indicate height at 50% maturity, with confidence intervals indicated by dotted horizontal lines.

similar rates to trawls, bottom trawling had a much greater overall impact on seahorse populations because of the large scale of the fleet. The large overall catch from Phu Quoc Island points toward a high volume of unmonitored and unregulated seahorse exploitation in Vietnam. Fishing pressure in the area may be leading to size-specific impacts and affecting the reproductive capacity of some seahorse species. Regular monitoring should be executed in order to determine the long-term impacts of seahorse fishing in the area and aid the continuous adaptation of effective management for sustainable wild seahorse populations. In the meantime, precautionary management efforts including minimum size limits and improved MPA enforcement and compliance should be implemented to mitigate any impacts.

This study shows how a snapshot investigation can be used to infer fisheries impacts in the absence of long-term data (Johannes, 1998; Pilling et al., 2008), the usual scenario for species not regarded as nationally important. In species other than seahorses, such snapshot studies of data-poor fisheries have been deployed to aid management, compensating for the dearth of time series information (Dowling et al., 2008; MacCall, 2009). Vietnam shows a pattern that is consistent with seahorse research elsewhere, revealing that relatively low seahorse catch rates scale up to large catches after accounting for intense fishing pressure (Lawson et al., 2017). This study accounted for the vast majority of fishing pressure on seahorses in Phu Quoc, Vietnam, by encompassing the fishing strategies that catch the largest volumes of seahorses (Stocks, 2015). Nonetheless, many other gear types used in the area reportedly catch seahorses at least occasionally (Stocks, 2015), and so the total annual catch is likely higher than estimated. Moreover, this study used a conservative number of fishing days when considering possible seasonal variations in catch and changes in fisher behaviour. Our snapshot study provides a foundation for the long term monitoring we propose below; long term monitoring will allow refinement of catch estimations and identification of patterns over time.

Phu Quoc is one of the few documented places where targeted seahorse fishing occurs; globally, about 95% of traded seahorses are caught incidentally (Vincent et al., 2011). Moreover, fishers on Phu Quoc use both diving gear and trawl nets to target seahorses whereas all other documented target fisheries involved collection only by hand (e.g. Brazil, India, Indonesia and the Philippines; Marichamy and Lipton, 1993; Rosa et al., 2011, 2005; Vincent et al., 2007). Target fishers on Phu Quoc caught seahorses at rates that were higher than all documented cases of seahorse fishing around the world (e.g. Giles et al., 2006; Vincent et al., 2007; Perry et al., 2010). Past studies of seahorse fisheries and trade executed in Vietnam estimated seahorse CPUE to be between 0.1–2.5 seahorses boat^{-1} day^{-1} based on interview and catch landings data (Giles et al., 2006; Meeuwig et al., 2006). Other estimates throughout Asia include 1–10 seahorses boat^{-1} day^{-1} in the Gulf of Mannar, India (Salin and Yohannan, 2005), 0–3 seahorses boat^{-1} day^{-1} in Malaysia (Perry et al., 2010), 2.9–3.4 seahorses boat^{-1} night^{-1} in the Philippines (Vincent et al., 2007), and 0.6–1.1 seahorses boat^{-1} day^{-1} in Thailand (Perry et al., 2010). In these fisheries, seahorses were caught as bycatch, although it is possible that boats target seahorses in these areas (as mentioned in Perry et al., 2010). Further investigations of seahorse fishing in Vietnam (and elsewhere) must explicitly note whether the seahorses are being caught intentionally or indiscriminately in order to improve catch estimates.

The estimated total annual seahorse landings from Phu Quoc exceeds Vietnam's annual documented exports (UNEP-WCMC, 2015), so the excess is either exported illegally without permits, exported with permits but goes unreported, or consumed domestically. According to official CITES statistics, which tend to underestimate true exports, the reported seahorse exports from Vietnam ranged from 20 to 90,000 individuals per year between 2004 and 2011 (Foster et al., 2016). These official exports for the entire country are less than 45% of our estimated total annual seahorse catch from Phu Quoc alone, and less than 5% of historic total annual seahorse catch estimates in Vietnam (Giles et al., 2006). Seahorses are consumed in Vietnam as health tonics but the volume is unknown − it seems unlikely, however, that domestic consumption accounts for the rest of the unreported catch, since it has been observed to be relatively low (Giles et al., 2006). Previous trade surveys suggest that illegal, unreported and unregulated (IUU) exports may well occur (Giles et al., 2006), supported by well documented IUU trade of a wide variety of other plants and animals from Vietnam (Athukorala, 2006; Ngoc and Wyatt, 2013).

Phu Quoc fisheries may be placing size-specific pressure on seahorse populations, and it is unclear if current selectivity is avoiding growth overfishing. The seahorses in our study were, on average, 25% smaller by weight than seahorses examined in a similar fisheries study in central Vietnam, where the catch composition was very near to that of Phu Quoc (comprised mostly of *H. spinosissimus* and *H. trimaculatus*) (Meeuwig et al., 2006). Such a difference may suggest a decline in adult size over the past ten years, as has been reported by fishers in the area (Stocks, 2015), but it could also reflect geographic differences in seahorse populations or seasonal influences on seahorse size (Martin-Smith and Vincent, 2005; Meeuwig et al., 2006).

The majority of seahorses sampled in this study were larger than the modeled species' height at 50% physical maturity, which suggests populations are not subject to growth overfishing. That said, this study may underestimate the proportion of individuals being caught before they can reproduce; the size at which seahorses start reproducing is larger than the size at which they are capable of reproducing (Lawson et al., 2014), and studies have observed that females mature later than males (Thangaraj et al., 2006 – *H. kuda*).

Long term monitoring of seahorse catch and effort is needed to confirm whether Phu Quoc seahorses are vulnerable to current levels of fishing pressure. Many of seahorses' life history traits may increase their susceptibility to overexploitation, including lengthy parental care, small brood sizes, low mobility, small home ranges and sparse distribution (as reviewed in Foster and Vincent, 2004). Furthermore, interviews with fishers on Phu Quoc revealed declines of up to 95% in seahorse CPUE between 2004 and 2014, above what could be accounted for with increased fishing effort (Stocks, 2015). A simple monitoring program could provide indications of whether seahorses are being overfished (e.g. Foster et al., 2014); efforts should focus on the smaller fleets of target trawl boats and divers that catch higher volumes than the indiscriminate fleets. This essential information on CPUE and inferred seahorse abundance will aid Vietnam's capacity to develop non-detriment findings, adhere to the CITES recommendations, and develop a national management plan for seahorses.

The high volume of unmitigated extraction determined in this study, combined with reported catch declines (Stocks, 2015), suggests that Phu Quoc's seahorse fisheries would benefit from precautionary management tools in order to ensure their sustainability. Enforcing the islands' two marine protected areas and encouraging fishers to respect these reserves would benefit seahorse benthic habitats, though the documented benefits of small MPAs to seahorse populations are limited (Yasué et al., 2012; Harasti et al., 2014). Instead large-scale removal of destructive fishing gears may be more effective at protecting seahorses (Yasué et al., 2012). Seasonal fishing restrictions exist in the area, but are minimally enforced. Minimum size limits are of little use for trawls because these gears cannot easily select for size and survival of discarded seahorses is assumed to be very low (Foster and Vincent, 2016). Enforcing the 10 cm size limit recommended by CITES (CITES, 2004), could, however, be an effective tool for managing divers who can be much more selective about what size seahorses they extract. The 10 cm MSL would confer reasonable precautionary protection of the three species, since they mature below or just slightly above this height.

Acknowledgements

This is a contribution from Project Seahorse. This study was made possible through collaborations with the Research Institute of Marine Fisheries (RIMF), Vietnam National University, the Vietnam CITES

Management Authority, and the Phu Quoc MPA staff. Many thanks to Do Thanh An and Nguyen Nhut Thanh who provided assistance with data collection, interpretation, and logistics. Thank you to L. Aylesworth, C. Kinzett, K. Gillespie, J. Lawson, and others for their support and reviews. We greatly appreciate the support for this research provided by Mitacs and The Explorers Club, and the additional support provided by Guylian Chocolates Belgium and an anonymous donor.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2017.07.021.

References

Athukorala, P., 2006. Trade policy reforms and the structure of protection in Vietnam. World Econ. 29, 162–187.
Boisseau, J., 1967. Les regulations hormonales de l'incubation chez un Vertébré mâle: recherches sur la reproduction de l'Hippocampe.
CITES, 2004. Trade in Seahorses − Implementation of Decision 12.54, Notification to the Parties No. 2004/033.
CITES, 2013. Implementation of Resolution Conf. 12.8 (Rev. CoP13), Review of Significant Trade in Specimens of Appendix-II Species, Notification to the Parties No. 2013/013.
DECAFIREP, 2015. Kien Giang Data. Ha Noi.
Dowling, N., Smith, D., Knuckey, I., Smith, A., Domaschenz, P., Patterson, H.M., Whitelaw, W., 2008. Developing harvest strategies for low-value and data-poor fisheries: case studies from three Australian fisheries. Fish. Res. 94, 380–390.
Foster, S.J., Vincent, A.C.J., 2004. Life history and ecology of seahorses: implications for conservation and management. J. Fish Biol. 65, 1–61. http://dx.doi.org/10.1111/j.1095-8649.2004.00429.x.
Foster, S.J., Vincent, A.C.J., 2016. Making Non-Detriment Findings for Seahorses − A Framework, Version 4. (Vancouver, Canada).
Foster, S.J., Loh, T.-L., Knapp, C., 2014. iSeahorse Landings Trends Toolkit.
Foster, S.J., Wiswedel, S., Vincent, A.C.J., 2016. Opportunities and challenges for analysis of wildlife trade using CITES data − seahorses as a case study. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 154–172. http://dx.doi.org/10.1002/aqc.2493.
Froese, R., 2004. Keep it simple: three indicators to deal with overfishing. Fish Fish. 5, 86–91. http://dx.doi.org/10.1111/j.1467-2979.2004.00144.x.
Giles, B.G., Ky, T.S., Hoang, D.H., Vincent, A.C.J., 2006. The catch and trade of seahorses in Vietnam. Biodivers. Conserv. 15, 2497–2513. http://dx.doi.org/10.1007/s10531-005-2432-6.
Harasti, D., Martin-Smith, K., Gladstone, W., 2014. Does a no-take marine protected area benefit seahorses? PLoS One 9, e105462.
Johannes, R., 1998. The case for data-less marine resource management: examples from tropical nearshore finfisheries. Trends Ecol. Evol. 13, 243–246.
Lawson, J.M., Foster, S.J., Lim, a. C.O., Chong, V.C., Vincent, A.C.J., 2014. Novel life-history data for threatened seahorses provide insight into fishery effects. J. Fish Biol. 86, 1–15. http://dx.doi.org/10.1111/jfb.12527.
Lawson, J.M., Foster, S.J., Vincent, A.C.J., 2017. Low bycatch rates add up to big numbers for a genus of small fishes. Fisheries 42, 19–33. http://dx.doi.org/10.1080/03632415.2017.1259944.
Long, N., Van Hoang, D.H., 1998. Biological parameters of two exploited seahorse species in a Vietnamese fishery. Mar. Biol. South China Sea 3, 449.
Lourie, S.A., Pritchard, J.C., Casey, S.P., Truong, S.K., Hall, H.J., Vincent, A.C.J., 1999. The taxonomy of Vietnam's exploited seahorses (family Syngnathidae). Biol. J. Linn. Soc. 66, 231–256.
Lourie, S., Foster, S., Cooper, E., Vincent, A., 2004. A Guide to the Identification of Seahorses. University of British Columbia and World Wildlife Fund, Washington, DC.
MacCall, A., 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES J. Mar. Sci. J. 66, 2267–2271.
Marichamy, R., Lipton, A., 1993. Large scale exploitation of sea horse (*Hippocampus kuda*) along the Palk Bay coast of Tamil Nadu. Mar. Fish. Inf. Serv. Tech. Ext. Ser. 119, 17–20.
Martin-Smith, K.M., Vincent, A.C.J., 2005. Seahorse declines in the Derwent estuary, Tasmania in the absence of fishing pressure. Biol. Conserv. 123, 533–545. http://dx.doi.org/10.1016/j.biocon.2005.01.003.
Meeuwig, J.J., Hoang, D.H., Ky, T.S., Job, S.D., Vincent, A.C.J., 2006. Quantifying non-target seahorse fisheries in central Vietnam. Fish. Res. 81, 149–157. http://dx.doi.org/10.1016/j.fishres.2006.07.008.
Ngoc, A., Wyatt, T., 2013. A green criminological exploration of illegal wildlife trade in Vietnam. Asian J. Criminol. 8, 129–142.
Otero-Villanueva, M., del, M., Ut, V.N., 2007. Sea cucumber fisheries around Phu Quoc Archipelago: a cross-border issue between South Vietnam and Cambodia. SPC Beche-de-mer Inf. Bull. 25, 32–36.
Perry, A.L., Lunn, K.E., Vincent, A.C.J., 2010. Fisheries, large-scale trade, and conservation of seahorses in Malaysia and Thailand. Aquat. Conserv. Mar. Freshw. Ecosyst. 20, 464–475. http://dx.doi.org/10.1002/aqc.1112.
Pilling, G.M., Apostolaki, P., Failler, P., Floros, C., Large, P.A., Morales-Nin, B., Reglero, P., Stergiou, K.I., Tsikliras, A.C., 2008. Assessment and management of data-poor fisheries. In: Payne, A., Cotter, J., Potter, T. (Eds.), Advances in Fisheries Science: 50 Years on from Beverton and Holt. Blackwell Publishing, pp. 280–305.
Rosa, I.M., Alves, R.R., Bonifácio, K.M., Mourão, J.S., Osório, F.M., Oliveira, T.P., Nottingham, M.C., 2005. Fishers' knowledge and seahorse conservation in Brazil. J. Ethnobiol. Ethnomed. 1, 12. http://dx.doi.org/10.1186/1746-4269-1-12.
Rosa, I.L., Oliveira, T.P.R., Osório, F.M., Moraes, L.E., Castro, A.L.C., Barros, G.M.L., Alves, R.R.N., 2011. Fisheries and trade of seahorses in Brazil: historical perspective, current trends, and future directions. Biodivers. Conserv. 20, 1951–1971. http://dx.doi.org/10.1007/s10531-011-0068-2.
Rosser, A., Haywood, M., 2002. Guidance For CITES Scientific Authorities: Checklist to Assist in Making Non-Detriment Findings for Appendix II Exports. IUCN No 27.
Salin, K.R., Yohannan, T.M., 2005. Fisheries and trade of seahorses, *Hippocampus* spp., in southern India. Fish. Manag. Ecol. 12, 269–273.
Stocks, A.P., 2015. Diversification and Depletion of Vietnamese Seahorse Fisheries. The University of British Columbia.
Thangaraj, M., Lipton, A., Victor, A., 2006. Onset of sexual maturity in captive reared endangered Indian seahorse, Hippocampus kuda. Curr. Sci. 91, 1714–1716.
UNEP-WCMC, 2015. CITES Trade Database. Available at http://www.unep-wcmc.org/citestrade/trade.cfm/ (last Accessed 15 August 2015).
Ut, V.N., Tam, T.C., 2012. Species composition and fishing status of seahorses (Hippocampus spp.) in Phu Quoc Island. In: Proceedings of International Conference on Bien Dong. Vietnam. pp. 1–7.
Vincent, A.C.J., Meeuwig, J.J., Pajaro, M.G., Perante, N.C., 2007. Characterizing a small-scale, data-poor, artisanal fishery: seahorses in the central Philippines. Fish. Res. 86, 207–215. http://dx.doi.org/10.1016/j.fishres.2007.06.006.
Vincent, A.C.J., Foster, S.J., Koldewey, H.J., 2011. Conservation and management of seahorses and other *Syngnathidae*. J. Fish Biol. 78, 1681–1724. http://dx.doi.org/10.1111/j.1095-8649.2011.03003.x.
Vincent, A.C.J., Sadovy de Mitcheson, Y.J., Fowler, S.L., Lieberman, S., 2013. The role of CITES in the conservation of marine fishes subject to international trade. Fish Fish. 15, 563–592. http://dx.doi.org/10.1111/faf.12035.
Vincent, A.C.J., 1994. Seahorses exhibit conventional sex roles in mating competition, despite male pregnancy. Behaviour 128, 135–151.
Yasué, M., Nellas, A., Vincent, A.C.J., 2012. Seahorses helped drive creation of marine protected areas, so what did these protected areas do for the seahorses? Environ. Conserv. 39, 183–193. http://dx.doi.org/10.1017/S0376892911000622.

Electronic References

IUCN (2013). *IUCN Red List of Threatened Species*. *Version 2013.2*. Available at http://www.iucnredlist.org/ (last Accessed 15 August 2015).