

DIVERSIFICATION AND DEPLETION IN VIETNAMESE SEAHORSE FISHERIES

by

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Abstract

The development of effective evidence-based management is limited by a lack of long-term records for many vulnerable marine species that are caught in small-scale fisheries. To address this data gap, I studied a small-scale fishery in southern Vietnam with a focus on seahorses (*Hippocampus* spp.), globally traded, cryptic fishes that are notably vulnerable to overexploitation. Using a combination of fisher interviews and catch landings surveys, I documented five fishing gears that regularly caught seahorses intentionally and/or incidentally: otter trawls, beam trawls, pair trawls, crab nets, and compressor diving. About 20% of fishers I studied specifically targeted seahorses and made the majority of their income from selling these fish; a novel finding. The seahorse catch consisted of three species – *Hippocampus spinosissimus*, *H. kuda* and *H. trimaculatus* – with catch composition varying by gear and fishing ground. Bottom trawl boats and compressor divers that targeted seahorses caught them at mean rates of 23 and 32 seahorses per day respectively, while those that caught seahorses incidentally caught 1 and 3 per day respectively. The total catch from the island from these two fishing methods was approximately 162,000–234,000 seahorses per year. This catch is up to four times higher than in other studied regions of Vietnam and throughout Southeast Asia. Fishers reported that seahorse catch rates had decreased by 86-95% from 2004 to 2014. Meanwhile, the landed value of seahorses had increased by 534% during the same time period, encouraging fishers to continue capturing and selling seahorses. These signs point toward a high-pressure fishery that is likely unsustainable. Fisheries management efforts in the area should be strengthened by enforcing marine protected areas and improving fishers' compliance to regulation. My findings emphasize the transitions that can occur in a high-pressure small-scale fishery and highlight the need for effective management to ensure sustainable seahorse populations.

Preface

I developed the research questions and methodological design of this thesis collaboratively with Drs. Amanda Vincent and Sarah Foster. I collected all of the data used for Chapters 2 and 3 of this thesis with the help of my research assistants, who were vital to the interpretation of interviews and port surveys. I carried out all analyses and prepared all manuscripts in this thesis.

A version of Chapter 2 is in preparation for publication. I am the lead author, along with Drs. Amanda Vincent and Sarah Foster, and my collaborators at the Research Institute for Marine Fisheries and Viet Nam National University, Nguyen Khac Bat and Nguyen Manh Ha. The data for Chapter 2 were collected during a series of interviews in Vietnam which were interpreted by my research assistants, Do Thanh An and Nguyen Nhut Thanh. Nguyen Khac Bat and Nguyen Manh Ha provided essential logistical, scientific, and cultural guidance during field data collection, which was essential to the success of both chapters. I conducted the analysis for Chapter 2 and wrote the paper in collaboration with Drs. Sarah Foster and Amanda Vincent.

A version of Chapter 3 is in preparation for publication. I am the lead author, along with Drs. Amanda Vincent and Sarah Foster and my collaborator at the Research Institute for Marine Fisheries Nguyen Khac Bat. The data for Chapter 3 were collected during port surveys in Vietnam which were made possible with the help of my research assistants, Do Thanh An and Nguyen Nhut Thanh. I conducted the analysis for Chapter 3 and wrote the paper in collaboration with Drs. Sarah Foster and Amanda Vincent.

The field research conducted for Chapters 2 and 3 was approved by the UBC Animal Care Committee, Permit A12-0288, project title: “Creating Momentum for Seahorse Populations in Southeast Asia” and UBC Behavioural Research Ethics Board, Permit H12-02731, project title: “Fishing and trade in Southeast Asia”.

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List of Abbreviations

ANOVA – Analysis of variance

CPUE – Catch per unit effort

CITES – The Convention on International Trade in Endangered Species of Wild Flora and Fauna

CBD – The Convention on Biological Diversity

CMS – The Convention on the Conservation of Migratory Species of Wild Animals

IMF – International Monetary Fund

IUU – Illegal, unreported, and unregulated

NDF – Non-detriment findings

RIMF – Research Institute of Marine Fisheries

RFMO – Regional Fisheries Management Organization

TCM – Traditional Chinese Medicine

USD – United States Dollar

VND – Vietnamese Dong

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For every teacher, parent, and peer that has inspired me to be curious,
to question authority, to be determined, and to never stop exploring.

Most of us who turn to any subject with love remember some morning or evening hour when we got on a high stool to reach down an untried volume, or sat with parted lips listening to a new talker, or for very lack of books began to listen to the voices within, as the first traceable beginning of our love. – George Eliot, Middlemarch

Chapter 1: Introduction

1.1 Rationale

The goal of this thesis was to explore the diverse and shifting nature of ocean exploitation in a conservation context, using seahorse fisheries in Vietnam as a case study.

1.2 Background

Fishing is important to human wellbeing but places intense pressure on the ocean. Fisheries employ 10-12% of the world's population and contribute billions of dollars to the global economy (FAO, 2014). They also provide critical sources of food and protein to a large portion of the world (Béné et al., 2007; le Manach et al., 2012; Pauly et al., 2005). Yet fishing pressure has led to changes in ecosystem structure and function (Jackson et al., 2001), along with causing habitat degradation (Turner et al., 1999) and fish biomass declines (Christensen et al., 2014). Fisheries catch hundreds of thousands of tonnes of fish each day (Roberts, 2010), and as of 2014, an estimated 30% of assessed fish stocks were considered overfished (FAO, 2014). Many species are not included in this official monitoring and could be under severe fishing pressure.

In the face of declining marine resources (Jackson et al., 2001), fisheries have continued to meet demand by spreading spatially, targeting new species, and advancing technologically (Pauly et al., 2002; Valdemarsen, 2001). Over the past hundred years, spatial expansion of fisheries coupled with advances in fishing technology has led to declines in fish biomass in many exploited areas (Christensen et al., 2014). As one resource becomes scarce, another is exploited to meet demand such that “yesterday’s bycatch may be today’s target species,” (Murawski,

1992). This substitution can lead to cascading declines and collapses in fisheries, in what is known as sequential or serial depletion (Berkes et al., 2006; Huitric, 2005). Fishers move spatially and across trophic levels towards new unexploited areas or alternative resources (Cardinale et al., 2011; Pauly et al., 2002), using multiple gears as necessary (Johnson, 2006).

1.2.1 Small-scale fisheries

Catch-all tactics and shifts in gear use are common in small-scale fisheries, which comprise the vast majority of fishing boats (80%) in the world (FAO, 2014). Small-scale fisheries operate close to shore using small (<15m in length) motorized or non-motorized vessels and catch a third (Chuenpagdee et al., 2006) to half (Berkes et al., 2001) of the world's fish biomass. Small-scale fishers tend to operate opportunistically, fishing seasonally and complementing their income with other economic activities (Salas et al., 2007). Small-scale fisheries target a variety of species using multiple boat types and fishing gears (Salas et al., 2007). This complex, shifting nature makes small-scale fisheries difficult to track.

Despite being widespread, small-scale fisheries are often poorly monitored and therefore largely data-deficient (Chuenpagdee et al., 2006). The vast majority (97%) of small-scale fishers are active in developing countries (Berkes et al., 2001), where people rely heavily on marine resources for food security and income (Sadovy, 2005). In these areas, small-scale fisheries tend to be highly diffuse, operating from remote villages and landing their catch at unofficial ports (Berkes et al., 2001). Low enforcement capacity is a common problem in many developing countries (Mora et al., 2009), adding to the difficulty of fisheries monitoring. As a result, compliance with fisheries regulation tends to be low, and fishers would rather risk the low

chance of being apprehended occasionally rather than lose potential income (Bach Dang and Momtaz, 2015).

The lack of data on small-scale fisheries has led to low capacity for management (Berkes et al., 2001; Chuenpagdee et al., 2006; McClanahan et al., 2009). Fisheries analyses like stock assessments and ecosystem modelling are rarely applied to small-scale fisheries because they are data-poor and found in countries with low capacity to assess stocks (Salas et al., 2007). Fisheries management measures like gear restrictions, reduction of overcapacity, and seasonal closures are difficult to enforce in small-scale fisheries that use multiple gears to catch many different species. As a result, small-scale fisheries are generally poorly managed (McClanahan et al., 2009) and risk being ecologically and economically unsustainable.

1.2.2 Marine species at risk

The lack of information on small-scale fisheries and their subsequent poor management is worrisome given the vulnerability of marine species to fishing pressure (Reynolds et al., 2005). Fishing pressure can put marine species at risk of local extinction (Lotze and Worm, 2009; Reynolds et al., 2005), lead fish stocks to collapse (Hutchings and Reynolds, 2004), and deplete corals (Hughes et al., 2003). Many marine species lack the high fecundity, rapid population growth, and large scale dispersal that could allow recovery from low numbers (Pitcher, 1998). While it was once assumed that marine species were more resilient to exploitation than terrestrial species (Hutchings, 2001 and citations therein), in fact some marine species are more vulnerable to extinction than taxa like butterflies and birds (Fagan et al., 2001). Small-scale fisheries place severe pressure on inshore areas (Chuenpagdee et al., 2006; Salas et al., 2007), which are some

of the most biologically diverse parts of the ocean (Tittensor et al., 2010). Without adequate understanding and management of these fisheries, marine species in these areas are at particular risk of being overfished (Alfaro-Shigueto et al., 2010; Peckham et al., 2007).

A variety of conservation tools are being employed to complement fisheries management in an effort to protect marine species. At the regional and national level, marine protected areas (MPAs), areas where fishing and other activities are limited, have been implemented to increase fish biomass, maintain ecosystem processes and function, accelerate habitat recovery, and/or promote resilience to disturbances and fluctuations (Côté et al., 2001; Hughes et al., 2003; Selig and Bruno, 2010). At the international level, several agreements are being implemented to advance marine conservation. These include the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), which aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival (www.cites.org); the Convention on Biological Diversity (CBD), which aims to develop national strategies for the conservation and sustainable use of biological diversity (www.cbd.int); and the Convention on the Conservation of Migratory Species of Wild Animals (CMS), which aims to conserve terrestrial, aquatic, and avian migratory species throughout their range (www.cms.int). The integration and application of these tools and many more are improving the fate of marine species.

1.2.3 The intersection of fisheries management and conservation

Several marine fish taxa have been at the forefront of the integration of fisheries management and biological conservation, including sharks and seahorses (Vincent et al., 2013). Despite the

fact that 40% of seafood by volume is traded internationally (FAO, 2014), marine fish remained absent from CITES until 2002, when seahorses and two species of shark were added to Appendix II. Under CITES Appendix II, member countries must demonstrate that the international trade of specimens does not harm wild populations. Such responsibilities require that member countries make non-detriment findings (NDFs), which are adaptive management plans for the exploitation of wild populations (Murphy, 2006; Rosser and Haywood, 2002). In the case of marine fish, this means that countries must ensure that fisheries are sustainable – quite a complicated task if these fish are obtained as bycatch in highly diffuse small-scale fisheries (Salas et al., 2007). As a result, CITES Appendix II listing of marine fish has increased the pressure for developing and enforcing marine fisheries management.

Seahorses are excellent examples of fishes that have been ignored by traditional fisheries management in the past but have recently attracted considerable conservation attention.

Seahorses are found in tropical and temperate oceans across the globe. They are caught primarily as bycatch (Lawson et al., *in review*) but also in targeted capture fisheries (Baum and Vincent, 2005; Perry et al., 2010; Salin and Yohannan, 2005; Vincent et al., 2007), to be sold for use in traditional medicine, aquaria, and as trinkets (Vincent, 1996). Twenty years ago, the worldwide trade of seahorses was uncovered by biologists, though it was ignored by governments and management officials (Vincent, 1996). To encourage the conservation of seahorses and aid in the development of effective management, Project Seahorse was created in 1996 and has been dedicated to advancing marine conservation since then.

Despite global efforts to study and protect seahorses, they are still under threat. The majority of seahorses are listed as Vulnerable or Data Deficient on the IUCN Red List of Threatened Species (IUCN, 2015). An estimated 40 million seahorses are caught each year as bycatch and in targeted fisheries (Lawson et al., *in review*). About 15-20 million of these fishes enter international trade, which involves at least 87 countries (Foster et al., 2014). Many of the countries involved in seahorse fisheries and trade lack sufficient information (whether biological, fisheries, or trade related) to prove the sustainability of these activities. This has made the application of the CITES Appendix II listing of seahorses extremely challenging. Many signs point towards unsustainable fisheries and trade, with fishers across the globe reporting declines in seahorse catch even in studies in which effort was controlled (Giles et al., 2006; Vincent et al., 2007).

1.3 Research objectives and thesis outline

My research is framed within the goal of exploring the diverse and shifting nature of ocean exploitation in a conservation context. To meet this goal I asked the following questions with my research:

1. What can local fishers tell us about historical changes in seahorse fishing? (Chapter 2)
2. What pressure is being placed on seahorses by target and incidental fisheries? (Chapter 3)

In Chapter 2, I used an interview-based approach to rapidly gain information on current fishing practices and historical changes to determine the sustainability of seahorse fishing in a key seahorse fishing area. Preliminary evidence from the area indicated that seahorses were caught in higher than usual numbers, though no formal studies of seahorse fishing in this area exist.

Chapter 2 provides the first comparison of historical changes in catch and price from this region, along with indications of future sustainability.

Chapter 3 builds on Chapter 2 by using a fisheries-dependent approach to quantify the catch per unit effort of target and incidental fisheries and their catches of multiple seahorse species. The majority of seahorse research has previously been focused on incidental capture (Baum et al., 2003; Lawson et al., 2014; Meeuwig et al., 2006) and information on target fisheries is rare.

Chapter 3 provides the first quantitative comparison of target and incidental seahorse fisheries.

My thesis concludes with a general discussion on the findings presented in Chapters 2 and 3, and how they contributed to answering my research questions (Chapter 4).

1.4 Context and collaborations

Project Seahorse has been involved in seahorse research and management efforts in Vietnam intermittently since 1995. Early work involved revising the taxonomy of Vietnam's seahorses (Lourie et al., 1999) and documenting seahorse fisheries and trade (Giles et al., 2006; Meeuwig et al., 2006). This work contributed to the CITES Appendix II listing of seahorses. Since 2000,

Project Seahorse has primarily been involved in policy and management work in Vietnam.

Project Seahorse maintains active relationships with senior representatives from the national CITES Authorities, the Institute of Oceanography (IO), the Research Institute for Marine Fishes (RIMF), and the Center for Natural Resources and Environmental Studies (CRES) at Vietnam National University (VNU).

Vietnam has emerged as one of the world's top seahorse exporters, yet needs to build capacity for effective management of this trade. Official export totals reported to CITES are incomplete (Foster et al., 2014) and these numbers likely underestimate actual exports. In March of 2012, the CITES Animal Committee made recommendations with regard to assessing the sustainability of Vietnam's wild sourced trade (Table 1.1). Vietnamese Authorities were unable to prove to CITES that its seahorse exports are non-detrimental to wild populations. This led to a failure to meet the CITES recommendations and a suspension of exports of the seahorse *Hippocampus kuda* from Vietnam as of March 2013 (CITES, 2013a). This is the first export ban of a marine fish species under any multilateral agreement. The failure of Vietnam to meet its obligations with respect to CITES and seahorses reflects a need for biological, fisheries, and trade information in order to improve management capacity. Vietnam must ensure the sustainability not only of the trade of *H. kuda*, but the fisheries and trade of all seahorses species found in Vietnam by demonstrating that trade does not harm wild populations.

Project Seahorse was invited by the CITES Secretariat to support Vietnam with the implementation of CITES regulations for seahorse exports. Part of this support took the form of a collaborative workshop on implementing CITES for seahorses in Vietnam in May of 2013, which included senior representatives from the national CITES Authorities, fisheries, academia, government research, and the aquaculture industry. One action item arising from this meeting was to carry out biological research on wild seahorse populations in strategic areas of Vietnam, including Phu Quoc Island, where preliminary work had been executed (Ut and Tam, 2012).

The collaborative work between Vietnamese stakeholders and Project Seahorse paved the way for my research. Representatives from RIMF, IO, CRES, and the Phu Quoc National Park staff were eager to assist and facilitate my research to the best of their ability. Essential guidance on field research, logistics, and culture came from partnerships that Project Seahorse developed with Nguyen Khac Bat at the Research Institute for Marine Fisheries and Nguyen Manh Ha at Vietnam National University. The memorandum of understanding between Project Seahorse/The University of British Columbia and the Research Institute for Marine Fisheries allowed me to conduct a four-month field survey under these colleagues' research permits in Vietnam (April – August 2014). This field survey was critical to the success of my thesis.

Table 1.1 Recommendations for species of urgent and possible concern (CITES, 2012).

<i>Hippocampus kuda</i>	
Vietnam ¹ Possible Concern	<p>Within 90 days the Management Authority should:</p> <ul style="list-style-type: none"> a) Clarify what legal protection is afforded to the species and inform the Secretariat whether the present policy allows for export of wild-taken specimens; b) If there is no intent to allow export of wild specimens of this species for the foreseeable future establish a zero export quota which should be communicated to the Parties by the Secretariat; or c) If trade is to be allowed, provide a justification for, and details of, the scientific basis by which it has been established that export is not detrimental to the survival of the species and is in compliance with Article IV, paragraphs 2 (a) and 3, taking into account any potential unregulated and/or illegal off-take and trade; d) Initiate measures to ensure that descriptions on all CITES permits are standardized such that trade is only permitted at species level and that, in compliance with Resolution Conf. 12.3, XIV e), trade ceases to be reported or permitted at higher taxon levels (genus or family). <p>Within 2 years the Management Authority should:</p> <ul style="list-style-type: none"> e) If trade in wild specimens is anticipated in the future conduct a study of the life history parameters of <i>H. kuda</i>, including growth rate, size and age at maturity, average annual reproductive output and annual survivorship of different age classes and make the results available to the Secretariat. Based on the outcome of this study, model population responses to exploitation pressures in order to review and revise export quotas; and if they <i>intend</i> to trade the species in the future, f) Provide to the Secretariat a justification for, and details of, the scientific basis by which it has been established that any proposed export quota for wild specimens of <i>H. kuda</i> will not be detrimental to the survival of the species and is in compliance with Article IV, paragraphs 2 (a) and 3 g) If trade in wild specimens is anticipated in the future, establish a detailed monitoring program of landings of <i>Hippocampus kuda</i> at representative sites, taking into account different gear types and means of extraction and recording catch and effort metrics and provide a report to the Secretariat.
<p>¹The following issues were referred to the Secretariat to follow up with the Management Authority of Viet Nam and to bring to the attention of the Animals or Standing Committee as appropriate: a) details of methods and facilities used to produce <i>Hippocampus kuda</i> in captivity and current and anticipated levels of production; b) measures to ensure that specimens produced from captive production systems are distinguished in trade from genuine wild harvested specimens, that separate export quotas are established and that, with the assistance of Secretariat, source codes appropriate to the production system are used on CITES permits; and c) the development and implementation of adequate control measures and inspection procedures to detect and intercept illegal shipments of specimens of <i>H. kuda</i>.</p>	

Chapter 2: Opportunistic and Intentional: Local Knowledge of Seahorse

Fisheries

2.1 Introduction

Fisheries can affect entire ecosystems through biomass declines and habitat degradation (Christensen et al., 2014; Hutchings and Reynolds, 2004; Pauly et al., 1998; Worm et al., 2006) and thus require informed management measures to effectively mitigate their impacts (Pauly et al., 2002). Complexities in fisheries and the variation in countries' capacity to manage them mean that a variety of complementary tools are needed to ensure their sustainability and limit their damage (Botsford and Brumbaugh, 2009; Pauly et al., 2005). Increasingly, conventional fisheries management practices such as gear restrictions and catch quotas are being integrated with non-conventional approaches like marine reserves (Hilborn et al., 2004; Pauly et al., 2003). As well, 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 species vulnerable to extinction (Caddy, 1999; Musick et al., 2000; Richards and Maguire, 1998).

Many conventional fisheries management tools that are useful 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). Unlike industrial fisheries, which generally use a single gear to target a single species, small-scale fisheries use a variety of gears to catch many species (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 (Jacquet et al., 2010; Zeller et al., 2007, 2006) leading to poorly informed management.

Underestimating the impacts of small-scale fisheries and/or managing them poorly has global implications. Small-scale fisheries account for anywhere from a third (Chuenpagdee et al., 2006) to over half of the world's fish catches (Berkes, 2003). 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). Small-scale fishing provides a critical contribution to the livelihood 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. 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 and Folke, 2002; Berkes et al., 2000; Gilchrist et al., 2005; Silvano and Valbo-Jørgensen, 2008). This approach is not without its drawbacks; fisher narratives have been probed for their accuracy and reliability (Bradburn et al., 1987; Henry et al., 1994; O'Donnell et al., 2012). However, interviews can provide reliable information on trends

and fluctuations, making them a quick way to track relative changes in fisheries (Tesfamichael et al., 2014).

Fisher knowledge is especially useful for understanding genera that have historically been of lower priority to local fisheries management but are now receiving conservation attention.

Among the most charismatic and notable of these species are the seahorses (*Hippocampus* spp.).

At least 40 million seahorses are caught annually (Lawson et al., *in review*), yet nearly none appear in fisheries records. The large-scale global trade in seahorses for traditional Chinese medicine, ornamental display, and trinkets (Vincent et al., 2011) led to all species being listed on CITES Appendix II. Member countries must now ensure that trade does not harm wild populations and that specimens are legally acquired. 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., 2012, 2010).

In Vietnam, a recent CITES-imposed ban on exports of one seahorse species, *Hippocampus kuda*, has highlighted the need to access any biological, fisheries, and trade data that fishers have accrued. Seahorses are fished throughout Vietnam and exported for use in traditional Chinese medicine, aquaria, and as trinkets (Giles et al., 2006; Vincent et al., 2011). They are also consumed within Vietnam for various purposes including tonics to promote kidney health and increase 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 wild seahorse

populations (Giles et al., 2006; Long and Hoang, 1998). Poor monitoring and documentation led to the first export ban imposed by CITES on exports of any marine fish, and a clear requirement that Vietnam develop adaptive management measures to lift the ban. As well, Vietnam is still responsible for ensuring that exports of six other seahorse species (not subject to the ban) comply with CITES requirements for sustainable sourcing.

The overall goal of this study was to obtain both a quantitative and qualitative understanding of seahorse fishing, trade, and domestic use in southern Vietnam. 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). At the time, no published studies of seahorse fishing had been executed in the area. 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.

2.2 Materials and methods

2.2.1 Study site

This 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, Figure 2.1).

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 40m) and lie within 50km of the coast (Pomeroy et al., 2009), making it 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.

2.2.2 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 seahorses. Interviews were conducted in ports and villages across Phu Quoc Island, as well as two of the southern islands: Hon Thom and Hon Roi (Figure 2.1). All interviews followed 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 A). The interviews were designed to take less than 30 minutes to complete, ideal for collecting specific, quantitative information

(Huntington, 2000). Not every fisher answered every question, and fishers sometimes only addressed a subset of the questions because of their time limitations, therefore sample sizes (n) vary throughout the text.

2.2.3 Data standardization and analysis

We used analysis of variance (ANOVA) tests to compare fishing effort among gear types, seahorse 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 in our study 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-hour 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 = 6.1g, Appendix B), or 350 individuals per kg of dried seahorses (1 seahorse = 2.9g, 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).

2.3 Results

2.3.1 Study participants

We conducted interviews with 77 fishers, each from different fishing boats, and all of whom had at least one year of experience using the gear type under discussion. Based on official reports of the number of boats on the island, we spoke with representatives from about 3% of the roughly 2500 boats 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; fewer than 1% of fishers we observed were women.

In addition to the fisher interviews, we conducted brief interviews with seahorse buyers. 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 ($n=15/39$). We interviewed five buyers, who had been purchasing seahorses for six to twenty years (10.9 ± 6 , $n=5$).

2.3.2 Description of fisheries

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 2.1): otter trawl nets ($n=55$), compressor diving equipment ($n=10$), crab nets ($n=6$), beam trawl nets ($n=4$), and pair trawl nets ($n=2$). Working alone or in groups of up to 12, fishers operated motorized boats ranging in size from 6 to 20m long (10.1 ± 4 m, $n=71$). They fished in sand, mud, seagrass, and coral reef at depths up to 60m (Table 2.1). 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 similar for otter trawls, beam trawls, divers, and crab nets, although we lack data for pair trawlers (Table 2.2). These gear types were deployed for similar number of days per month, 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 ($P<0.05$).

2.3.3 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 of whom 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 ($F=10.13$, $df=4$, $P < 0.05$, Figure 2.2; $F=10.91$, $df=4$, $P < 0.05$, Figure 2.3). 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 ($P<0.05$).

The mean size of seahorses that fishers reportedly caught did not vary by gear type (though sample sizes were not large enough for pair trawls to be included in this analysis). There was no significant difference in the size of seahorses caught by fishers using beam trawls, otter trawls, compressor diving equipment, or crab nets (Figure 2.4, $F=0.87$, $df=4$, $P > 0.05$).

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.

2.3.4 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 30mm ($n=23/35$). 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 for 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 ($n=11$).

2.3.5 Changes over time

Fishers reported declines in seahorse CPUE, decreased mean size 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 (Figure 2.5). 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 size of seahorses being caught over the past ten 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 ($r^2=0.72$, $P < 0.05$, Figure 2.6).

2.3.6 Perceptions of sustainability

Most respondents were concerned about the sustainability of the fishery, with 63% saying that it was not sustainable ($n=35/56$). Of these, 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 ($n=21/56$) said that seahorse fishing was sustainable ($n=21/56$). Twelve 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 sustainability 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 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.

2.3.7 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), 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 is 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 ten 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 kilograms of fresh seahorses per day, to a maximum of 100 kg in one day, according to one major buyer. Now they can obtain less than 1kg of seahorses per day ($n=4$). Only one buyer commented on the change in size of seahorses. He noted that seahorses > 12cm 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.

2.4 Discussion

Our study revealed that fishers off Phu Quoc have made the remarkable 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. They reported declines in catch rates of up to 95% between 2004 and 2014, while the ex-vessel price of seahorses rose by 534%. Moreover, some fishers and buyers indicated that seahorses had decreased in size over time. 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 exporter of live wild seahorses (UNEP-WCMC, 2015) yet seahorses are also consumed domestically to an extent that is not fully appreciated. 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 managed.

Ours is a rare example where active gears – specifically beam and otter trawls – are deliberately employed to catch seahorses. Many gear types throughout the world catch seahorses incidentally (Vincent et al., 2011), but targeted seahorse fishing is only well documented in the Philippines where seahorses are caught by hand along with many other species (Baum and Vincent, 2005; Vincent et al., 2007). Targeted seahorse fishing using trawl nets has been noted in Thailand and Malaysia but these fisheries have not been analyzed quantitatively (Perry et al., 2010). This is the first comparison of targeted and incidental seahorse fisheries, and raises further questions about the global nature of seahorse fishing.

The Phu Quoc seahorse fishery differed from other documented Southeast Asian seahorse fisheries in terms of catch rates and seahorse size. Mean CPUE based on fishers' reports ranged from 1.3 to 92.7 seahorses boat⁻¹ day⁻¹. In other parts of Asia, in contrast, seahorse CPUE ranges from 0.1-10 seahorses boat⁻¹ day⁻¹, with most boats catching around 1-2 seahorses boat⁻¹ day⁻¹ (Giles et al., 2006; Meeuwig et al., 2006; Perry et al., 2010; Salin and Yohannan, 2005; Vincent et al., 2007). If the catch rates reported by Phu Quoc fishers are accurate (though they are likely overestimated; O'Donnell et al., 2012), they are much higher than previously documented seahorse fisheries. Fishers' estimates of seahorse size (80-100mm) were not specific to any species, nor did they reveal the proportion of individuals that were caught before reaching maturity. Landings surveys should be conducted on Phu Quoc in order to determine the accuracy of fishers' estimates of seahorse CPUE, size, and fishing seasonality.

The declines in seahorse CPUE reported in our study – of about 90% over 2004 to 2014 – are consistent with some investigations of historical seahorse fishing (Giles et al., 2006; Pajaro et al., 1997), while others 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 declines must raise questions about population health and fisheries sustainability (Harley et al., 2001). That said, while the trends in CPUE are clear, fishers’ recall is seldom entirely accurate and the rate of decline in seahorse catch may have been different than stated. For example, a previous study showed that fishers’ reported CPUE values in the central Philippines might be double the actual values (O’Donnell et al., 2012). Our ability to understand past declines is limited by our lack of fishing effort and fleet size data during this time period (2004-2014), which would affect the interpretation of declines in CPUE. Additionally, changes in the size of seahorses and species composition would influence our calculation of CPUE as we used a constant conversion of weight-to-individuals.

The decrease in seahorse CPUE and increase in ex-vessel price reported by fishers indicate a fishery where demand outstrips supply. The demand generated by Traditional Chinese Medicine (TCM) has increased with human population growth and rising affluence (Chen et al., 2007), placing higher pressure on desirable rare species (Still, 2003). As the demand for seahorses rises, many areas where seahorses are caught have experienced similar declines in catch (Giles et al., 2006; Pajaro et al., 1997). 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.

This study gives plenty of warnings that the Phu Quoc exploitation of seahorses is probably unsustainable, and that management is urgently needed. Yet, 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. Any such measures will need to be developed in conjunction 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 exports of six species (*Hippocampus comes*, *H. histrix*, *H. kelloggi*, *H. mohnikei*, *H. spinosissimus*, and *H. trimaculatus*) do not damage wild populations even as it tries to lift the ban on exports of *H. kuda*. 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 effect of its fisheries and trade management. Hopefully 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.

Table 2.1 Description of some of the fishing gears and boats used in Phu Quoc’s fisheries, based on interviews with local fishers. Targeted organisms and habitats are listed in order of most common to least common response.

Fishing gear	<i>N</i>	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 2-4 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	6-20m 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	2-60m	1-6 cm	12-20m long with 56 – 110 hp engine	7-12
Beam trawl	4	Seahorses, shrimp, squid	Cone-shaped net, whose horizontal opening is provided by a 5-6m 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	2-12m	2-3 cm	6-10m long with 15-22hp engine	1-2
Compress or (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 300m-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	2-30m	N/A	6-10m long with 8-24hp engine	1-4
Crab net	6	Swimming crab, mud crab	Stationary net 1-2m high and 1-6km long weighted with cement blocks.	Weighted nets left in the water and checked daily.	Sand, mud, small rocks	2-30m	3-10 cm	7-8m long with 8-24 hp engine	2-3

Table 2.2 Fishing effort of four fishing gears used in Phu Quoc's fisheries, based on interviews with local fishers.

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

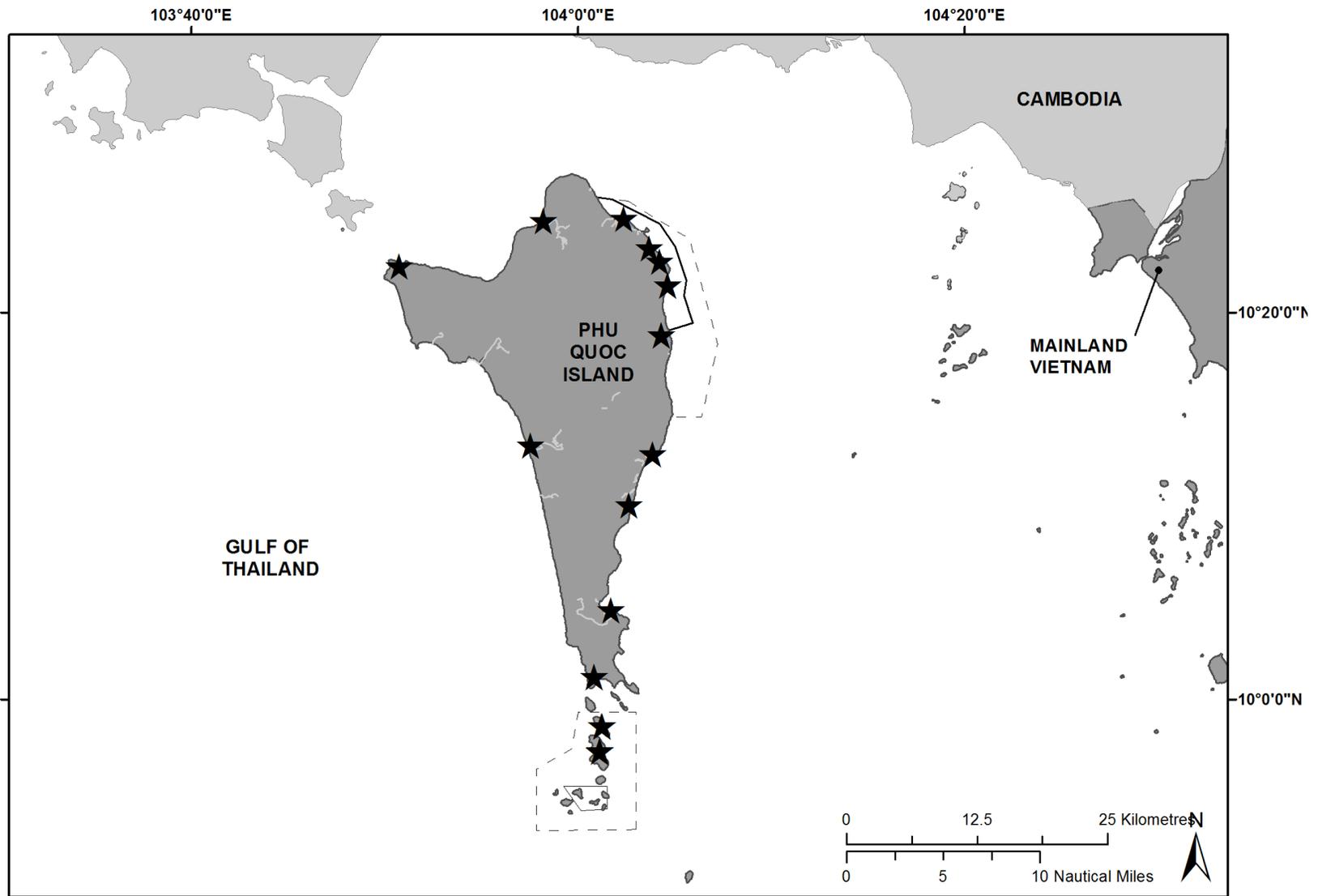


Figure 2.1 Map of study location in southern Vietnam showing Phu Quoc Island and the thirteen An Thoi Islands, as well as mainland Vietnam (dark grey) and Cambodia (light grey). Stars indicate sites where fishers and buyers were interviewed, including An Thoi, Bai Thom, Cay Sao, Da Bac, Ganh Dau, Ham Ninh, Hon Roi, Hon Thom, Rach Tram, Vinh Dam, and Xa Luc. 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).

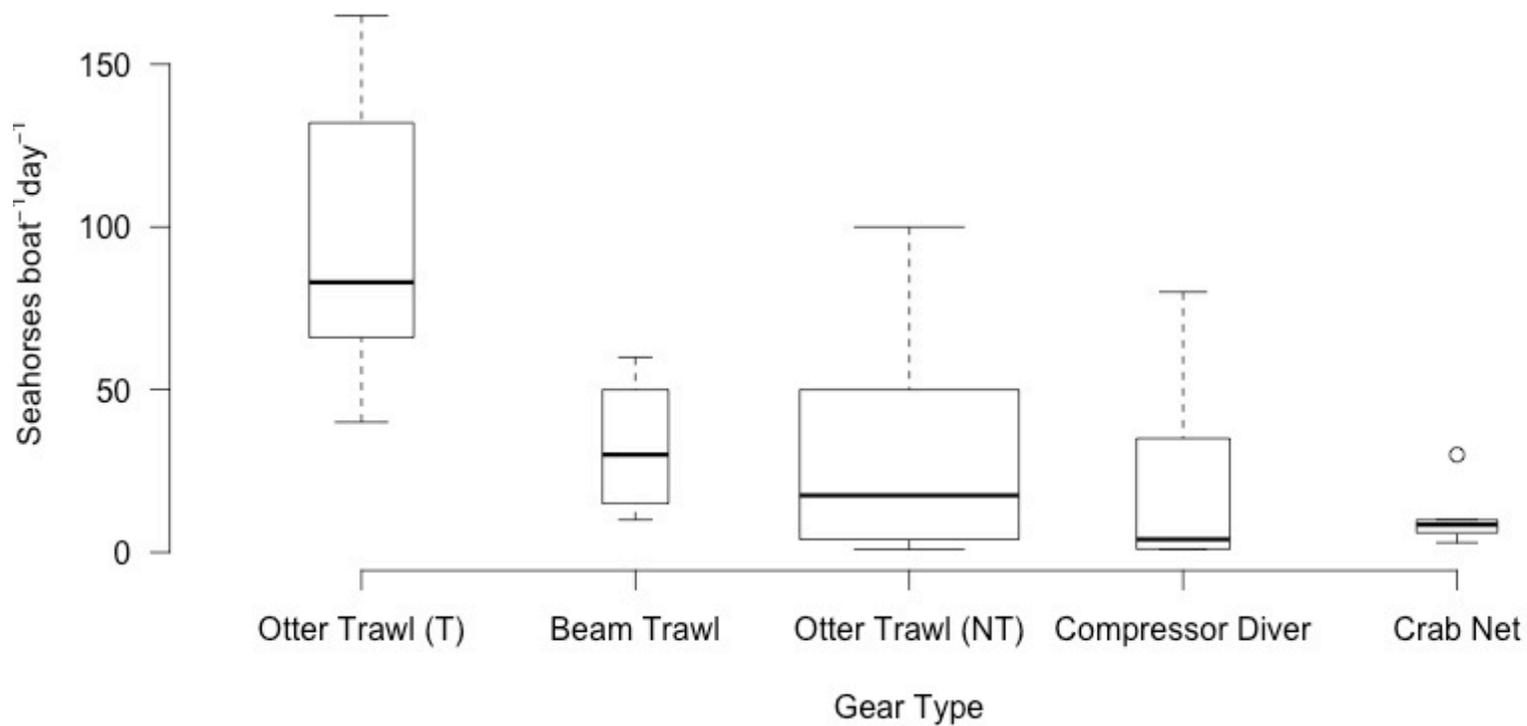


Figure 2.2 Maximum CPUE estimated by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets. Width of boxplots is proportional to sample size (n = fishers interviewed). Median number of seahorses caught per boat per day by target otter trawls=83, $n=10$; beam trawls=30, $n=4$; non-target otter trawls=17.5, $n=44$; compressor divers=4, $n=8$, crab nets=8.5, $n=6$.

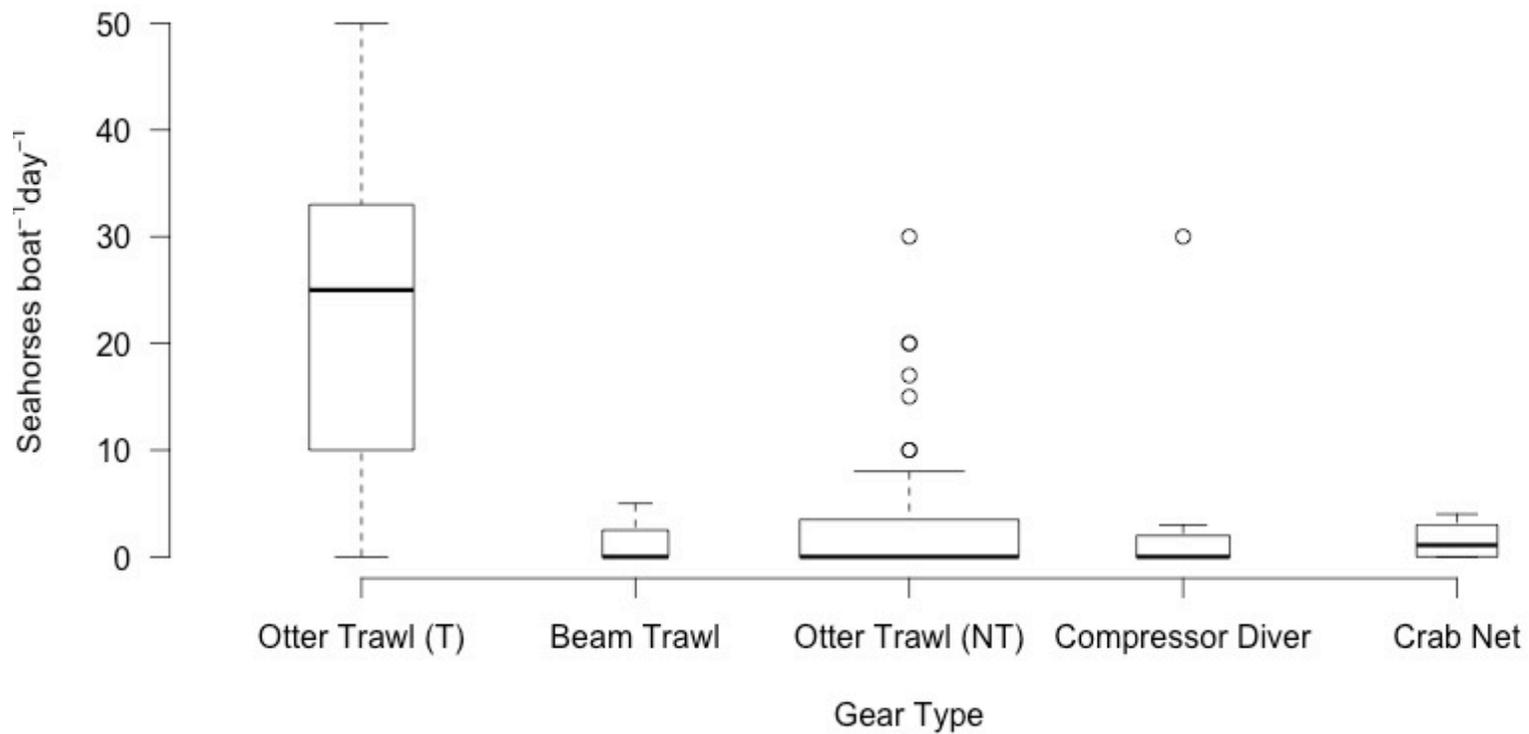


Figure 2.3 Minimum CPUE estimated by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets. Median number of seahorses caught per boat per day by target otter trawls=25, $n=10$; beam trawls=0, $n=4$; non-target otter trawls=0, $n=44$; compressor divers=0, $n=8$, crab nets=1.1, $n=6$. Width of boxplots is proportional to sample size.

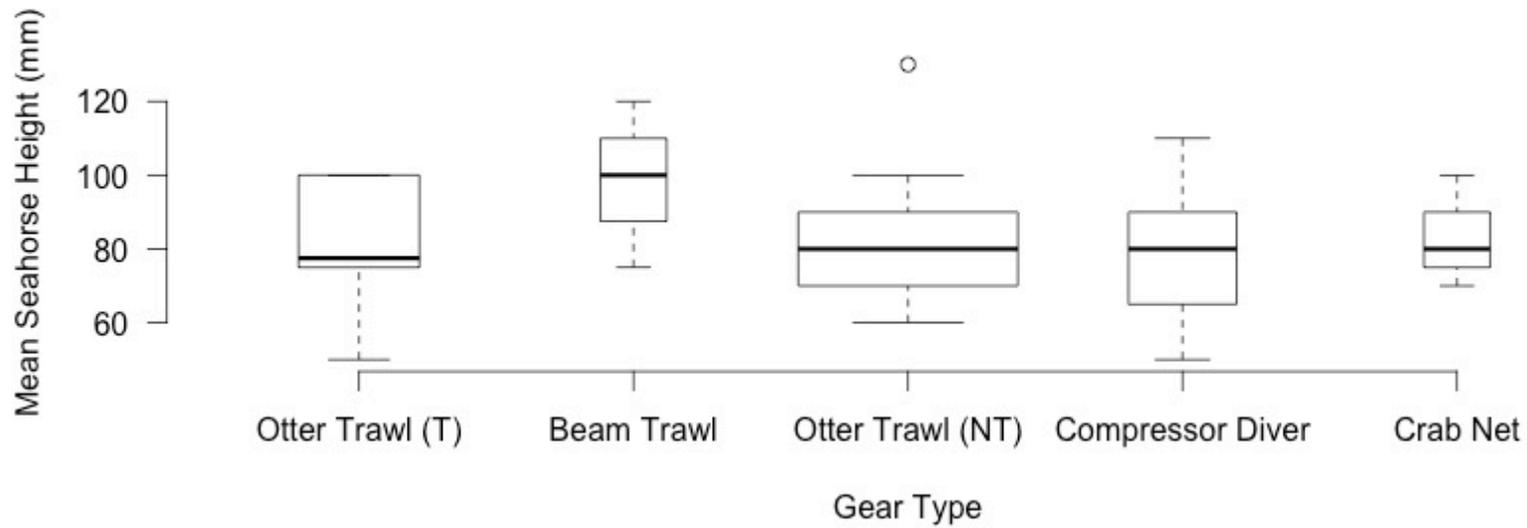


Figure 2.4 Estimated mean height of seahorses caught by fishers using otter trawls (target), beam trawls, otter trawls (non-target), compressor diving and crab nets. Median of mean seahorse height for target otter trawls=77.5, $n=10$; beam trawls=100, $n=3$; non-target otter trawls=80, $n=33$; compressor divers=80, $n=8$, crab nets=80, $n=3$. Width of boxplots is proportional to sample size.

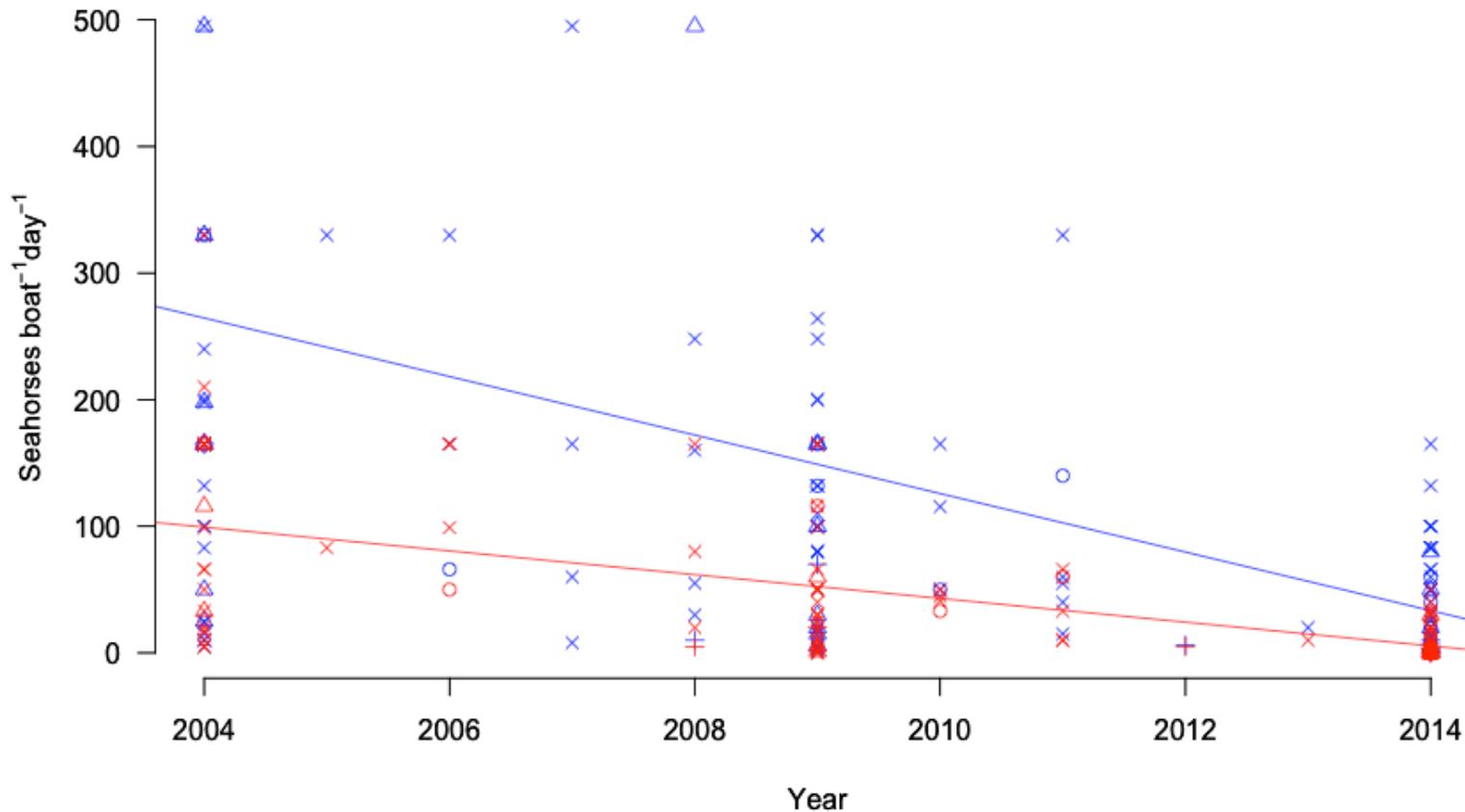


Figure 2.5 Declines in seahorse CPUE from 2004 to 2014 as reported by fishers. Estimates of maximum past catches in blue ($y = -23.12x + 46600.34$; $r^2 = 0.16$, $P < 0.05$), estimates of minimum past catches in red ($y = -9.392x + 18920.545$, $r^2 = 0.39$, $P < 0.05$).

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.

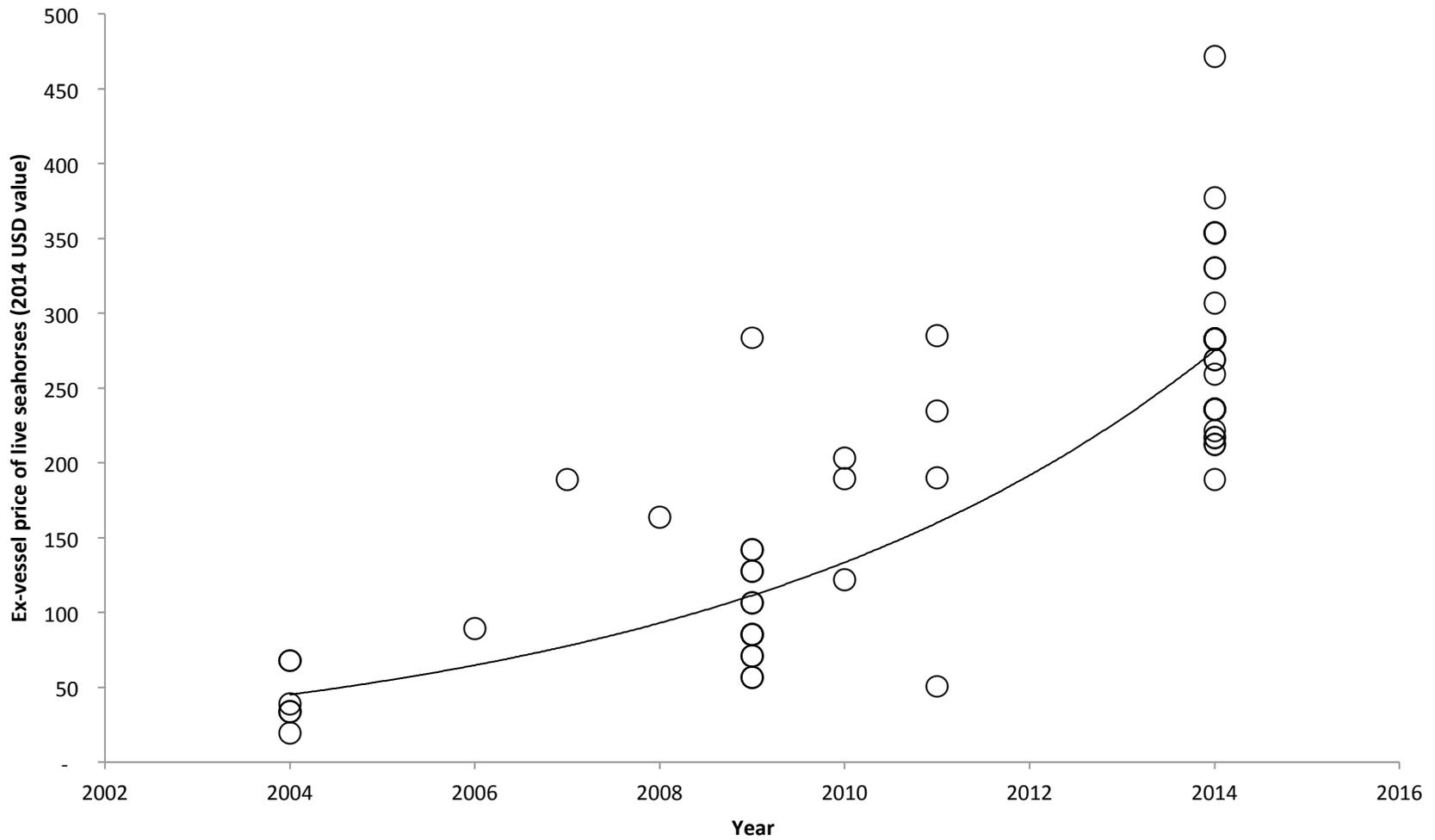


Figure 2.6 Increase in ex-vessel price of live seahorses from 2004-2014 as reported by fishers. $y=2E-156e^{0.1808x}$, $R^2= 0.72$, $P < 0.05$.

Chapter 3: Catch as Catch Can: Extracting Seahorses Using Multiple Fishing Strategies

3.1 Introduction

In the wake of declining fish stocks, fisheries have adapted by spreading spatially, employing a multitude of gears, and targeting smaller and more diverse marine organisms (Pauly et al., 1998). As fishing efficiency improves, marine resources are exploited at the risk of local extinction (Dulvy et al., 2003). Because of these ‘catch-all’ tactics, many inshore fisheries in developing countries face serial depletion, where fishers move to alternative resources or locations to obtain their catch (Berkes et al., 2006; Huitric, 2005). Although these fisheries apply pressure to all species, many smaller species tend to be overlooked in research and management efforts (Vincent et al., 2011; Wilson et al., 1994). This is in part due to the fact that many of these species may have previously been caught opportunistically or as bycatch (Alverson et al., 1994; Davies et al., 2009). As a result, the fishing pressure on these low-priority species is left unregulated, leaving them at risk of being overexploited (Hutchings and Reynolds, 2004; Powles, 2000).

Documenting the catch and effort of different gear types is a critical research challenge necessary to the broader goals of management and enforcement. Quantifying catch is especially difficult for small-scale fisheries in developing countries where low enforcement capacity and corruption prevent regular monitoring (Agnew et al., 2009; Berkes, 2003; Sumaila et al., 2006). These small-scale fisheries are also challenging to monitor because they involve multiple gear types targeting multiple species (Chuenpagdee et al., 2006; Hicks and McClanahan, 2012).

Furthermore, fishers generally land their catch at widely dispersed, remote landing sites (Salas et al., 2007). Where catch information does exist, it tends to focus on large marine fish of commercial importance, while reliable information on smaller marine species – especially those caught as bycatch and with limited export markets – is scarce (Lawson et al., *in review*).

Seahorses (genus *Hippocampus*) are economically valuable species that are readily extracted by fishers using many different gears (Baum et al., 2003; Vincent et al., 2007). 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 – in countries such as India, Malaysia, Thailand, Brazil, and the Philippines (Marichamy and Lipton, 1993; Perry et al., 2010; Rosa et al., 2011, 2005; Vincent et al., 2007). However, the majority of seahorses are caught as bycatch in non-selective gears such as trawl nets and purse seines (Baum and Vincent, 2005; Baum et al., 2003; Perry et al., 2010). 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.

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). One such agreement increasingly being used to improve the status of fish populations is the Convention on

International Trade in Endangered Species of Wild Flora and Fauna (CITES). All seahorse species were added to Appendix II of CITES in 2002, which requires the 181 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 are adaptive management plans for the exploitation of wild populations (Murphy, 2006; Rosser and Haywood, 2002). The vast majority of seahorse-exporting nations do not have a sufficient understanding of their wild seahorse populations or fisheries to make defensible NDFs (Smith et al., 2011; Vincent et al., 2011). In order to ameliorate this and develop effective management, the first step is to gain an understanding of the pressures facing seahorse populations.

In Vietnam, seahorses are caught in vast quantities for global export and domestic consumption, but this extraction is not regulated. According to CITES reports, the total number of seahorses exported from Vietnam per year between 2004 and 2011 was between 20,000 and 90,000 (UNEP-WCMC, 2012). This is likely an underestimation, since many exports are undocumented (Foster et al., 2014) and historic data from pre-CITES trade surveys suggest much higher figures (Giles et al., 2006). Not only are they exported in vast quantities, but seahorses are also consumed within Vietnam as tonics to promote kidney health and increase sexual potency (Giles et al., 2006). There is evidence that the exploitation of seahorses is causing declines in wild populations in Vietnam (Giles et al., 2006; Long and Hoang, 1998) but Vietnam has no official management measures in place to regulate this 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, 2013a). This is the first export ban ever imposed for any marine fish species under a multilateral environmental agreement. It

highlights an urgent need to collect fisheries and biological data in Vietnam since *H. kuda* can still be traded domestically, and all other seahorse species in Vietnam can still be traded domestically and internationally.

Our objectives in 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; and 4) draw conclusions about the overall sustainability of a seahorse fishery in southern Vietnam. By comparing and contrasting fishing methods in this area for a suite of seahorse species, we identified high pressure points in the fishery in order to prioritize future monitoring efforts. This research will contribute to the development of an adaptive management plan for sustainable seahorse fisheries in Vietnam.

3.2 Materials and methods

3.2.1 Study site

In a large study of Vietnamese seahorse fisheries 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). Anecdotal fishing reports identified the Phu Quoc District in the Gulf of Thailand (from 9.45 -10.30° N to 103.55 – 104.05° E) as an area where seahorses were caught in multiple fishing gears. Thus we chose this as our research location. 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 km²). Fishing grounds between the island and the mainland are greater than 5000km². Maximum water depth to the east of Phu Quoc is approximately 10m and the substrate is predominantly soft-bottom (sand or mud) and seagrass (Otero-Villanueva and Ut,

2007). The north and east coasts of Phu Quoc Island face inshore to mainland Cambodia (within 10km) and Vietnam (40km), while the west coast and southern An Thoi islands are more exposed to the Gulf of Thailand (Figure 3.1).

Our surveys focused on ports along the east coast of Phu Quoc, where fishers operated in shallow (mostly <10m deep) fishing grounds and caught seahorses. Fishing grounds were grouped into three regions: north, central, and south (Figure 3.1). 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 marine protected areas (MPAs) that were funded by the Danish International Development Agency and implemented in 2007 under statute 1297/2007 QD-UBND (DANIDA-Copenhagen and Ministry of Agriculture and Rural Development, 2011). Under this statute, fishing activity is prohibited, but enforcement of the MPAs is extremely limited, and fishing still occurs.

3.2.2 Fisheries-dependent surveys

From April to July 2014, catches were surveyed for *Hippocampus* spp. at 10 landing sites along the east coast of the islands (Figure 3.1): seven 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 higher volumes of seahorses (see Chapter 3). These gears were then categorized by whether they targeted seahorses or caught them incidentally (referred to hereafter as: targeted divers, incidental divers, target trawls, and incidental 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, incidental dive, target trawl, and incidental 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, effort was documented as gear type, trip length, active fishing time, fishing depth, fuel use, and distance from shore. When seahorses were landed the total number of individuals and/or total mass of the landings was recorded depending on whether the seahorses were live or dead. If the seahorses were sold immediately to a buyer, the price paid for the seahorses was recorded. Whenever fishers allowed, the species, sex, height, mass, and reproductive state of each seahorse in the landings were recorded. Seahorses were identified using the taxonomy of 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). In contrast, standard length would have been the total length from the snout tip to where the opercular ridge and mid-

line meet to the tail tip (Lourie et al., 1999). Male seahorses were visually distinguished from females by the presence of a brood pouch or, for juvenile males, the presence of a darkened oval zone where a brood pouch was developing (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).

3.2.3 Data analyses: fisheries catch and effort

For nearly all catch landings, both the total number of seahorses and total mass of the seahorse catch were recorded. These data were used to calculate a conversion for kilograms of live seahorses to the number of individual live seahorses, using a general linear model. In the few instances where only the total mass of the seahorse catch was recorded, the conversion ratio was used to determine the equivalent number of live individuals.

Landings and trip durations were used to calculate seahorse catch per unit effort (CPUE) (seahorses day⁻¹ boat⁻¹). Analysis of variance (ANOVA) tests were used to examine mean CPUE by fishery, fishing location, and habitat substrate (data met assumptions of ANOVA tests).

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. Mean CPUE was extrapolated to estimate total annual seahorse catch using reported fleet sizes (Phu Quoc Economic Department, 2015) and a measure of annual vessel effort based on weather, rest days, and gear rotation. Median CPUE was not used to scale to total annual catch because it obscured occasional catches. Total annual catch was compared between fisheries and location,

but data did not allow for comparison of total catch among substrates. All statistical analyses in our study were carried out in the R statistical platform (R Development Core Team; www.r-project.org).

3.2.4 Data analyses: 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 seahorse samples (85%) were collected directly from catch landings ($n=1319$).

Supplementary samples ($n=227$) were collected from buyers at their market stalls, or from fishers' seahorse collections at home, but were used only to calculate species height at maturity (see below). Nearly all seahorse samples were measured by hand, but a few specimens were photographed and later measured digitally 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 $HMH=2.1869(DMH)^{0.8297}$ (Appendix B).

After mathematical conversion, digitally measured sample heights were not significantly different from hand-measured sample heights (Mann–Whitney U -test for *H. spinosissimus*: $W = 2724$, $P > 0.05$; *H. trimaculatus*: $W = 1846$, $P > 0.05$). There was no significant difference in mean height between dry and wet samples (Mann–Whitney U -test for *H. spinosissimus*: $W = 17428$, $P > 0.05$; *H. trimaculatus*: $W = 10014$, $P > 0.05$) so all samples were pooled in subsequent analysis.

Height at physical maturity (H_M), the point at which 50% 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. Sex ratio was calculated as the number of mature males to the number of mature females of a species. A chi-square test was used to identify if the ratio was significantly different from unity for each fishery. Minimum, maximum, median, and mean heights were compared between fisheries for each *Hippocampus* spp. using ANOVA.

3.3 Results

3.3.1 Description of fisheries

Approximately 124 bottom trawl boats and 46 compressor diving boats operated from the islands and regularly caught seahorses (see Chapter 2 for gear descriptions). Of this total, six dive boats and 24 trawl boats (a mix of otter and beam trawls) targeted seahorses specifically (see Chapter 2 for detailed information on target and non-target seahorse fishing). Most boats fished indiscriminately (40 dive boats and 100 trawl boats), catching seahorses incidentally 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.

3.3.2 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, incidental divers, target trawls, and incidental trawls (ANOVA, $F=98.25$, $df=3$, $P < 0.05$).

A post hoc Tukey test showed that target fishing was significantly different from non-target fishing ($P < 0.05$), 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 (Figure 3.2, Table 3.1). In contrast, the CPUE from incidental trawls was much lower, while incidental divers had the lowest CPUE (Figure 3.2, Table 3.1). Seahorse catch rates also varied regionally ($F=34.18$, $df=2$, $P < 0.05$), with each group being significantly different based on a post hoc Tukey test ($P < 0.05$). The highest CPUE for target divers was in the central region while incidental divers had a slightly higher CPUE in the north than the central region (Table 3.2). CPUE was highest in the south for both target trawls and incidental trawls (Table 3.2).

Seahorse CPUE varied by substrate for both compressor divers ($F=1.63$, $P < 0.05$) and trawl boats ($F=4.89$, $df=5$, $P < 0.05$). Based on a post hoc Tukey test, the CPUE of divers (both target and incidental combined) was significant ($P < 0.05$) in sandy areas (8.5 seahorses boat⁻¹ day⁻¹, $n=26$) and sandy, debris-strewn areas (8.4 seahorses boat⁻¹ day⁻¹, $n=18$). There was no significant difference in CPUE among areas of mixed seagrass, sand, and debris; coral reef; seagrass beds; or areas where substrate was unknown ($P > 0.05$). The CPUE of trawls (both target and

incidental combined) was significant ($P < 0.05$) in sandy, debris-strewn areas (13.2 seahorses boat⁻¹ day⁻¹, n=35) and seagrass beds (12 seahorses boat⁻¹ day⁻¹, n=21), while there was no significant difference between areas of mixed seagrass, sand, and debris; or areas where substrate was unknown ($P > 0.05$.)

3.3.3 Extrapolation of total catch per annum

We estimated that seahorse landings were between 162,000–234,000 individuals year⁻¹ with the majority (82%) coming from the target and incidental trawl fisheries (Table 3.1). These numbers represent 1200–1800 kg year⁻¹ based on 165 live seahorses kg⁻¹ (Appendix B). 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 3.2).

3.3.4 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 hedgehog seahorse *Hippocampus spinosissimus* Weber 1913, the three-spot seahorse *H. trimaculatus* Leach 1814, and the common seahorse *H. kuda* Bleeker 1852. Catch composition varied by gear type: target divers caught the highest proportion of *H. spinosissimus*, while incidental trawls and target trawls caught the highest proportion of *H. trimaculatus* and *H. kuda* respectively ($\chi^2=494$, d.f.=6, $P < 0.05$). When scaled to annual catch, target trawls caught the greatest number of *H. spinosissimus* and *H. kuda*, while incidental trawls caught the most *H. trimaculatus* (Figure 3.3). Catch composition also varied regionally, the highest proportion of *H. spinosissimus*, *H. kuda*, and *H. trimaculatus* were caught in the north, central, and south regions

respectively ($\chi^2=184$, d.f.=4, $P < 0.05$). When scaled to annual catch, the vast majority of *H. kuda* were caught in the central region, most *H. trimaculatus* were caught in the south and *H. spinosissimus* were widely caught across all regions (Figure 3.4).

For all gear types and species, mean height of captured seahorses was remarkably similar (Table 3.3). There was no difference between mean height of *H. trimaculatus* caught across the four fisheries, or *H. kuda* caught across the four fisheries ($F=0.2$, $df=3$, $P > 0.05$; $F=2.0$, $df=3$, $P > 0.05$). Mean heights of *H. spinosissimus* across the four different fisheries were, however, distinct ($F=9.75$, $df=3$, $P < 0.05$), with the smallest seahorses caught by target divers (post hoc Tukey test $P < 0.05$).

Species differed minimally in height at physical maturity (H_M), with confidence intervals overlapping for *H. trimaculatus* and *H. kuda* (see Appendix B for H_M graphs). H_M was 98.5mm for *H. spinosissimus* (95% C.I. = 97.3 – 99.7mm, $n = 324$), 108.8mm for *H. trimaculatus* (95% C.I. = 106.0 – 111.6mm, $n = 130$) and 106.1mm for *H. kuda* (95% C.I. = 101.0 – 111.2mm, $n = 26$). Incidental divers and incidental trawls caught the highest proportions of immature seahorses (Table 3.4).

In nearly all fisheries, there was an equal sex ratio for *H. kuda*, *H. spinosissimus*, and *H. trimaculatus* (Table 3.5). Only *H. spinosissimus* caught incidentally in trawl nets showed a skewed sex ratio, with more mature males sampled than mature females (61% males, $\chi^2=5.24$, $P < 0.02$).

3.4 Discussion

This is the first quantitative comparison of targeted and incidental seahorse capture by two fishing methods: bottom trawling and compressor diving. Fishers that targeted seahorses caught up to 20 times more seahorses per day than those that caught them incidentally. As a result, despite being a relatively small fishery, the target boats caught the majority of the total annual catch of seahorses from the area. Fleet size greatly influenced total annual catch, and since the majority of the fleet was made up of bottom trawls (both boats targeting seahorses and catching them incidentally), these boats placed the highest pressure on these fishes. Seahorses were primarily caught in open, sandy, debris-strewn areas where they are easily caught either by hand or by trawl nets that drag along the ocean floor. The majority of the catch came from the north and south of the island primarily because larger fleets of vessels operated in these areas. Efficient monitoring of the target fleet will determine the long-term impacts of seahorse fishing in the area and aid the development of effective management for sustainable wild seahorse populations.

About 95% of traded seahorses globally are caught incidentally (Vincent et al., 2011), making Phu Quoc one of the few documented cases of targeted seahorse fishing in the world. Moreover, fishers on Phu Quoc use both diving gear and trawl nets to target seahorses whereas all other target fisheries (in, for example) Brazil, India, Indonesia and the Philippines, involved hand collection of seahorses (Marichamy and Lipton, 1993; Rosa et al., 2011, 2005; Vincent et al., 2007). Though physically high-risk, compressor diving requires low fuel, small boats, and only one or two crewmembers to be economically feasible (Ferse et al., 2012). Trawl fishing, however, requires greater fuel use, larger boats, and more crewmembers, making searching for seahorses a riskier investment (Suuronen et al., 2012). Rising fuel costs globally will

disproportionately affect developing countries, with low-income families receiving the least benefit from subsidies (Arze del Granado et al., 2012). This could decrease the economic viability of targeted seahorse trawl fishing and lead these fishers to target other species, use other gear types, or perhaps engage in biomass trawling with no target species.

Target fishers on Phu Quoc caught seahorses at higher rates than all documented cases of seahorse fishing around the world (e.g. Vincent et al., 2007; Perry et al., 2010; Giles et al., 2006). 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 2.9-3.4 seahorses boat⁻¹ night⁻¹ in the Philippines (Vincent et al., 2007), 0-3 seahorses boat⁻¹ day⁻¹ in Malaysia (Perry et al., 2010), 0.6-1.1 seahorses boat⁻¹ day⁻¹ in Thailand (Perry et al., 2010), and 1-10 seahorses boat⁻¹ day⁻¹ in the Gulf of Mannar (Salin and Yohannan, 2005). It is likely these studies may have inadvertently combined target and non-target fishing, and further investigations of seahorse fishing should explicitly investigate whether the seahorses are being caught intentionally or as bycatch in order to improve catch estimates.

Phu Quoc fisheries may be placing size-specific pressure on seahorse populations. The seahorses in our study were, on average, 25% smaller by weight than seahorses examined in a similar fisheries study in central Vietnam (Meeuwig et al., 2006), where the catch composition was very near to that of Phu Quoc (comprised mostly of *H. spinosissimus* and *H. trimaculatus*). Such a difference may suggest a decline in adult size over the past ten years 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 height at physical maturity (H_M) of the seahorses in our study were slightly different from other recent investigations in Southeast Asia: our estimates of H_M for *H. spinosissimus* were fairly similar (Lawson et al., 2014), slightly larger for *H. trimaculatus* (Lawson et al., 2014) and much smaller for *H. kuda* (Lourie et al., 1999). This could be due to variations in measuring techniques or demonstrate that species might be subjected to differences in size-specific pressure, as there is no clear pattern across species. The majority of seahorses caught in our study were larger than their species' average height at maturity, adhering to the "spawn-at-least-once" principle (Myers and Mertz, 1998). However, up to 40% of the catch of indiscriminate trawls and divers was immature. While this is considered within precautionary limits for sustainable populations, if this rose above 50% juveniles, it could adversely affect seahorse populations (Vasilakopoulos et al., 2011).

Bottom trawl boats, both target and incidental, were the source of the greatest sex- and species-specific pressures. Only the incidental trawl fleet caught an unbalanced proportion of males to females, with 61% males. While this is not alarmingly imbalanced, catching more males than females is particularly problematic for seahorses because of their lengthy and specialized male parental care (Foster and Vincent, 2004). As target trawls caught the greatest number of *H. kuda*, efforts to manage and protect this species would be best placed on these boats. This is particularly important because CITES has banned exports of *H. kuda* until Vietnam can prove they do not damage wild populations, which will require regulating fisheries and domestic consumption of these fish. Regulating targeted seahorse trawl fishing would also benefit *H. spinosissimus*, but not greatly affect catches of *H. trimaculatus*, which were mostly obtained in the south by incidental trawls. Bottom trawling in general is extremely destructive (Althaus and

Williams, 2009; Jones, 1992), so focusing management efforts on these boats could be beneficial for the entire ecosystem.

The estimated total annual seahorse catch from Phu Quoc exceeds Vietnam's annual documented exports (UNEP-WCMC, 2015) so the excess is either exported illegally without records or consumed domestically. According to official CITES statistics, the reported seahorse exports from Vietnam ranged from 20-90,000 individuals per year between 2004 and 2012 (UNEP-WCMC, 2015). These official exports for the entire country are less than 45% of our estimated total annual seahorse catch from Phu Quoc and less than 5% of the estimated total annual seahorse catch in Vietnam (Giles et al., 2006). It seems unlikely that domestic consumption accounts for the other 95% of the catch and previous trade surveys suggest that illegal, unreported, and unregulated (IUU) exports may well occur (Giles et al., 2006).

Total annual seahorse catch from the area may pose a threat to local seahorse populations based on experiences in other regions (Vincent et al., 2011) and historic data from Phu Quoc (Chapter 2). 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 (Curtis et al., 2007; Foster and Vincent, 2004; Martin-Smith and Vincent, 2005; Vincent et al., 2005). Unregulated exploitation of seahorses is likely affecting wild populations (Vincent et al., 2011), with fishers globally reporting declines in seahorse catch rates (Giles et al., 2006; Perry et al., 2010; Vincent et al., 2007). 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 (Chapter 2). Furthermore, Phu Quoc has experienced

heavy fishing pressure over the past 20 years, with documented declines in overall fish CPUE, overexploitation of sea cucumbers and pearl oysters, and the disappearance of dugong and sea turtle (Hines et al., 2008; Otero-Villanueva and Ut, 2007; WWF, 1993). Monitoring the fleet size and total annual catch in future years will determine whether seahorses can withstand this fishing pressure, though precautionary measures must be implemented and enforced in the meantime.

Establishing a simple monitoring program on Phu Quoc that focuses on the target fisheries – which involve fewer boats, each with higher CPUE – will most efficiently provide indications of whether seahorses are being overfished. Monitoring the target boats from a few key locations (i.e. one port in the north, central, and south) a few times a year would require minimal time and funds, yet could yield enough data to determine trends in CPUE, species proportions, and species size along with changes in fishing practices. 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.

Phu Quoc seahorse fisheries require improved management efforts in order to ensure their sustainability. First and foremost, enforcing the marine protected areas and encouraging fishers to respect these reserves would benefit not only seahorses but also benthic habitat and many other species (Gell and Roberts, 2003; Mosquera et al., 2000; Roberts et al., 2001). Other possible fisheries management options include seasonal fishing restrictions (which exist in the area but are minimally enforced) or minimum size limits. Size limits can be difficult to enforce and adhere to (Foster and Vincent, 2013), especially for gears like trawls that are the highest concern in this fishery. However, based on our measures of H_M , an 11cm minimum size for

allowable seahorse catch might ensure that all three seahorse species reach maturity before being fished. This is slightly higher than the 10cm minimum size now recommended by CITES, which may not be providing adequate protection at this time for *H. kuda* and *H. trimaculatus*, which mature past this height.

Table 3.1 Mean catch-per-unit-effort of seahorses \pm standard error (seahorses boat⁻¹ day⁻¹) and estimated total landings per annum for the Phu Quoc trawl fishing fleet and compressor diver fishing fleet. *n*=number of fishing trips sampled.

Fishery	<i>n</i>	Mean CPUE (\pm 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 (\pm 5.6)	6	150	28 620	23 580	33 660
Incidental divers	117	1.3 (\pm 0.2)	40	150	7 800	6 600	9 000
Target trawls	42	23.3 (\pm 2.9)	24	200	111 840	97 920	125 760
Incidental trawls	123	2.5 (\pm 0.8)	100	200	50 000	34 000	66 000
Total					198 260	162 100	234 420

*Estimates of fleet size and number of days fished are based on interviews with fishers in communities across Phu Quoc Island (Chapter 2) and consultations with Vietnamese fisheries officials.

Table 3.2 Mean catch-per-unit-effort of seahorses \pm standard error (seahorses boat⁻¹ day⁻¹) of each fishery by region fished and estimated total landings per annum (seahorses year⁻¹). *n*=number of fishing trips sampled.

	North				Central				South			
	<i>n</i>	Mean CPUE (\pm S.E.)	Fleet Size	Annual landings	<i>n</i>	Mean CPUE (\pm S.E.)	Fleet Size	Annual landings	<i>n</i>	Mean CPUE (\pm S.E.)	Fleet Size	Annual landings
Target												
divers	2	14.5 (\pm 3.5)	1	2175	13	34.5 (\pm 6.1)	5	25875	0	NA	0	NA
Incidental												
divers	59	1.4 (\pm 0.3)	15	3150	54	1.2 (\pm 0.4)	10	1800	4	0.5 (\pm 0.5)	15	1125
Target												
trawls	9	18.1 (\pm 6.3)	12	43440	20	14.7 (\pm 2.3)	4	11760	13	40.1 (\pm 5.4)	8	64160
Incidental												
Trawls	73	1.7 (\pm 0.6)	30	10200	37	3.2 (\pm 2.2)	10	6400	13	5.2 (\pm 1.9)	60	62400
Total				58,965	Total			45,835	Total			127,685

Table 3.3 Minimum, mean, median, and maximum heights (mm) for sampled seahorses in the four fishery types.

	<i>H. spinosissimus</i>					<i>H. trimaculatus</i>					<i>H. kuda</i>				
	<i>n</i>	Min	Mean	Median	Max	<i>n</i>	Min	Mean	Median	Max	<i>n</i>	Min	Mean	Median	Max
Target divers	145	55	98*	102	140	22	100	118	120	132	1	-	-	-	-
Incidental divers	68	58	103	108	140	14	100	115	114	132	15	91	127	128	147
Target trawls	28	86	118	119	144	1	-	-	-	-	4	95	115	118	128
Incidental trawls	152	55	102	104	142	112	82	117	120	168	11	100	116	115	131

Table 3.4 Proportion of juvenile seahorses in catch by fishery.

	Immature <i>H. spinosissimus</i> (% of catch)	Immature <i>H. trimaculatus</i> (% of catch)	Immature <i>H. kuda</i> (% of catch)
Target divers	33	12	n/a
Incidental divers	40	40	5
Target trawls	17	n/a	9
Incidental trawls	31	29	6

Table 3.5 Counts of males to females along with sex ratios and p-values from χ^2 -tests for sampled seahorses in the four fisheries.

	<i>H. spinosissimus</i>		<i>H. trimaculatus</i>		<i>H. kuda</i>	
	<i>M:F</i>	Ratio (p-value)	<i>M:F</i>	Ratio (p-value)	<i>M:F</i>	Ratio (p-value)
Target divers	114:100	1.14 (0.34)	15:15	1 (1)	0:1	-
Incidental divers	32:22	1.45 (0.17)	7:2	3.5 (0.1)	9:11	0.82 (0.65)
Target trawls	22:33	0.67 (0.14)	2:2	1 (1)	64:55	1.16 (0.41)
Incidental trawls	67:43	1.56 (0.02)	41:44	0.93 (0.74)	9:8	1.13 (0.81)

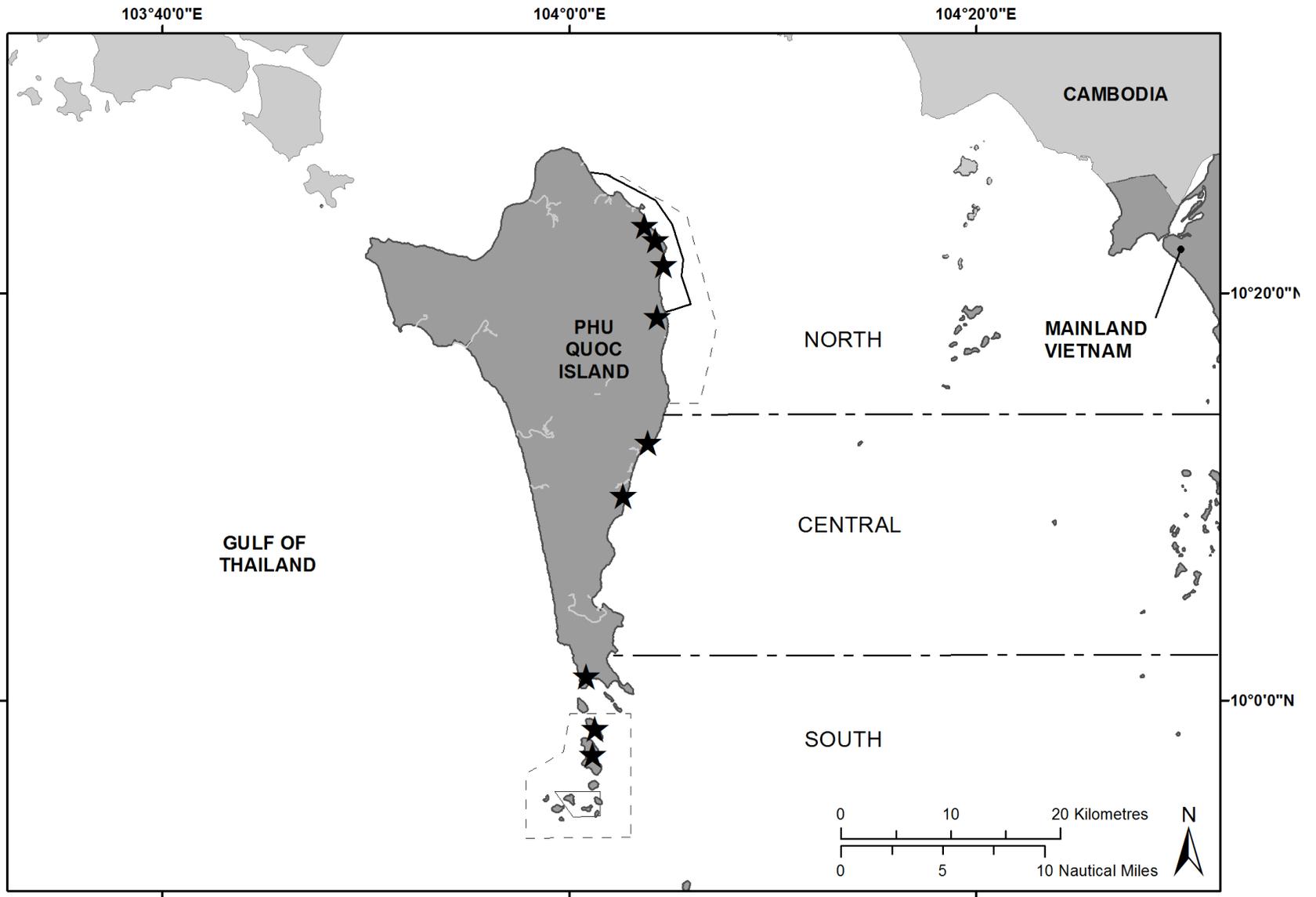


Figure 3.1 Map of study location in southern Vietnam showing Phu Quoc Island and the thirteen An Thoi Islands, as well as mainland Vietnam (dark grey) and Cambodia (light grey). Stars indicate sites sampled for fisheries data (from north to south): Xa Luc, Da Chong, Bai Bon, Ham Ninh port, Ham Ninh village, 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). Dot-dash lines denote fishing areas (north, central, and south).

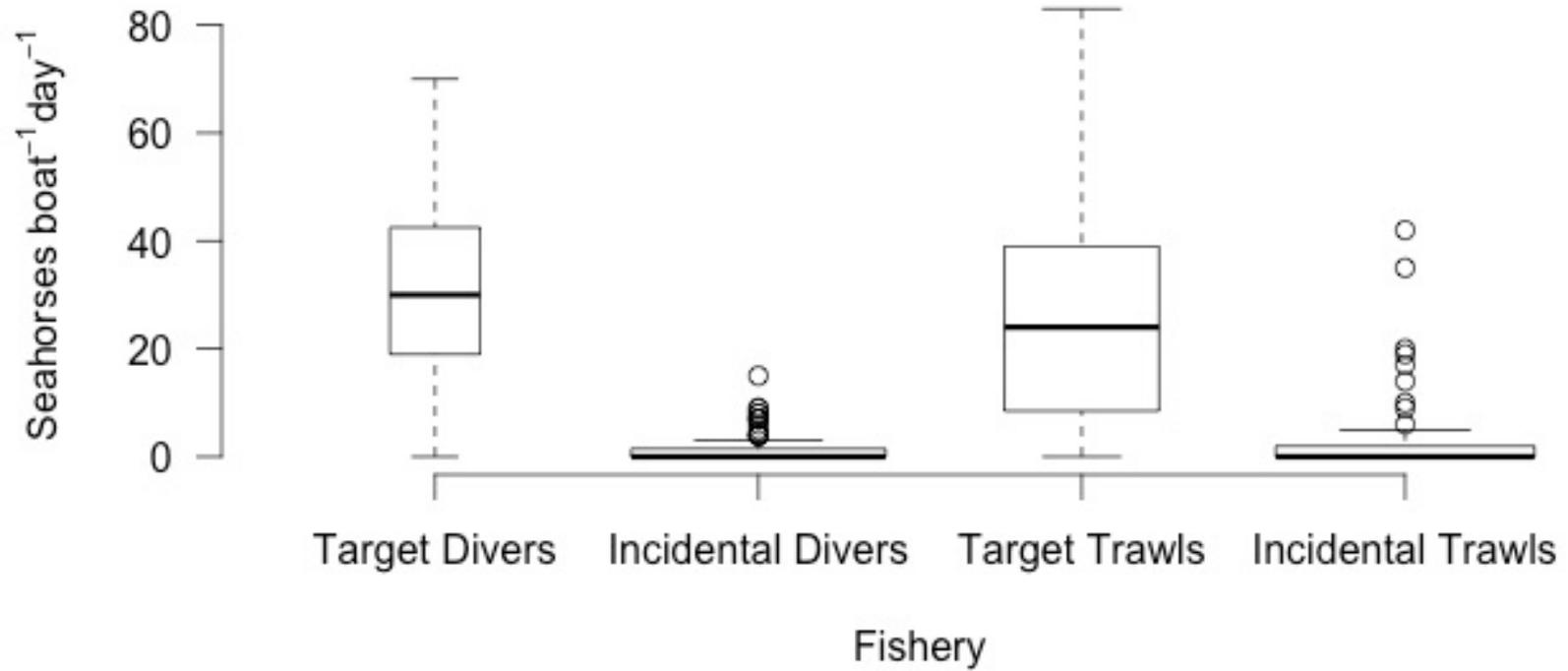


Figure 3.2 Comparison of seahorse CPUE of target and incidental fisheries. Median number of seahorses caught per boat per day by target divers=30, $n=15$; incidental divers=0, $n=119$; target trawls=21, $n=42$; incidental trawls=0, $n=123$. Width of boxplots is proportional to sample size.

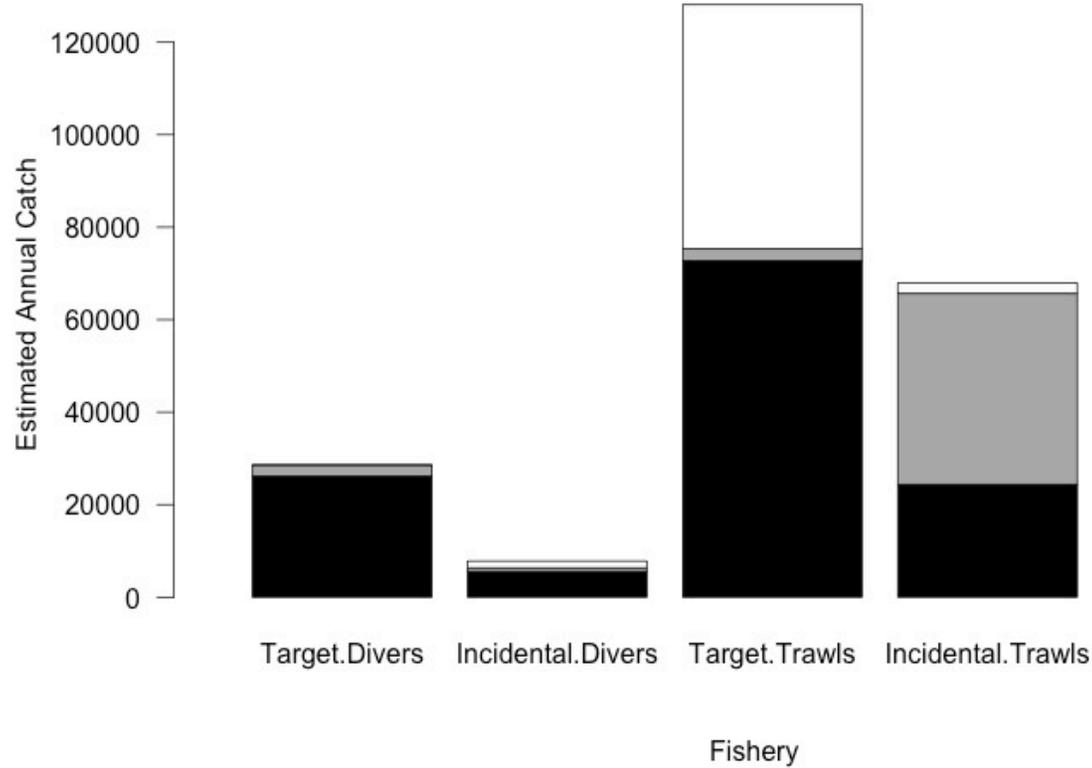


Figure 3.3 The proportion of *Hippocampus* species in total annual catch of the four fisheries (*H. spinosissimus* in black, *H. trimaculatus* in grey, and *H. kuda* in white) based on proportions in sampled fishing catches, d.f.=6, $\chi^2=494$, $P < 0.05$. Target divers (91.4% *H. spinosissimus*, 8.4% *H. trimaculatus*, 0.2% *H. kuda*), incidental divers (70.8% *H. spinosissimus*, 10.2% *H. trimaculatus*, 19.0% *H. kuda*), target trawls (56.8% *H. spinosissimus*, 2.0% *H. trimaculatus*, 41.2% *H. kuda*), incidental trawls (58.0% *H. spinosissimus*, 36.6% *H. trimaculatus*, 5.4% *H. kuda*).

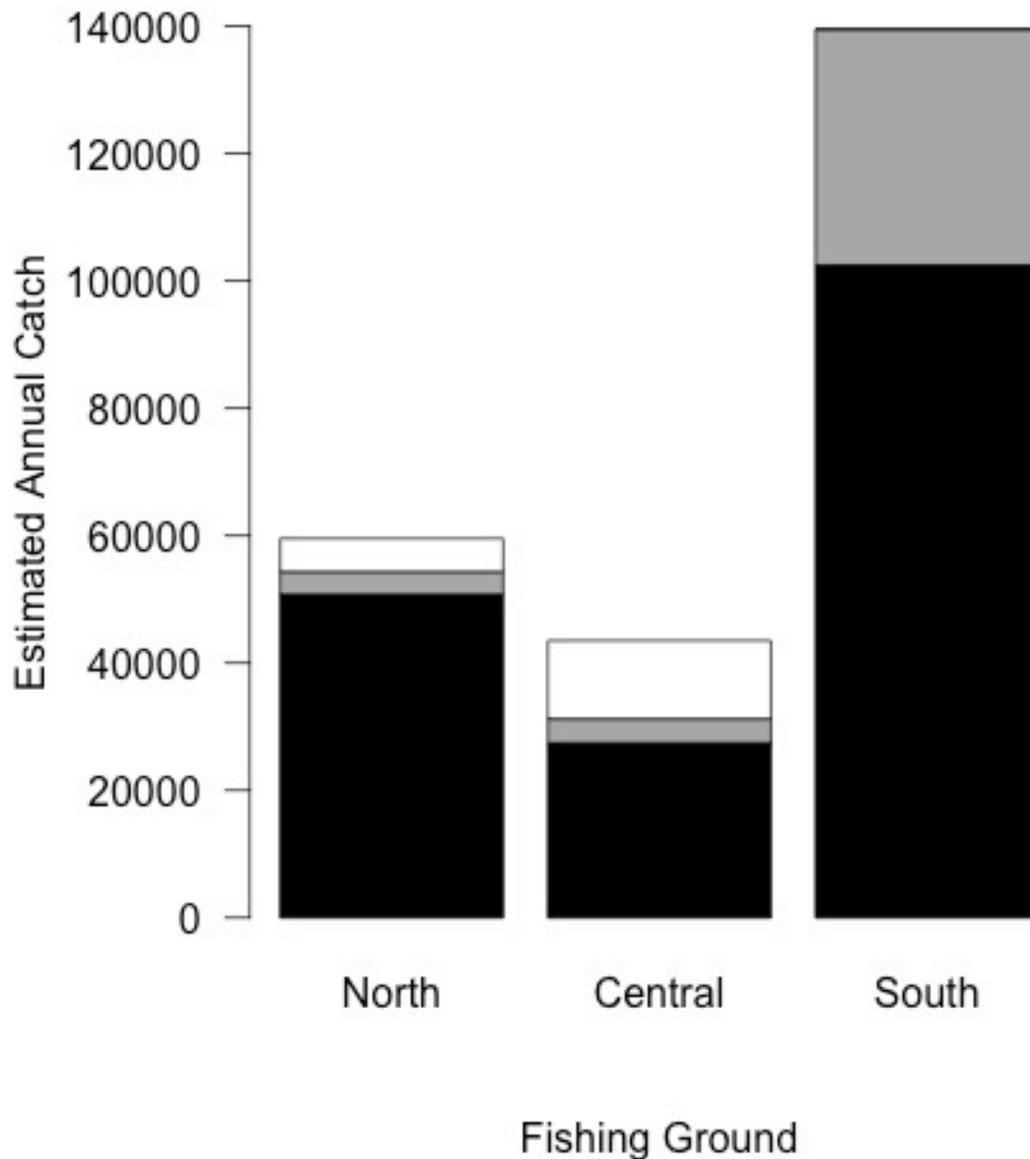


Figure 3.4 Proportion of species in total annual catch of the three fishing grounds (*H. spinosissimus* in black, *H. trimaculatus* in grey, and *H. kuda* in white) based on proportions in sampled fishing catches, $\chi^2=184$, d.f.=4, $P < 0.05$. North (81.3% *H. spinosissimus*, 10.2% *H. trimaculatus*, 8.5% *H. kuda*), central (58.0% *H. spinosissimus*, 10.0% *H. trimaculatus*, 32.0% *H. kuda*), south (78.7% *H. spinosissimus*, 21.3% *H. trimaculatus*).

Chapter 4: Conclusion

In revealing that some trawl fisheries now exist solely to target seahorses, my thesis has highlighted the dismal state of ocean exploitation and emphasized the need for urgent action to reconcile fisheries and conservation. Using two approaches, my research has generated biological and fisheries data that emphasize the dwindling availability of marine resources under both opportunistic and intentional capture. In this concluding chapter I summarize my research of small-scale fisheries, the conclusions drawn regarding the state of these fisheries, and highlight advances made toward sustainable seahorse fisheries and trade in Vietnam. This research emphasizes straightforward approaches to studying data-poor fisheries and encourages comprehensive efforts to study and manage these fisheries in the future.

4.1 Phu Quoc seahorse fisheries: overview of past and present

My first data chapter (Chapter 2) highlighted the astounding fact that fishers deliberately employ bottom trawls to catch seahorses, which has been mentioned only once in published literature (Perry et al., 2010) but has never been studied in detail. Tapping into local knowledge to explore the nature of seahorse fishing, I explored a situation where multiple gears were used to catch seahorses at reported rates of up to 90 seahorses per boat per day. Most fishers caught seahorses incidentally, as is common throughout the world (Baum et al., 2003; Martin-Smith and Vincent, 2006; Meeuwig et al., 2006), but nearly 20% of the fishers we interviewed deliberately targeted seahorses. Unlike most target fisheries where seahorses are collected by hand (Rosa et al., 2011; Salin and Yohannan, 2005; Vincent et al., 2007), fishers in Phu Quoc employed beam and otter trawls to capture seahorses. This unusual fishing practice could have arisen because of a combination of depletion and demand. Fishers on Phu Quoc might be forced to fish seahorses

because of declines in other valuable species in the area such as pearl oysters, sea turtles, sea cucumbers, and/or other species (Otero Villanueva, 2005; WWF, 1993). Another factor is the high price of seahorses, which provides incentive for fishers to target them. Fishers' reports of seahorse CPUE declines of 86-95% were compatible with worldwide evidence of declining seahorse catches (Giles et al., 2006; Vincent et al., 2007).

The results of my second data chapter (Chapter 3) reflected the finding that many small individual catches can lead to large global catches (Lawson et al., *in review*), but highlighted the substantial contribution of targeted seahorse fishing. I presented the first quantitative comparison of targeted and incidental seahorse capture by two fishing methods: bottom trawling and compressor diving. Boats that targeted seahorses caught up to 20 times more per day than those that caught them incidentally. The 170-boat fleet (140 non-target and 30 target boats) caught an estimated total of 162,000–234,000 seahorses per year in an approximately 5000km² fishing ground. This is about four times higher than the catch of a similarly sized trawl fleet in central Vietnam that did not target seahorses (Meeuwig et al., 2006). Moreover, the total catch from the island is likely even higher than I estimated since I did not account for all gear types that catch seahorses and used conservative estimates of total fleet size and fishing effort.

4.2 Comparison of fisher knowledge and landings surveys

My combination of fisher interviews and landings surveys resulted in a comprehensive understanding of the Phu Quoc fisheries from the past to the present and allowed insights into the future. For Chapter 2, I conducted interviews to draw upon local knowledge and gain a broad understanding of the fishery, both past and present. Because these fisheries have never been

monitored, interviews were critical to establishing a brief history of the fishery and understanding the financial and social values of seahorses. Unfortunately, fisher interviews were time consuming, fishers were not always willing to discuss all of their fishing practices, and the accuracy of fishers' recall is open to question as noted in past fisheries research (O'Donnell et al., 2012, 2010; Tesfamichael et al., 2014). Fortunately, however, I was able to corroborate the data I collected during interviews with direct monitoring of fisheries (Chapter 3). By visiting landings sites and observing fishers' daily catch, I was able to collect robust biological and fisheries data.

In the case where interviews are the primary method of data collection, I would recommend using fishers' minimum CPUE estimates as the closest approximations of CPUE from landings. When using fishers' estimates of seahorse CPUE, it was their minima that most closely resembled the CPUE determined via catch landings surveys (Table 4.1 and Table 4.2). Using their maxima, estimates were up to 15 times higher than seahorse CPUE determined via catch landings surveys (Table 4.1 and Table 4.2), probably because their maxima reflected rare events (O'Donnell et al., 2010). Indeed, maxima were found in catch landings as outliers (catch rates in Chapter 3 were as high as 83 seahorses per day from target trawl boats). Allowing for these disparities, fishers' recall served as a very useful proxy for seahorse CPUE from landings.

Table 4.1 Mean CPUE calculated from fisher interviews and catch landings surveys for target trawls, non-target trawls, and non-target compressor divers (target divers were omitted as none were interviewed for Chapter 2).

Fishery	Interview mean CPUE		Landings mean CPUE
	Minimum	Maximum	
Target trawls	23.3 ± 16.8	92.7 ± 39.2	23.3 ± 22.5
Non-target trawls	3.7 ± 6.8	30.1 ± 31.7	2.5 ± 5.8
Non-target divers	4.3 ± 10.4	20.1 ± 29.5	1.3 ± 2.5

Table 4.2 Median CPUE calculated from fisher interviews and catch landings surveys for target trawls, non-target trawls, and non-target compressor divers (target divers were omitted as none were interviewed for Chapter 2).

Fishery	Interview median CPUE		Landings median CPUE
	Minimum	Maximum	
Target trawls	25	83	24
Non-target trawls	0	17.5	0
Non-target divers	0	4	0

4.3 Conservation concern for seahorses in Phu Quoc

Given the relative accuracy of fisher recall, the perceived 86-95% decline of seahorse catch rates is concerning from both a fisheries and conservation perspective. Fish stocks will usually decline under fishing pressure, but aspects of seahorse life history (e.g. lengthy parental care, long-term

pair bonding, small brood sizes, low mobility, and site fidelity) mean that these fishes are particularly vulnerable to high levels of exploitation (Foster and Vincent, 2004; Lawson et al., 2014). The reported declines in individual vessel CPUE of 86-95%, if used to represent abundance, would classify these seahorse populations as Critically Endangered on the IUCN Red List (IUCN, 2015). Ideally, these declines should be substantiated with historic effort data (changes in fleet size, gear use, active fishing time), underwater seahorse abundance, and year-round monitoring. Without these data, however, the ongoing threat of continued fishing pressure around Phu Quoc should be enough to incite prompt conservation action.

Several other pressures in the Phu Quoc fisheries could affect seahorse populations. Foremost, the exponentially increasing price for seahorses will encourage fishers that target seahorses to continue to do so and prevent fishers that obtain seahorses in bycatch from throwing them back. Indeed, fishers did not hesitate to express that they would not decrease their fishing intensity, regardless of future catch, as long as the price made it economically feasible. The proportion of juveniles in catch (up to 40% for *H. spinosissimus* and *H. trimaculatus* caught by divers) is considered a sustainable level; most studies suggest that the proportion of juveniles in catch should be less than 50% (reviewed in Vasilakopoulos et al., 2011). Seahorse reproduction, however, involves high parental investment (exhibiting *K*-selective traits), making each individual highly important (Perante, 2002; Vincent and Sadler, 1995). If the proportion of juvenile seahorses in catch near Phu Quoc were to increase, this could be a cause for concern, but would require year-round monitoring to determine any seasonal variations. Finally, the relative impacts of each gear type on individual seahorse species (e.g. target trawls catching the highest number of *Hippocampus kuda*) could result in changes in species abundance. This could

be exacerbated if certain species are more susceptible to fishing pressure than others (Curtis et al., 2007).

4.4 Moving forward: addressing concerns and establishing effective management

All evidence suggests that implementing fisheries management should be an immediate priority in Phu Quoc. My research indicates that management efforts should focus on community engagement and education, seasonal restrictions, minimum size limits, and spatial refuges, and be monitored for their effectiveness. Foremost, working collaboratively with fishers, community members, managers, scientists, policy makers, and other stakeholders will be key to achieving sustainability in these fisheries (Pomeroy, 1995). Effective management requires compliance (Hauck, 2008; Mora et al., 2009) and enforcement (Keane and Jones, 2008), which have been lacking on Phu Quoc. Restrictions on the deployment of certain fishing gears for certain months (Circular No 89/2011/TT-BNNPTNT) and in certain areas (DANIDA-Copenhagen and Ministry of Agriculture and Rural Development, 2011) already exist in the area but are weakly implemented (N. K. Bat, *pers. comm.*). With greater enforcement and compliance, these seasonal and spatial restrictions could allow recovery from fishing pressure for seahorses and many other species (Gell and Roberts, 2003; Mosquera et al., 2000; Roberts et al., 2001). Additionally, setting a minimum size limit above 11cm for seahorse catch would ensure that *Hippocampus spinosissimus*, *H. kuda*, and *H. trimaculatus* would reach maturity before being caught and have a chance to breed. But size limits can be difficult to enforce (Foster and Vincent, 2013), especially for gears like trawls that are the highest concern in this fishery. All of these management efforts would need to be monitored in order to analyze their effectiveness

(Hockings, 2006; Mora et al., 2009) and establish whether they would reverse the decline in seahorse catch rates.

Vietnam's unique requirement to take action for seahorse sustainability under international law may benefit many other species through improved sustainable fisheries in Vietnam. To prove to CITES that seahorse exports do not harm wild populations, Vietnam must monitor trade, legally source specimens, and deter illegal trade – which all link to fisheries. The current CITES ban on exports of *H. kuda* highlights not only unsustainable seahorse trade, but also many broader issues in Vietnamese small-scale fisheries from a lack of monitoring, to ineffective management, to low fisher compliance. Fisheries management in Vietnam is hindered by limited resources, lack of personnel, and overall low capacity (Bach Dang and Momtaz, 2015) and a lack of community-level management efforts, which were dismantled in the 1980s during political regime shifts (Boonstra and Bach Dang, 2010). The social and economic stressors of poverty, low education, and food insecurity add to the complex task of small-scale fisheries management (Allison and Ellis, 2001; Béné et al., 2007; le Manach et al., 2012). Given that similar declines in seahorse catch rates have occurred across Vietnam (Giles et al., 2006; Meeuwig et al., 2006), many of the management efforts outlined for Phu Quoc could apply to the whole country. This could lead to more sustainable small-scale fisheries, thereby protecting many other small, demersal marine species that do not have the charisma and following that seahorses do.

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Appendices

Appendix A

GENERAL BIO-DATA

1. How old are you?
2. How many years have you been fishing for?

EFFORT DATA

1. What kind of fishing gear are you using?
2. Do you use the same type of gear year-round?
3. What is the length of the boat are you using?
4. How big is your net? What is the mesh size?
5. What type of engine are you using?
6. How much fuel do you use on an average fishing trip?
7. How many people work on your boat?
8. How long is an average fishing trip for you? What time do you usually go out to sea, and what time do you come back?
9. How much time do you leave your nets down, or how long do you spend diving?
10. How many days per month do you fish?
11. How many months of the year do you fish, and how much time using each type of gear?
12. Where do you fish? Do you fish there all the time?
13. How long does it take to travel to and from your fishing grounds?
14. What depth do you fish at?
15. What is the substrate and habitat in this area?

CURRENT CATCH DATA

1. What species do you fish?
2. Do you fish this / these species year-round?
3. Do you ever catch seahorses?
4. Is there any season when you catch more/ find more seahorses? (High season)
5. For an average *unit of time* in *high season*, how many seahorses do you catch?
6. For an average *second unit of time* in *high season*, how many seahorses do you catch?
7. Is there a season when you catch less / find less seahorses? (Low season)
8. For an average *unit of time* in *low season*, how many seahorses do you catch?
9. For an average *second unit of time* in *low season*, how many seahorses do you catch?
10. What types of seahorses do you catch?
11. Are the seahorses live or dead when you bring them up?
12. What size range of seahorses do you catch? What size are most of the seahorses you catch? [= average size]
13. What do you do with the seahorses you catch?
14. How do you keep the seahorses (a) in the boat and (b) back at shore?
15. Do you ever throw them back? If so, are they alive or dead? Do you throw them back in the same general area from which they were caught?
16. Is there anything you can use seahorses for?

17. How many years have you been selling the seahorses/have the buyers been buying seahorses? How did you get started?
18. How many people are there who buy/are interested in buying seahorses?
19. Are there any seahorses that the buyers won't take?
20. What is the price for seahorses? Do you sell them wet or dried?
21. How does the value of seahorses compare to other marine products?
22. How much of your income comes from selling seahorses?

HISTORICAL CATCH DATA

1. Time fishing using same gear in the same place:
2. How long have you been fishing with the same type of gear and boat, in the same places?
3. Compared with ___ years ago, is there any difference in the number of seahorses that you catch (for high and/or low season)?
4. Any change in the types / size of seahorses?
5. Compared with ___ years ago, is there any difference in the price of seahorses?
6. How does the quantity of seahorses you catch compare with other boats, or other types of boats or gear?
7. Do you think the fishery in this area is sustainable?
8. If yes, why? If not, why not?
9. What can be done to improve the sustainability of fishing where you fish?

Appendix B

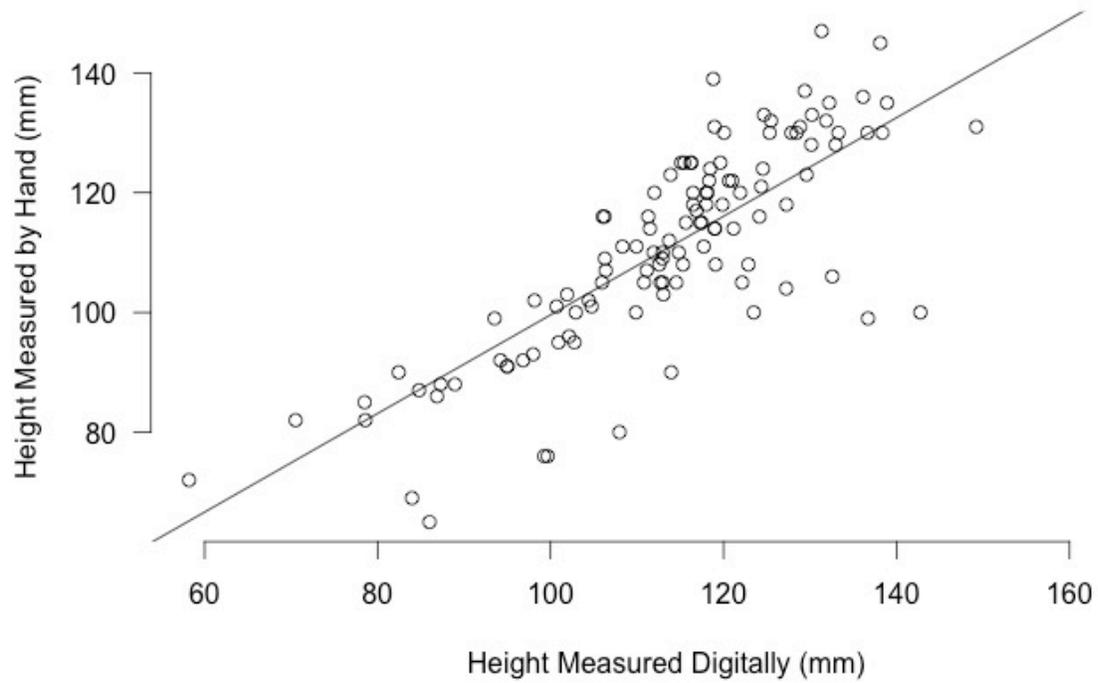


Figure B.1 Conversion of digitally measured heights (DMH) to hand-measured heights (HMH);

$$\text{HMH} = 2.1869(\text{DMH})^{0.8297}$$

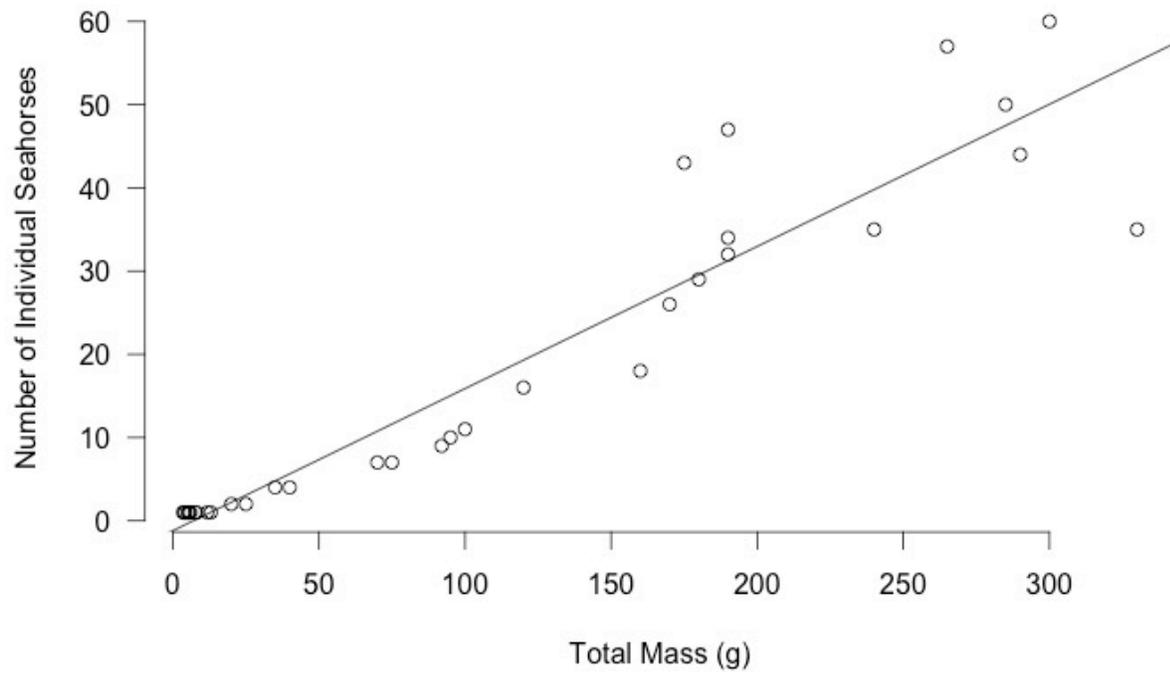


Figure B.2 Linear regression of total seahorse mass to number of individual seahorses.

$y=0.17079x-1.20232$. Mass of one wet seahorse = $6.06 \pm g$ ($n=593$).

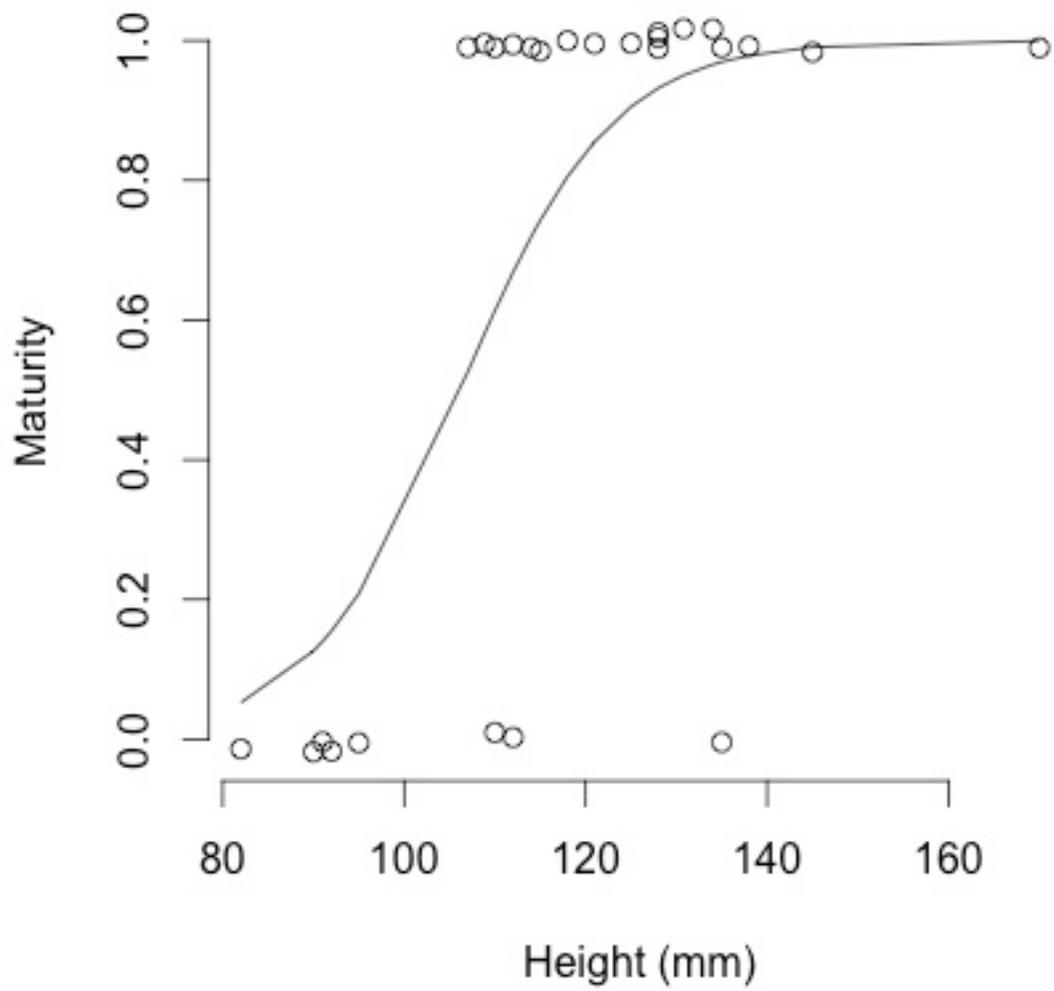


Figure B.3 Logistic regression curve of height at maturity (H_M) for *Hippocampus kuda* obtained from April to July 2014 across the Phu Quoc District.

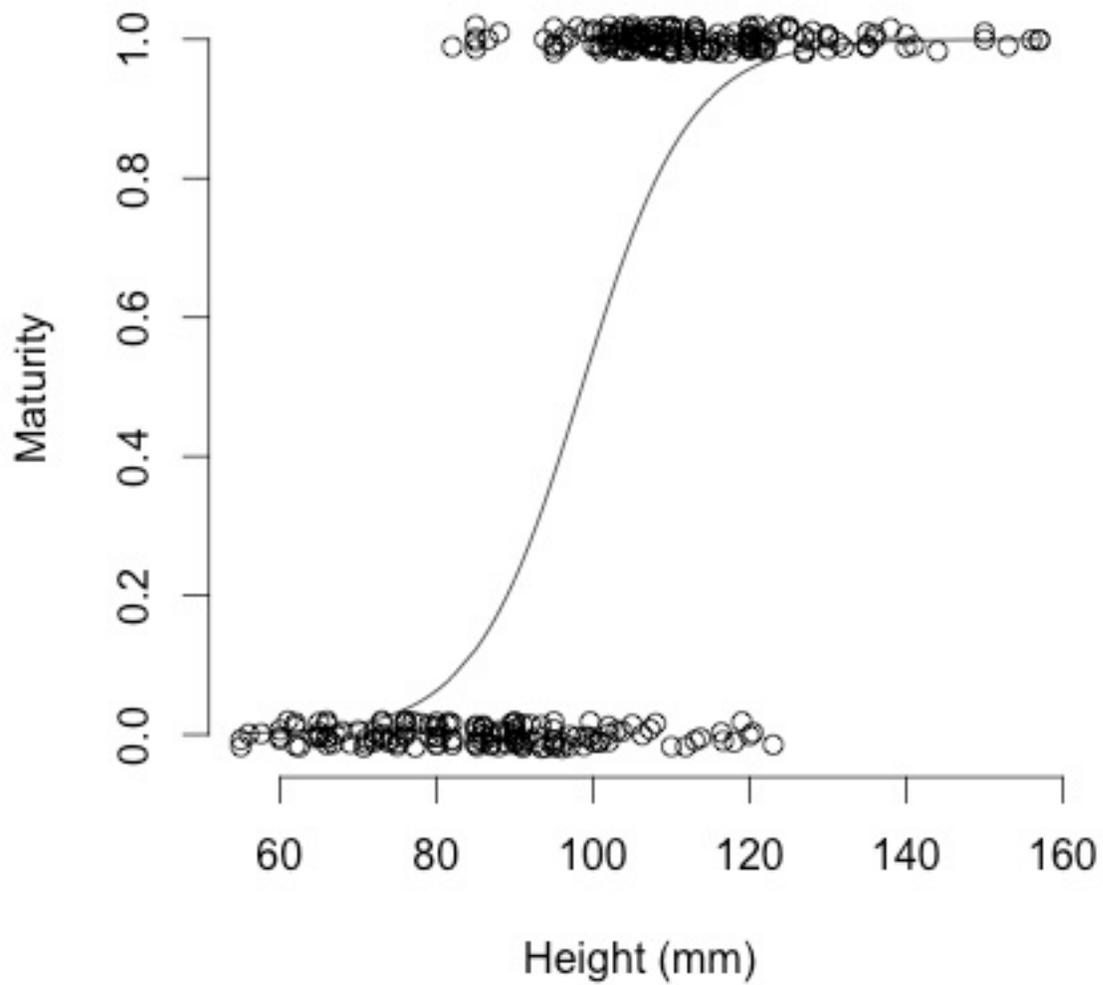


Figure B.4 Logistic regression curve of height at maturity (H_M) for *Hippocampus spinosissimus* obtained from April to July 2014 across the Phu Quoc District.

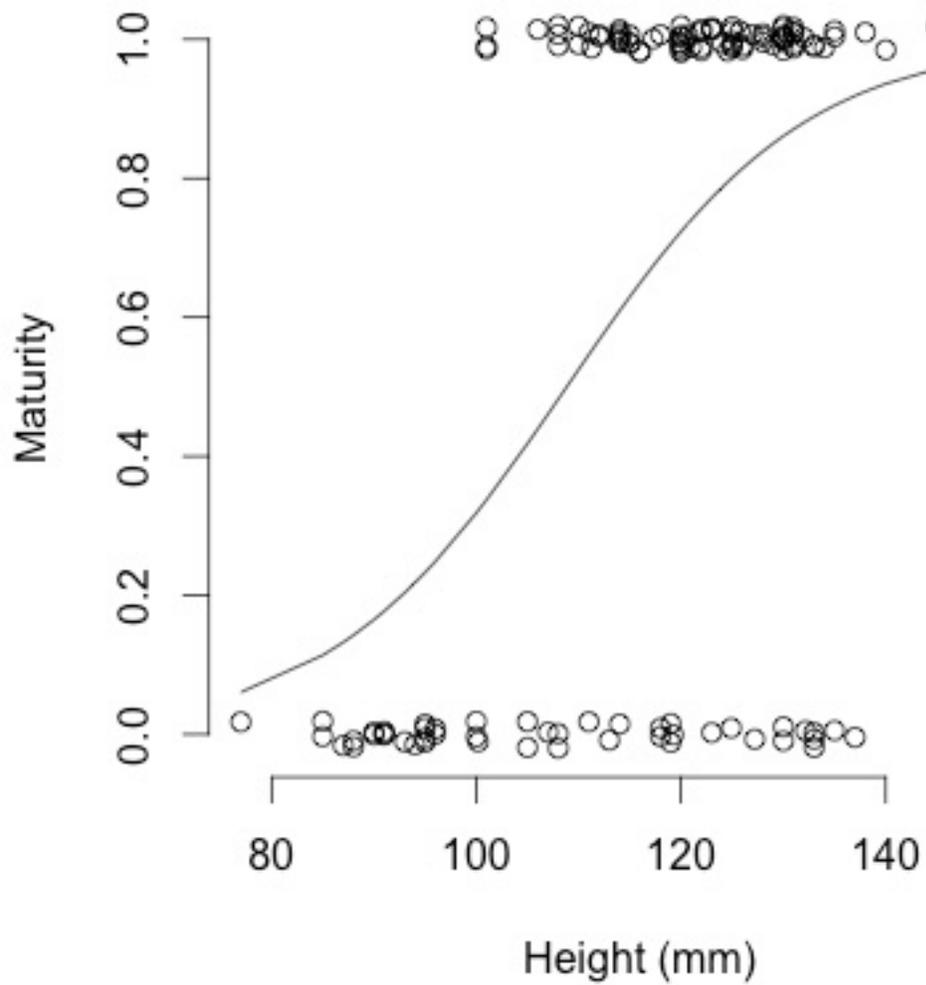


Figure B.5 Logistic regression curve of height at maturity (H_M) for *Hippocampus trimaculatus* obtained from April to July 2014 across the Phu Quoc District.