The limitations of bans when conserving species that are incidentally caught: a case study of India's seahorses

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Abstract

Bans on exploitation and trade are increasingly being used in wildlife conservation. However, their effects on small, incidentally caught marine fishes are rarely examined. For my thesis, I evaluate the impact of one such paired ban in India, across different spatial scales, on the conservation of seahorse species and on the fishers who depend on them.

In my first two research chapters, I investigated the effects of India's ban on seahorse capture and trade, at two scales: nationally (Chapter 2) and in Tamil Nadu state (Chapter 3). In Chapter 2, I found that seahorse extraction continued, mostly from non-selective fishing gear such as trawlers and drag-netters. I also found that by far the most seahorses were caught from the state of Tamil Nadu, even though the fishers there were most aware of the ban. In Chapter 3, I found that higher seahorse catches in Tamil Nadu were associated with (i) biogenic habitats and (ii) active and non-selective benthic fishing gear. I also found that despite the ban, seahorse populations in the state appeared to be declining and that illegal trade persisted.

In Chapter 4, I explored why fishers continued catching protected species. I found a convergence of factors such as high economic value, ease of catching seahorses in non-selective gear, and fisher exclusion from the decision-making process, all helped to explain poor compliance. In Chapter 5, I showed a pragmatic spatial analysis of the pressures on wild seahorse populations, derived from fisher knowledge, which can be used to evaluate the effectiveness of existing management and guide a path to sustainable exports. My tiered mapping assessments of risk and responses can be deployed in other data-poor situations to help assess the sustainability of exploitation and overcome management paralysis.

My thesis illuminates the failures of bans in managing catch and trade of incidentally caught marine fishes and the need instead to constrain indiscriminate fishing pressures like bottom trawling. These findings have implications for other countries considering bans as measures to manage wildlife.

Lay Summary

I wanted to know whether bans on capture or trade of threatened species helped with their conservation. So, I went to India to study seahorses, charismatic species that were, in principle, fully protected there in 2001. By interviewing 1200 people, I discovered that most seahorses were caught in non-selective fishing gear, such as trawls, primarily in Tamil Nadu. In that same area, traditional sail-powered dragnets also obtained a great many seahorses, again incidentally. Given that seahorses were caught without being targeted, it is not surprising that capture and trade of seahorses continued apace, despite the bans. Catching these quirky fishes involved no extra effort and selling them provided fishers with supplemental income. Given the failed implementation – and, indeed, the futility – of the ban, I propose simple ways to move towards management of seahorse extraction that embraces sustainable use, drawing on fishers' knowledge. Such approaches would be valuable for many species.

Preface

This thesis represents my own work, some of which has been published elsewhere. Two chapters of this thesis have been published in a peer-reviewed journal (Chapters 2 & 3). A version of Chapter 4 is being revised for re-submission to a peer-reviewed journal. My final chapter (Chapter 5) is being prepared for submission to a peer-reviewed journal. I am (or will be) the lead author on all four papers.

I was primarily responsible for conceptualization, experimental design, collecting information (with help from research assistants), data management, data analysis, and writing in each of the manuscripts. Dr. Vincent had a central role in conceptualizing the thesis, shaping the ideas for each chapter, editing my writing and played a critical role in securing funding for my research.

My co-authors have made significant contributions and improved the manuscripts substantially. I list my co-authors and outline their contributions to each specific chapter below.

A version of Chapter 2 has been published as

- Vaidyanathan, T., & Vincent, A. C. J. 2021. State of seahorse fisheries in India, nearly two decades after they were banned. *Biodiversity and Conservation*, 1-31. https://doi.org/10.1007/s10531-021-02188-6.

Dr. Vincent provided feedback on the experimental design, analysis, and writing of the manuscript.

A version of Chapter 3 has been published as:

- Vaidyanathan, T, Zhang, X, Balakrishnan, R, & Vincent, A (2021). Catch and trade bans for seahorses can be negated by non-selective fisheries. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(1), 43-59.

Dr. Zhang created the model structure and model scenario analysis for variations of seahorse presence or absence in catch. Mr. Balakrishnan helped secure access to seahorse traders and provided crucial clarifications and edits to the manuscript. Dr. Vincent provided feedback on the fieldwork design of scientific surveys and fisher interviews and provided edits throughout the analysis and writing.

A version of Chapter 4 is being revised for re-submission to a peer-reviewed journal as "Vaidyanathan T, & Vincent ACJ. Benefits of catching banned species exceed the costs: a case study of seahorses and trawl fishing in India." ES-2021-12542, Version 1. Dr. Vincent gave feedback on the design of fisher interviews and provided edits throughout the analysis and writing.

A version of Chapter 5 is in preparation for submission as "Vaidyanathan, T, Foster, SJ, Balakrishnan, R, & Vincent, ACJ. A practical approach to meeting national obligations under CITES." Dr. Foster and Dr. Vincent provided significant input into this chapter with the creation of the CITES NDF framework for seahorses and with brainstorming the storyline of this research. Mr. Ramkumar played a major role in data collection. Both Dr. Foster and Dr. Vincent contributed key insights into how the research in this chapter contributed to the larger issue implementation of CITES for marine fishes based on their experience. Dr. Foster and Dr. Vincent edited the chapter for content throughout the analyses and writing.

All fieldwork in this dissertation was approved by UBC's animal care committee (A12-0288) and UBC's human ethics committee (H12-02731).

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List of Symbols

₹ - Indian Rupee

List of Abbreviations

AIC- Akaike information criterion

BIC- Bayesian information criterion

CI- Confidence Interval

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

CMFRI- Central Marine Fisheries Research Institute

CPI- Consumer Price Index

CPUE – Catch per unit effort

EEZ- Exclusive economic zone

EBM- Ecosystem based management

ETP- Endangered, threatened, and protected species

ESA- Endangered Species Act

FAO- Food and Agriculture Organization

FK- Fisher knowledge

GAM- Generalized additive models

GBIF- Global Biodiversity Information Faculty

GLM- Generalized linear models

GLMM- Generalized linear mixed models

GoMNP- Gulf of Mannar Marine National Park

IUCN – International Union for Conservation of Nature

IUU – Illegal, unregulated, and unreported fishing

K-W- Kruskal Wallis test

MEA- Multilateral Environmental Agreement

MCC- Matthew's correlation coefficient

MFRA- Marine Fisheries Regulation Act

MPA – Marine protected area

MSY- Maximum Sustainable Yield

NDF – Non detriment finding

OBIS- Oceanic Biodiversity Information System

PES- Payment for ecosystem services

PL- Published Literature

RF- Random Forest

RST – Review of significant trade

SD – Standard deviation

SDG- Sustainability Development Goals

SL- Standard Length

SS- Seahorse sightings

SSC- Species Survival Commission

TM – Traditional medicine

TNMFRA- Tamil Nadu Marine Fisheries Regulation Act

UBC – University of British Columbia

UT- Union Territory

USD – US dollar

WLPA- Wild Life Protection Act

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First and foremost, I would like to acknowledge that this work was largely carried out on the traditional, ancestral, and unceded territory of the Musqueam, Squamish and Tsleil-Waututh Nations.

I first dreamed of doing a PhD during my bachelors, and then over the years, people, places, and topics were added, and refined, until it got to the place it is today. There is a long list of people who helped turn my dream into a reality. I would like to start by thanking the driving force for me to pick a study on seahorses, and focus on India, Dr. Amanda Vincent, without whose support and guidance, this PhD would have been a non-starter. Her profound knowledge and passion for marine conservation, and clear vision, helped me shape my own vision for this thesis, and my future. My committee members, Dr. Julia Baum, Dr. Kai Chan, and Dr. Mary O' Connor, have been a great support for me throughout this journey, and have contributed greatly to my learnings, and provided me with invaluable inputs and guidance. None of this would have been possible without the International Conservation Fund of Canada (ICFC), International Development Research Centre (IDRC), Ocean Park Conservation Fund Hong Kong (OPCFHK), UBC Ocean Leaders Program, and Guylian Belgian Chocolate, all of whom provided financial and in-kind support. I would also like to thank The Bay of Bengal Programme- Intergovernmental Organization, India, and Dr. Yugraj Yadava for their support when I was in India

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Dedication

With all my love and gratitude to my parents Subha and Bhaskar, my grandparents Lalitha and Sivaramakrishnan, and my late grandmother Chitra. Thank you for your unwavering support and being a constant source of inspiration.

Chapter 1: Introduction

1.1 Rationale

Conservation of threatened species may involve a diversity of tools and approaches. For example, when managing activities such as hunting and fishing, we can limit what is extracted (protected species), when (closed seasons), where (protected areas), how (e.g., gear controls) and how much (catch limits). In these contexts, direct conservation measures for wildlife conservation have included restricting extraction through i) input controls that limit the amount of effort that goes into extraction and ii) output controls that limits the actual levels of removal (Cochrane, 2002). Other types of conservation measures have included the use of economic instruments such as Payment of Ecosystem Services (PES) to regulate exploitation. Users of these resources pay taxes, payments for eco-certification or ecotourism, park entrance fees to protect the ecological resources (Wunder et al., 2008) and incentivize resource managers to commit to conservation goals (Engel et al. 2008). Further, hybrids of these instruments for wildlife conservation are gaining traction as, for example, with quota allocations for individuals or groups of extractors. However, a commonly used and immediate response for wildlife conservation has been to declare a ban on take and or trade (Roe et al., 2020).

Countries often resort to extraction and trade bans as ways to conserve species, often when they lack the capacity and support to manage their exploitation and trade sustainably (e.g., Foster et al., 2019). Bans are implemented with the expectations that resource users will change their exploitation methods, and that the demand for the wildlife resource will decline because of the consequent prohibitive prices and a lack of willingness to indulge in illegal activities (Heimert, 1995). It is clear, however, that bans seldom have this intended outcome. Instead, in certain circumstances, such as a delay between the proclamation and implementation of a ban (e.g., rhino horn; Rivalan et al., 2007), bans may result in increased black-market prices (Wyatt, 2009), which could provoke increased exploitation and trade. Furthermore, in conditions including where i) no substitutes exist (Santos et al., 2011) and when ii) a positive relationship exists between the rarity and value, which in turn causes enough of a demand that results in the market prices being greater than the greater exploitation costs of a less abundant species (Courchamp et al., 2006), the value of a banned species increases because of their perceived rarity (Courchamp et al., 2006), thus provoking additional exploitation (e.g., consumption of luxury food items such as the sturgeon caviar) (Courchamp et al., 2006). Bans on exploitation of wildlife also often result in the loss of livelihoods for local communities, commonly taking away incentives for communities to be invested in conservation initiatives (Broad et al., 2003). Such dynamics may ultimately result in the extinction of the protected species (Courchamp et al., 2006). While the imposition of bans is challenging the best of times, the situation becomes especially complicated in the case of bycatch species, where the exploitation is generally unregulated (Davies et al., 2009). The pressure on the species of concern is even more notable if those organisms die while obtaining the target species (Hutchinson et al., 2015). Finding appropriate management approaches that may improve the conservation status of these species has become an urgent need.

In this thesis, I investigate how a ban affects the exploitation and trade of incidentally caught marine species and explore how to develop management approaches that may improve their conservation status. I use the case study of seahorses in India, where a catch and trade ban was imposed on the entire genus (now 46 *Hippocampus* spp.) in 2001. Seahorses are a charismatic genus of fishes that are commonly caught incidentally in large numbers by a variety of fishing gears. About one-third of seahorse species (14 of 42 assessed species) are threatened with extinction, according to the International Union for Conservation of Nature (IUCN) Red List (www.iucnredlist.org). They were also the first fully marine fishes to be added to Appendix II of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) in 2002. While India was the first country to implement an extraction and trade ban on seahorses, even before the CITES listing, many countries have since followed suit, making my work globally relevant.

My thesis consists of six chapters, with chapters 2 to 5 representing new knowledge and chapter 6 comprising an integrated discussion. In Chapters 2 and 3, I examine fisheries and trade in seahorses at a national level and local level, in the context of a national ban. I then examine the importance of these fisheries to fishers across various districts and why fishers may or may not comply with a ban (Chapter 4). Finally, I lay the foundation for a spatial approach to evaluate the effectiveness of existing management measures that could help countries identify gaps and develop practical measures that may lead the way for sustainable exports (Chapter 5). My findings expand on my understanding of conditions under which bans are or are not effective as tools for species conservation, instead encouraging a suite of management measures.

1.2 Background

In the past, conservation has been directed at terrestrial issues affecting mammals or birds with little attention to marine concerns or freshwater species, invertebrates or even plants. Historically, the common perception was that humans had little impact on marine habitats or ecosystems, potentially because of my inability to observe the change. Only recently has it even been acknowledged that marine fishes are wildlife that need to be protected (Vincent et al., 2014). The first global conservation assessments for marine fishes were only undertaken in 1996 (Vincent & Hall, 1996). In addition, marine species have only been included in Multilateral Environmental Agreements (MEAs) of late (Doukakis et al., 2009) and the process has been much slower for commercially important fish species (Vincent et al., 2014). Many management measures, such as protected areas, have been developed for, and based on, an understanding of terrestrial wildlife (Soule´ and Terborgh, 1999). These management measures have rarely considered the differences between terrestrial and oceanic realms, such as the larger spatial scales in the ocean, greater connectivity, lack of distinct boundaries among habitats in water, and most importantly, the three-dimensional nature of marine ecosystems (Carr et al., 2003). Measures for the conservation of terrestrial wildlife have often excluded communities that depend on them but replicating this approach for marine wildlife – and especially for species associated with fisheries – sets the scene for failure (Sridhar and Shanker, 2007). When we draw on my long history in dealing with terrestrial conservation, we need to learn from my conflicts and successes in terrestrial management but add a distinct marine perspective for the conservation of ocean species and spaces.

One of the foremost tools used to conserve threatened species is bans on exploitation and trade. Bans are generally imposed by governments and range from those that are durable and national to those that are narrowly restricted in time and/or space. The United States has been a notable leader in the use of bans as conservation tools, introducing its Endangered Species Act (ESA) in 1973. For the most part, species listed on the ESA as 'Endangered' are protected from any kind of exploitative activity such as hunting, killing, or harming (https://www.fisheries.noaa.gov/topic/laws-policies#endangered-species-act, accessed on 10 Oct 2020). The Act has had many successes - and is considered a key agent for restoring populations of the bald eagle, American bison, American alligator, Humpback Whale, while preventing the extinction of other species (Doub, 2012) - but has also been at the centre of numerous disputes and challenges. The use of bans is not limited to the United States, and national bans on i) killing, as seen with the use of a hunting ban in Botswana (Mbaiwa, 2018), ii) capture, as used by Canada with the prohibition of the capture of marine mammals (Bill S-203, https://www.parl.ca/DocumentViewer/en/42-1/bill/S-203/third-reading, accessed on 10 Oct, 2020) and iii) trade, such as that observed with a national ban on trade of wild-animals in Brazil (Bragagnalo et al., 2019), are commonly used for conservation in many countries in the world (Swanson et al., 1993). India has taken a similar approach, and hunting (including killing and capture) is banned for many species listed under the various schedules of its Wild Life Protection Act (WLPA), 1972, and stronger measures offered in matters of trade and penalties for species provided the highest level of protection under the Act (http://legislative.gov.in/sites/default/files/A1972-53_0.pdf, accessed on 10 Oct 2020).

Despite their widespread use, virtually all bans on capture and trade of wildlife are accompanied by considerable controversy, to the extent that challenges the use of such absolute approaches. Bans on trade assume that such controls will limit the extraction of a species from the wild. Globally, bans on international trade in wildlife have emerged from CITES, which forbids commercial exports of all species listed under Appendix I (species threatened with extinction) (https://www.cites.org/eng/app/index.php, accessed on 10 Oct 2020.) However, the use of trade bans resulting from listings on Appendix I of CITES has met with notable challenges. Some of the key issues associated with bans include (1) an increase in black market prices in some circumstances (e.g., situations where there is a lack of political will, lack of resources for enforcement, corruption; Abensperg-Traun, 2009), which may actually prompt more illegal extraction (Abensperg-Traun, 2009), (2) emergence of underground markets, which makes it challenging to track and enforce a trade ban (Martin, 2000), (3) a loss of livelihoods for local communities, thereby taking away incentives for communities to be invested in conservation initiatives (Broad et al., 2003), and (4) presence of unregulated domestic markets that undermine the utility of export bans (Lemieux and Clarke, 2009). Often as species become increasingly rare, their value to traders and consumers may drastically increase, providing greater monetary incentives for illegal extraction (Brook and Sodhi, 2006). Despite trade bans, species such as the African elephant (Underwood et al., 2013), pangolins (Challender et al., 2015), black and white rhinos (Rivalan et al., 2007; t'Sas-Rolfes, 2000), and tigers in India (Stoner & Pervushina, 2013) are still illegally caught and traded in large numbers. Illegal trade of wildlife renders the CITES Convention and national scale regulations ineffectual and has actually increased in the face of wildlife trade bans (Oldfield, 2003). Ultimately, the effectiveness of a ban depends on a country's ability to generate compliance or provide sustainable enforcement for a ban (Phelps et al., 2016; Santos et al., 2011; Underwood et al.,2013). Finding ways to move away from bans and towards sustainably managing extraction has become an urgent conservation challenge- one with great ecological, economic, and social ramifications.

Bans on exploitation are complex on land and even trickier in the ocean. Conservation outcomes of bans on hunting or fishing are rarely evaluated, but they often meet with resistance from local communities (e.g., Cockerill and Hagerman, 2020; Mbaiwa, 2018). Bans on hunting often result in a loss of revenue to local communities (e.g., Lindsey, 2010), reduce revenue streams for conservation (e.g., Mbaiwa, 2018) and negatively impact community conservation efforts (e.g., Peake, 2004), which may result in local communities partaking in illegal hunting (e.g., Deere, 2011). Even the largely successful ESA receives its fair share of criticism for reasons including the use of a large portion of recovery funds towards a very small number of species (Simon et al. 1995), a species rather than ecosystem focus (Rohlf 1991), flaws in its implementation (Simon et al. 1995), and the undue costs of species protection on private landowners (Kerkvliet & Langpap, 2002). Bans on exploitation in the marine realm have had some success when focussed on larger charismatic animals like humpback whales (Magera et al., 2013) and turtles (Chaloupka et al., 2008) or on commercial fish species in North America (Lotze et al., 2011). However, bans on fishing many ocean species are complicated by the economic importance of fish to the world economy, livelihoods, and food security. Marine fishes annually contribute more than US$200 billion to the world economy (Sumaila, 2010), provide income either directly or indirectly to around 12% of livelihoods worldwide (FAO, 2014) and are a cheap source of protein to greater than one billion people (Gutierrez et al., 2011). Bans on extracting marine life are also compromised by factors such as the challenge of tracking activity in the ocean (Nyman, 2019), gaps in governance (Kelly et al., 2018) and that often the actual source of pressure remains unmanaged. Apart from the enormous fishing pressure in general, marine species are also threatened by illegal, unreported, and unregulated (IUU) fishing. Such activity may amount to 15% of legal catches (up to 26 million tons of fish a year) (Agnew et al., 2009), and the costs are valued at between US$15.5 billion and US$36.4 billion per year (May, 2017). The importance of marine exploitation is such that, in the absence of good compliance or enforcement, many fishers dismiss regulations and continue with the extraction of banned species (Charles et al., 1999).

Overfishing is, with other destructive fishing practices, the biggest threat to wild species and spaces in the oceans, with fisheries expanding and conservation concern rising (e.g. Buchanan et al., 2019; Linardich et al., 2018; Worm et al. 2009; Watson et al. 2012). Despite an increase in fishing effort, including a greater number of boats fishing, increased size of the boats, and more engine power, the catch in many fisheries has either remained the same or declined, indicating that fish stocks are also declining. Of the marine fish stocks monitored by the Food and Agricultural Organization (FAO) in 2017, about 34.2% were assessed as overxploited, an increase of about 10% from the 1970's (FAO, 2017). While the extinction risks of species resulting from overfishing is debated, there is consensus that there are catastrophic declines in populations of species with formerly large distributions (Le Pape et al., 2017), which may impact the associated fisheries Hutchings and Reynolds, 2004). These population declines may also have impacts on the ecosystem level, resulting in different, and potentially problematic, community structures (Reynolds and Peres, 2006).

Conservation concerns further arise because most threats to commercially fished species and their ecosystems are only detected very late, raising questions on the number of marine ecosystems that are already on the brink of collapse (Burgess et al., 2013). While the argument has traditionally been that marine fish exploitation has been driven by food security, it is now largely recognized that many fisheries strive for a quick economic profit and are less concerned by the long-term sustainability of the fishery (Sethi et al., 2010). As a result, reversing the status of the fishery and ecosystem may prove to be highly challenging, and maybe even impossible, with a need for intensive management measures which may prove to be extreme and costly (Arnason et al., 2000), and could even include shutting down entire fisheries (Scheffer et al., 2005).

Fisheries management has historically been directed towards production, with much less focus on conservation. Such a bias largely reflects the integral role that marine fisheries play in food security, particularly as a cheap source of protein (Hilborn et al., 2020). Throughout history, fish stocks have largely been regarded as inexhaustible (Huxley, 1883), such that unmanaged extraction was the norm. For stocks that do raise concern, management of marine fisheries has for long taken a single-species approach (Froese, 2016) and has been based on the premise of maximizing production, primarily anchored in the concept of Maximum Sustainable Yield (MSY) (Schaefer, 1954). Only in the last few decades have fisheries begun shifting towards management at an ecosystem level rather than for a single species. Even so, ecosystem management remains more aspirational than real for most fisheries. This is worrisome because fisheries with limited management and assessments, where fish stocks or populations commonly fare poorly, are primarily found in tropical and sub-tropical regions (Hilborn et al., 2020). These are areas where fish stocks play a critical role in food security but where a single-species approach is not practical because of the many mixed stocks (Hilborn et al., 2020). While the mandate of fisheries managers is generally to balance ecological, economic, and social objectives, it is clear that conservation measures are less likely to be implemented if they have significant economic and social costs, even in the short-term (Beddington et al., 2007).

Reconciling biodiversity conservation with the exploitation of the oceans remains a major challenge (Cochrane, 2020). The mandates of marine conservation and marine fisheries have often been at cross-purposes, with the former mainly focussed on protecting the full diversity of organisms, species, and spaces (e.g., Grafton et al., 2010), while the latter focusses on the maximum exploitation possible without extirpating populations (Caddy and Mahon 1995). Conflicts further arise between conservationists and fishers, notably when fishers are excluded from accessing resources (Redpath et al., 2013) and/or if the resource is considered as threatened (Allan et al., 2005; Tsounis et al., 2010). In fact, such divergence is evident in the way most countries manage their resources, with separate ministries, departments, and legal frameworks, for fisheries and conservation (Grip and Blomqvist, 2020). However, only recently has it been recognized that these two fields have many common objectives, such as preventing overfishing while also protecting livelihoods dependent on these fisheries (Salomon et al., 2011). Indeed, successful management measures for both conservation and sustainable exploitation involves moving away from solely top-down measures such as prohibiting access to resources, and instead combining them with bottom-up approaches that try to match individual and community interests with broader societal goals (Hilborn et al., 2010). While an ecosystem approach towards management is increasingly seen as a solution towards the reconciliation of divergent interests in the marine realm (UNEP, 2011), its implementation is expensive, and time-consuming (Wasson et al., 2015), and can be challenging to agree on specific objectives, and even more to actually achieve them (Salomon et al., 2011).

Reconciliation between conservation and fisheries is particularly troublesome in the case of fisheries methods that impose significant pressure on non-target organisms and habitats. Of major concern is the use of bottom trawls. These are highly destructive fishing gear operating along the seabed, resulting in physical disturbances of more than 80% of the seabed in some of the world's ocean (Amoroso, 2018). While considered to be a highly efficient method of fishing, bottom-trawls are also responsible for the bycatch and discards (part of the catch thrown back into the sea, either dead or alive) of many endangered, threatened, and protected (ETP) species (Roda et al., 2019). Much of this bycatch occurs in tropical waters, and in where intensive shrimp trawl fisheries operate, with bycatch-to-shrimp ratios reported of 10:1 reported in a number of countries (EJF,2003; Siar et al., 2017).Worryingly, exploited species have declined so severely that many trawl fisheries have recently shifted to wholesale targeting of all species, with all manner of species being caught indiscriminately and sold for fish oil or fish meal directed at animal feed or aquaculture feed

(Lobo et al., 2010). In countries like India, trawls contribute to over 75% of fish catches, despite comprising only 25% of the fleet size, while causing widespread ecological damage (Kumar and Deepthi, 2006) and numerous conflicts with the traditional fishing sector. Though there is substantial evidence for the ill-effects of trawling, it remains one of the most widespread forms of fishing because of the contribution to global fish catches and the livelihoods associated with it (Gupta et al., 2019, McConnaughey et al., 2020). Finding ways to reduce its extent and impact is central to marine conservation (Loh and Jaafar, 2015).

Difficulties with bans are magnified when the species of concern are incidentally caught, especially where enforcement capacity is limited, and when resource users question the legitimacy of such bans. Bytake is a considerable issue on land as in the ocean. For example, the Critically Endangered and (theoretically) protected saola ungulates in Lao PDR and Vietnam (Baillie and Butcher, 2012) are caught in selective snares set for other species. Similarly, bycatch is a large cause of mortality for a great diversity of marine species, including sharks (Beekircher et al., 2002), cetaceans (Reeves et al., 2005), sea turtles (Lewison and Crowder, 2007), snappers (Gallaway and Cole, 1999), and many other fish species (Stobutzki et al., 2001). Bans on capturing these animals have not been very useful in reducing exploitation unless accompanied by mitigation measures, which may themselves be ineffectual and/or expensive (e.g., sharks: Collins et al., 2020). Similarly, a ban on harming the Critically Endangered vaquita porpoise while fishing for totoaba (itself Critically Endangered) has not affected the conservation status of the porpoise (Rojas-Bracho and Reeves, 2013). Part of the problem may be that many governments lack the will and/or the resources to protect the species, particularly when it may involve shutting down commercially important fisheries to prevent the incidental catch of a few highly threatened organisms. Conservation of incidentally caught ETP species is further complicated when stakeholders have no say in the imposition of a ban (Collins et al., 2020). A feeling of exclusion results in a decreased likelihood of compliance with the ban. The corollary is that obtaining stakeholder input before considering bans may help avoid actions that undermine sustainability while improving the conservation status of ETP species (Collins et al., 2020). In moving away from dubious bans, the challenge is to find other management measures that work better.

Ultimately, simple bans may not be the answer, and we need to look at a suite of other tools. Given the challenges associated with banning exploitation and trade, and the dearth of analyses showing that they are effective in conservation, it is time to probe the role of bans on land and in the ocean and to examine complementary measures. Useful input controls to reduce fishing pressure include well-enforced spatial closures, temporal closures, constraints on the number, size, and horsepower of trawl boats, limits to the duration of trawl fishing, and alterations in the mesh sizes in a net (Mahon and Hunte, 2001; Madhu et al., 2015). Output controls such as quotas on the number and size of fish have also been successful in managing bycatch, though they do require greater technology and observer coverage (Diamond, 2004). Such controls are, however, narrow in focusing on the species directly while not addressing habitat damage caused by destructive gears such as trawls. This is where marine protected areas (MPAs) could be critical in protecting both species and habitats. MPAs, where some parts (or the entire area) are designated as no-take zones, prevent fishing, and help in population recovery while also potentially benefitting fishers by increasing catches in the adjacent fished areas (Cochrane, 2002). The critical issue is to have clear objectives and tailor conservation action, accordingly, seeking to temper idealism with reality.

1.3. Focal species and country

For this thesis, I use the case study of seahorses (*Hippocampus* spp.) in India to understand the impact of a national level catch and trade ban on the conservation status of species when the cause of exploitation remains unabated.

Seahorses are a charismatic marine genus that serves as flagship species for a wide range of marine conservation issues. Of the 42 species of seahorses that have been assessed globally, 14 species are considered threatened (2 of which have been declared Endangered), 11 are not threatened, while 17 are listed as Data Deficient on the IUCN Red List (www.iucnredlist.org). Although targeted fisheries exist for seahorses, most seahorses caught in the wild are caught incidentally in fishing gear such as trawls and gill nets, with an estimated 37 million seahorses believed to be obtained as bycatch annually (Lawson et al., 2017). The issues facing seahorse conservation, such as overexploitation, bycatch, and habitat degradation, are also concerns for marine conservation in general (Foster and Vincent, 2004).

Seahorses are particularly vulnerable, however, because of their biology and behaviour. For example, the young depend on parental survival far longer than most fish, and many species are monogamous, forming long term pair bonds (Foster and Vincent, 2004). These characteristics, combined with the fact that seahorses have a patchy distribution, limited mobility, and small home range, make them highly susceptible to overfishing (Foster and Vincent, 2004). Seahorses are mainly traded for use in traditional medicine (TM), aquariums and curios (Foster and Vincent, 2004). The unsustainably high demand for seahorses worsens the pressures of overexploitation. Official trade records estimated that between 3.3 and 7.6 million seahorses were exported annually between 2004 and 2011 (Foster at el., 2016), and about 31 species of seahorse were traded by 87 countries worldwide (Foster et al., 2016). However, fisheries and trade surveys from seahorse source countries with trade bans reveal persistent and substantial illegal, unregulated, and unreported (IUU) exports of dried seahorses (Foster et al., 2019), probably amounting to tens of millions of seahorses annually.

One of the tools being increasingly used to ensure sustainable exports of marine fishes, and therefore promote sustainable use of fisheries is CITES (Bellwood, 2015; Vincent, 2014). CITES is one of the largest and oldest multilateral conservation agreements and the only one with enforcement capacity (www.cites.org). The strength of CITES lies in the listing of species in one of three Appendices. Commercial trade is banned for species listed on Appendix I, whereas it must be regulated to ensure sustainability and legality for those on Appendix II. Parties wanting to export an Appendix II species must first make a non-detriment finding (NDF), or in other words, they must prove such exports will not be detrimental to wild populations (Online at https://cites.org/eng/prog/ndf/index_new.php, accessed on 10 Oct 2020). Where there are concerns about a Party's ability to meet CITES criteria, CITES may call for a Review of Significant Trade (RST) to evaluate the Party's trade. If Parties cannot allay CITES concerns or address the recommendations adequately, it may result in a trade suspension.

Considering the global trade pressure on seahorses and the threatened status of many *Hippocampus* species, all seahorses were listed on CITES in 2002, with implementation since 2004. Seahorses were the first fully marine fishes to be listed on Appendix II since the Convention's inception. The listing requires that the 183 CITES Parties (at the time of writing) ensure that their wild seahorse populations are not affected detrimentally by international trade. Seahorses were also the first marine fishes for which an NDF framework was created (Foster and Vincent, 2016). However, Parties have struggled to make robust NDFs because of i) the lack of baseline population, distribution, and exploitation data, and ii) limited capacity, funding, and stakeholder involvement (Vincent et al., 2014).

The challenges that Parties face in making NDFs and proving the sustainability of their seahorse trade resulted in seahorses becoming the marine fishes for which CITES required an RST (RST: Vincent 2014). An inability to address the RST – that is, to meet the obligations for sustainable exports – has resulted in many countries suspending international trade, sometimes because of CITES reviews of their regulations (Foster, 2016). Thailand, which was amongst the largest exporters of seahorses globally, resorted to a self-imposed export suspension because it was unable to satisfactorily address and implement the RST (CITES SC67 Doc. 15 Annex 2). RSTs with Vietnam, Guinea, and Senegal resulted in CITES imposed suspensions on *H. kuda* exports from Vietnam (CITES, 2013) and *H. algiricus* from both Guinea (Foster, 2016) and Senegal (CITES, 2016). Such bans have not, however, deterred the trade in seahorses. In fact, it was estimated that almost all dried seahorses in Hong Kong SAR (95%) had been imported from source countries with export bans in place, indicating a widespread lack of enforcement (Foster et al., 2019).

India took a different approach to manage their seahorse populations and banned the catch and trade of all species of seahorses (in fact, all *Hippocampus* spp.) in 2001, even before the CITES listing. Until 2001, India was amongst the top four exporters of seahorses (by weight), with approximately 12.5 tons estimated to have entered international trade from the country in 1999 (Perry et al., 2020). Based on growing concerns of the increasing and unsustainable trade, seahorses were listed under Schedule I of India's Wild Life Protection

Act (WLPA), 1972 (Ministry of Environment and Forests, Govt. of India, 2001), the only Act in India focusing on the conservation of habitats and species (Sridhar et al., 2007).

Twenty years into the ban, little is known about the status of India's seahorses. Conservation concerns include that, of the seven species of seahorses (*H. camelopardalis*, *H. histrix*, *H. kelloggi*, *H. kuda*, *H. mohnikei, H.spinosissimus,* and *H. trimaculatus*) identified from the Indian coast, five species of seahorses are listed as Vulnerable under the IUCN Red List of Threatened Species (www.iucnredlist.org). In a country ever more intense fishing effort - with great use of technology and too many boats chasing too few fish using highly damaging gears (Devaraj and Vivekanandan, 1999) - seahorses now face additional pressures. Worryingly, issues that existed when the ban was imposed, such as uncertainty and a dearth of data on seahorse abundance, distribution, and exploitation along the Indian coast (Sreepada et al., 2002), persist nearly two decades later.

1.4. Context and Collaborators

My work was executed as a member of Project Seahorse, an interdisciplinary and international organization committed to conservation and sustainable use of the world's coastal marine ecosystems. Project Seahorse serves as the IUCN SSC Seahorse, Pipefish and Seadragon Specialist Group, the global expert group for this taxon. Project Seahorse first uncovered the global trade in seahorses in the mid-1990s. Project Seahorse has worked in India since 1995, providing the first trade estimates from the country. A subsequent fisheries and trade survey conducted by Project Seahorse in 1999 was the last comprehensive survey of the entire Indian coastline before the imposition of a ban on extraction and trade of seahorses in 2001. Project Seahorse has developed great expertise in trade research and serves as the key advisory group for CITES as it implements the Appendix II listing for seahorses. As a PhD student at Project Seahorse, I was given the opportunity to return to work in my home country and build on this existing knowledge-set.

In India, my work was primarily supported by the Bay of Bengal Programme Intergovernmental Organization. My work was also supported by other local collaborators, including local researchers, government agencies, non-governmental organizations, fishers, traders, conservation, and community groups. I introduce my collaborators in each thesis chapter and note their intended contributions to my research.

1.5 Positionality Statement

I grew up and completed most of my education in the Indian coastal city of Chennai, in Tamil Nadu, India. I am from an upper-middle-class family and belong to a traditionally vegetarian, Tamil Brahmin family. I have had a privileged upbringing and all my education has been entirely in English. I was given access to the best resources and provided with all the opportunities to pursue higher education in the field of my interest. I have a Masters in Marine Sciences from the University of Goa, India, and a Masters in Marine Affairs from the University of Rhode Island, USA. Despite being from India, until my fieldwork, I had not spent any time in the coastal villages of the country, or even in my home state. In most senses, I was an outsider conducting work with communities I had few commonalities with. My work was particularly challenging because I have a poor working knowledge of Hindi, and even struggled with my mother-tongue of Tamil, being entirely unfamiliar with the various terms for fish and fishing. Over the course of my work, particularly in Tamil Nadu, I found a greater sense of acceptance and comfort with the communities I worked with. I was originally apprehensive of the reception I would receive because of my caste and gender, but I received a warm welcome in all the fishing villages and fish landing sites I surveyed. While comparing notes with my assistant in the Ramanathapuram District, it appeared that the fishers were more open to answering questions from me than my assistant. I approached my research through the lens of a conservationist, but with an understanding and appreciation of the livelihoods dependent on marine resources. I still struggle with my perspective, understanding that any conservation measure I suggest will not personally impact me, and acknowledging the dire conditions in which many of these families survive in.

1.6 Research Questions

I explore three research questions in this thesis.

1. Does a national ban on fishing seahorses affect the catch of those species, nationally and locally? (Chapters 2 & 3)
2. Why do fishers keep catching seahorses when that catch is banned? (Chapter 4)

3. How well do current management measures work for the conservation of wild populations, and how can we identify measures for fisheries that would perform better than the ban? (Chapter 5)

1.7 Thesis Outline

This dissertation contains the introduction (Chapter 1) and four research chapters, followed by a general discussion about conservation implications and recommendations for management measures for the conservation of incidentally caught marine species.

In Chapter 2, I investigate seahorse fisheries in India and how they reflect the implementation and listing of species for which exploitation and trade is banned. I explore how many seahorses are caught, the factors determining seahorse catches in fishing gear, and the apparent awareness of fishers to a ban. Given that it has been two decades since the ban, I use fisher interviews to understand the status of seahorse fisheries and how the fisheries may have changed in response to a ban.

In Chapter 3, I focus on the local scale, the state of Tamil Nadu, a traditional hotspot for seahorse catches and trade of seahorse. In this chapter, I aim to understand whether the ban has affected seahorse fisheries, trade, or neither.

In Chapter 4, I focus on three districts in the state of Tamil Nadu to better understand why fishers continue catching a protected species. I examine the beneficiaries of the income from seahorses, who values it most, and why fishers may not comply with an extraction and trade ban.

In Chapter 5, I explore how to generate simplified spatial NDFs, using local knowledge, to help countries that are struggling to make them. Such work acknowledges the apparent futility of trying to ban exports and offers a pathway to sustainable use. Data generated from this chapter help identify where species are found, the pressures they face, management measures in place, and whether these management measures are effective. Ultimately, my findings from Chapter 5 could help countries develop practical management measures, particularly in data-limited situations, that may improve the conservation status of species.

In Chapter 6, I discuss the major findings presented in this thesis and the implications of those findings for the overall conservation of seahorses. I then place such findings in the global context of addressing bans on exploitation and exports in other taxa.

Chapter 2: State of seahorse fisheries in India, nearly two decades after they were banned

2.1 Synopsis

Implementing a ban on fishing specific taxa is difficult enough without the added complexity of the taxa being primarily obtained as incidental catch. Most measures for restricting capture and trade to sustainable levels are directed towards targeted species, while overlooking the needs of incidentally caught species. My study investigates the exploitation and conservation of seahorses (*Hippocampus* spp) in India, which have been primarily obtained as bycatch globally, in the context of a ban on their catch and trade. I found that seahorse extraction continues, with annual catches of around 13 million seahorses, based on estimates from the locations I surveyed along mainland India. Most of these animals were perceivably obtained by nonselective fishing gear operating along the sea bottom, close to the shore, at lower latitudes and shallower depths, particularly in biogenic habitats. I found that the state with the highest catch and trade of seahorses was also the state where the largest number of fishers provided unprompted comments about the national ban. My work indicates the serious limitations of extraction and trade bans on species that are taken incidental to other extractive activities, a message that should also apply to terrestrial and freshwater species.

2.2 Introduction

Bans on either the extraction and/or the trade of wildlife are often used as management measures for the protection of species (Challender, Harrop & MacMillan 2015; Oldfield, 2003; Pain et al., 2006; Roe et al., 2002; Wright et al, 2001). In marine environments, bans that are intended to address species conservation have largely focused on larger charismatic marine organisms (e.g., whales and sharks) (Baker & Clapham, 2004; Tolotti et al., 2015) and commercially important fish species (e.g., cod and haddock) (Lotze, 2010). Preventing the exploitation of species has helped restore the populations for marine mammals such as humpback whales (Magera et al., 2013) and other species such as green turtles (Chaloupka et al., 2008). Bans on exploitation (and reduced exploitation) have helped 95% of the exploited marine species in estuarine and coastal regions in Northern America recover (Lotze et al., 2011). However, in marine fisheries, as in the case with the wildlife trade, illegal fishing activities often persists despite regulations because of poor governance, and limited regulatory and enforcement capacities (Worm and Branch, 2012).

The use of taxon-specific bans on catch and trade for conservation is controversial both on land and in the ocean (e.g., Challender et al., 2011; Foster et al., 2019; Moyle, 2003; Rivalan et al, 2007). Bans on exploitation of wildlife often result in the loss of livelihood for local communities, taking away the incentive for communities to be invested in these conservation initiatives (Broad et al, 2003). On land, bans resulting from listings on Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) may actually increase black market prices, which also causes an increase in illegal trade (Abensperg-Traun, 2009). Additionally, despite trade bans, species such as the African elephant (Underwood et al., 2013), black and white rhinos (Rivalan, 2007; t'Sas-Rolfes, 2000), and tigers in India (Stoner & Pervushina, 2013) continue to be illegally caught and traded in large numbers. In the oceans, bans have had limited success, especially in the face of Illegal Unreported and Unregulated (IUU) fishing (Foster et al., 2019), and in the case of incidentally caught organisms. A list of failures include the continued bycatch of the totoaba fish despite it being listed on the Mexican Endangered Species List in 1975 (Findley, 2010); the finning of shark populations, such as the oceanic white tip, that continued in the Western Pacific despite legislation prohibiting it (Clarke et al., 2012); and in the sustained, lucrative trade of caviar despite a ban on sturgeon fishing in the Caspian Sea (van Uhm & Siegel, 2016).

More tractable bans may include those imposed on specific fishing gear and methods. These bans have been successful as in the case of beach seines in some Kenyan coastal communities, which led to an increase in fish catch (McClanahan et al., 2008). Bans on gill net and trammel net in Southern California Bight (USA) resulted in the recovery of a number of apex predators (Pondella & Allen, 2008). In Alaska (USA), a ban on non-pelagic trawls in the walleye pollock fishery resulted in reduced bycatch (Graham et al., 2007). In Indonesia, the government imposed a total ban on trawling in 1980, and it was found that enforcing a complete ban on trawlers was relatively easier than enforcing regulatory measures such as curtailing trawl operations in coastal waters (Bailey, 1997). However, where compliance is low and fishers lack the capacity to move less destructive fishing gear (Cinner, 2009), as is the case in many small-scale fisheries in developing countries, the use of banned fishing gear continues, and often results in overfishing, catch of juveniles and habitat damage (Mangi & Roberts, 2006).

Bans on capture may not be particularly effective for species obtained in nonselective gears (Tolotti et al., 2015, Vaidyanathan et al., 2021). This is particularly true for species caught in active indiscriminate gears like bottom-trawls, where dragging removes vast numbers of animals and causes large scale habitat destruction. Local damage is multiplied by the huge scale of bottom-trawling. Bottom-trawls may hinder the conservation of a large number of endangered, threatened and protected species (ETPs) from a range of taxa including fishes - teleosts such as seahorses (Lawson, Foster, & Vincent, 2017) and elasmobranchs such as sharks (Cook, 2003; Worm et al., 2013), seabirds (Moore & Zydelis, 2008), marine turtles (Fransesc et al., 2014), and marine mammals (Franco-Trecu et al., 2019). However, small fish and invertebrate species that are incidentally caught by bottom-trawls have often been overlooked, potentially because their life history traits, such as fast growth, small body size, low age, and small size at maturity, are believed to make them less vulnerable to fishing impacts (Winemiller, 2005).

Seahorses (*Hippocampus spp.)* are a charismatic genus that serve as flagship for a wide range of marine conservation issues, including bycatch (Vincent, Foster & Koldeway, 2011). The issues facing seahorses, such as overexploitation and habitat degradation, are also major concerns for marine conservation in general (Foster and Vincent, 2004). Their biology and behaviour -- for example, the young depend on parental survival far longer than most fish, and many species are monogamous -- make them susceptible to overfishing (Foster & Vincent, 2004). A large number of seahorses are incidentally caught by nonselective gear such as bottom-trawls. Their high demand in traditional medicine (TM) and curios (Foster & Vincent, 2004) is largely met by nonselective take, and to a lesser extent through targeted take, while the substantial trade for aquarium display is more targeted. All seahorses (the whole genus *Hippocampus*) are listed in Appendix II of CITES (effective since 2004; CITES, 2002). They were the first marine fishes to be listed in the Appendix II since the

Convention's inception. This list regulates the export of selected species to ensure that wild populations are not damaged by international trade. Currently, of the 46 species of seahorses found globally, 14 are listed as 'threatened' (two Endangered and 12 Vulnerable), 11 are considered as 'not threatened', 17 species are Data Deficient, and four new species have not been evaluated (IUCN, www.iucnredlist.org).

India was among the top four export nations for seahorses by weight (Anon, 2003), until it banned seahorse catch and trade in 2001. All seahorses (and all other syngnathid fishes) were placed under Schedule I of the Wild Life Protection Act (WLPA), 1972 (Ministry of Environment and Forests, Govt. of India, 2001). This listing happened a year before seahorses were listed in CITES Appendix II, which permits continued exports. Though technically the penalty for catching a seahorse is a three to seven-year prison term, with a fine ranging from ₹10000 (~USD 137) to ₹ 25000 (~USD 342) (1USD= ₹73.13), and while a number of fisher apprehensions have taken place, no court case has seen a logical conclusion (D. Bilgi, former Wildlife Warden, Gulf of Mannar Marine National Park, *personal communication*). Seahorses have been largely caught incidentally by some fishing gears, but a substantial targeted seahorse fishery, primarily by divers in the India's southeastern coast also existed (Perry et al., 2020), both of which mostly contributed to the dried seahorse trade. The ban on capture most likely affected fishers who targeted these animals for their livelihoods (Vinod et al., 2018). Their losses were compounded by a ban o n sea cucumber extraction around the same time. Although dried seahorse exports were estimated at 3.6 t in 1996 (Vincent, 1996), export volumes may have been as high as 12.5 t in 1999-2000 (Perry et al., 2020). It has been nearly two decades since the ban, but there is little research done on the status of the seahorse fisheries, other than a few studies along landing centres of the southern states of Kerala (Lipton & Thangaraj, 2013) and Tamil Nadu (Lipton & Thangaraj, 2013; Murugan, 2011, Vinod et al., 2018, Vaidyanathan et al, 2021).

In this study, I generate and share new knowledge about India's seahorse fisheries and how they reflect the implementation and listing of species under the Indian WLPA,1972, the policy used to ban the catch and trade of seahorses. I gathered data on fishers' apparent awareness of the ban, species caught, method of capture (e.g., target/incidental capture), catch per unit effort (CPUE), seahorse numbers in catch, factors determining seahorse presence or absence in catch, fate of seahorses caught, prices that fishers obtained for seahorses. This study should help India—and any country considering taxon-specific catch bans—to (i) evaluate their potential effectiveness and (ii) prompt them to explore alternative solutions.

2.3 Methods

I generated knowledge about the status of seahorse (*Hippocampus* spp.) fisheries in India through semi-structured interviews of fishers from both the mechanized and non-mechanized sectors. For my study, I tried to maximize both the geographic locations and number of fishers interviewed to gather a broad understanding of seahorse fisheries in the country. No official records on landings existed for seahorses, and I therefore collected information through fisher interviews.

2.3.1 Data Collection

To understand how India's seahorse fisheries reflected the implementation and listing of species under the Indian WLPA, I conducted comprehensive surveys comprising 1145 structured and semi-structured interviews with fishers, defined as fishing crew, boat drivers and owners, in nine Indian states and two Union Territories (U.T.) (Figure 2.1). My interviews were conducted during three time periods: (i) July 2015 to April 2016, (ii) August 2016 to May 2017 (iii) September 2017. Puducherry and Karaikal, part of the U.T. of Puducherry, lie within the state of Tamil Nadu, so I included data from these two landing centres with Tamil Nadu (hereafter referred to as just Tamil Nadu). I treated the U.T of Daman and Diu separately and not as a part of Gujarat despite being located within the state because of the proximity of Daman to the state of Maharashtra.

I carried out surveys along the entire coastline of mainland India during the first time period, but for the second and third time periods, I focused on the state of Tamil Nadu, where I had uncovered much of the seahorse catch during my first set of surveys. During these second and third time periods, I made three adjustments from the first surveys while still including questions on seahorse fisheries: (1) I conducted interviews with more fishers in areas already covered in the first time period, making it a priority to expand my sample size, (2) I increased my geographical coverage to new locations (3) I focused more broadly on the socio-economic of trawl fisheries.

I selected some interview locations based on previous studies (Marichamy et al., 1993; Murugan et al., 2008; Perry et al., 2020; Salin, Yohanan & Nair, 2005). I then selected additional locations based on regions that seahorses were known to be found according to 1) current researchers and academics and 2) through snowball sampling in which one respondent indicates other potential locations. In my interview locations, I spoke with some participants recommended by local researchers. However, for most of my interviews, I used convenience sampling, wherein I interviewed an array of people – local fishers, comprising boat crew, boat drivers, and owners of fishing vessels – who were most easily accessible and available. I used convenience sampling because it was a cheap and fast method to gather data (Etikan, Musa & Alkassim, 2016; Patton, 2002) and was appropriate for my goal of gathering a breadth of information.

I conducted each interview in the appropriate regional language with the help of 14 local field assistants, and questions and answers were translated between the local language and English. Assistants were primarily responsible for translating interviews from the local language to English. In Tamil Nadu, however, three assistants conducted structured interviews and one assistant (who had been extensively trained) conducted semi-structured interviews. Where my interviews involved more than one participant (as was often the case), I considered all responses together unless participants explicitly mentioned that they were from different boats. While most fishers were willing to participate in my interviews, some fishers in Tamil Nadu refused to reply because of their concerns about the ban. During an interview, I asked questions about types of seahorse characteristics (colour, spiny/non-spiny, size), uses of seahorses, habitats, catch location (distance from shore, depth, habitat), fishing gear, fishing effort, seahorse catches, trade, and values (Appendix A.1). I recorded catch and trade data in units cited by the fishers and then standardized them for my analysis. I used triangulation to cross-validate information received within interviews by asking the same questions in different ways and comparing the answers within and among interviews. All research was covered by approvals from the University of British Columbia's Animal Care Committee (6253-13) and Human Behavioural Research Ethics Board (H12-02731 and H15-00160).

2.3.2 Apparent awareness of the ban

All my information related to ban awareness resulted from unprompted mentions of the ban. I waited for fishers to mention fishing and trade bans before I asked any further questions about the ban. If a fisher brought up the topic of bans without prompting, I considered the response as "Aware" of the ban. If fishers introduced the subject of bans with regards to other fishing restrictions, I took the opportunity to ask them about constraints in the context of seahorses. If fishers then mentioned that they were aware of the ban, I also considered this response as "Aware", and if they stated they were unaware of the ban, I considered the response as "Unaware". However, if the topic of bans did not arise over the duration of my interviews, I did not force the subject and simply noted down a "No Mention" for the respondent. I included only 961 of 1145 interviews for my analysis of the impressions of bans because my second field season was focused on trawl fisheries more broadly. As a result, many of my interviews were structured and directed towards the economics of trawl fisheries, respondents had fewer opportunities to bring up the topic of bans during these interviews.

2.3.3 Species Composition

I identified seahorse species based on specimens observed during my interviews with fishers and traders.

2.3.4 Catch Monitoring

To estimate the total seahorse catches, I took fisher individual reports on seahorse landings for discrete time periods (i.e., per haul, per day, per week, trip, month, or year) and the reported mean number of days fished (estimates based on days per week, per month, per year, and months per year they fished) and scaled up to calculate annual seahorse catches per vessel. From all my reports for a given gear type, I then obtained the median estimates by bootstrapping the sample 1,000 times using the 'boot' function in R (Canty and Ripley, 2019). Next, to obtain state-wide estimates, I multiplied the annual catch per vessel obtained by boat numbers reported to be operating for each gear type, but only for the locations I sampled, or the smallest given area for which I could obtain gear data. However, for the state of Tamil Nadu, for which I had a greater number of samples and resolution, I further broke my data down into four broad locations and obtained greater resolution for catches by different gear types (Vaidyanathan et al., 2021), which I have consolidated for the purpose of this paper.

The numbers of boats came from local officials and state fishery department statistics, where available, but otherwise depended on the Central Marine Fisheries Research Institute (CMFRI) census, last updated in 2010. In my calculations, I accounted for apparent seasonal variation in catches, i.e., fisheries closed season. Because of the large uncertainty associated with Indian fisheries (e.g., vessels and gears in operation), I include 95% Confidence Intervals for my CPUE estimates to show effects of variation in CPUE on total estimates (Giles et al., 2006). I considered negative lower confidence intervals as 0. While obtaining data was more straightforward for larger vessels like trawlers, I had to rely heavily on local information for the number of smaller boats operating with different gear types. I acknowledge that my estimates include large extrapolations and potential unknown sources of variation, including the number of boats in operation, the fact that multiple gears being often used on the same boat, and fishers often being employed on boats for only certain times of the year. While my estimates were only based on the locations I surveyed, I also acknowledge that my samples were probably a fraction of the fishers operating at the various sites. It is difficult to estimate exactly how many fishers were active in most locations, but I are aware that my extensive sampling probably only covered about 1% of boats in operation in these locations.

I categorized fishing gear I encountered according to the nine Food and Agricultural Organization (FAO) gear-type categories where applicable, while adding a separate category for divers (Table 2.1). This broad classification of fishing gear resulted in additional uncertainties, because, for example, I considered all trawl gear (regardless of horsepower or size class) in one category, and a wide diversity of gill nets (small mesh sizes operating inshore, large mesh for larger fish, bottom-set, and the multi-layered trammel nets) as a second category.

2.3.5 Important predictors and their relationships with the presence or absence of seahorses catches in fisheries

I collated a total of 1379 observations of eight predictor variables and one response variable related to seahorse catch based on information from my interviews. These predictors were either directly provided by fishers or obtained from my field notes. The eight predictors included two location variables (i.e., latitude- one coordinate per state, and state), depth, habitat type, and four categorical variables related to fishing gears (Table 2.2). For gear type, I categorized gears as diving, gill net, seines, trawls, and others (falling nets, hook and line, surround nets and trap nets). I categorized habitats as i) biogenic (seagrass, seaweeds, soft coral, and sponges), ii) flat (muddy, sandy, and bare bottoms) and iii) rocky.

I constructed three sets of data scenarios to identify important predictors for seahorse presence/absence in the catch. While I would have liked to have modelled the relationships between seahorse presence/absence in the catch for all my data points reported by fishers, data for two variables (i.e., habitat and depth) were not available (NA) for a high number of observations (n = 681 for habitat, n = 630 for depth). I then conducted a sensitivity analysis by creating three scenarios using seahorse presence/absence in the catch as the response variable. In the first scenario, I retained all variables but removed samples that contained 'NAs' in one or more variables, resulting in a subsample dataset with only 520 observations. In the second, I retained the sample size but removed the two predictors that contained a large number of 'NAs' (i.e., habitat and depth). In the third scenario, I used the same dataset as that of the first scenario (n=520), except I removed habitat and depth variables. By comparing the 1st scenario with the 3rd scenario, I aimed to understand if habitat and depth variables are vital in predicting seahorse presence/absence in the catch based on the subsample dataset (N = 520). By comparing the 2nd scenario with the 3rd scenario, I explored the effect of removing samples containing ‘NAs’ on model results (e.g., predictor importance).

For my three scenarios, I first used random forests (RFs) to detect important factors and their relationships with seahorse presence/absence in fisheries (R package ‘randomForest’, Cutler et al., 2007; Liaw & Wiener 2002;). I selected important predictors from the original predictors based on the ‘Boruta algorithm’ (R package ‘Boruta’, Kursa, 2018). The importance was measured by the normalized mean decrease in model accuracy after permutating data of the predictor ‘shadowMax’, the maximum importance of ‘shadow’ variables in each permutation. The values for shadow variables were derived by shuffling values of the original attribute across objects. Each time, the minimum, mean, and maximum importance value of all shadow variables were calculated. This shuffling was performed multiple times to obtain statistically valid results. The maximum importance of the shadow variables was used as a reference for detecting important attributes. The algorithm identified important predictors by iteratively comparing predictors’ importance with those achieved at random (using permuted copies of all predictors, Kursa and Rudnicki, 2010).

I used 1000 classification trees to model the relationships between seahorse presence/absence with eight predictors based on the RF model for the first scenario and with six predictors for the second and third scenario. The accuracy of the RF model was evaluated based on three measures: presence accuracy, absence accuracy, and the Matthews correlation coefficient (MCC, Matthews 1975). The MCC considers true and false positives and negatives, and thus is considered a balanced measure of model quality. The value of MCC ranges from -1 (worst) to 1 (best) and is widely used in machine learning such as random forest algorithm, even for the classes of different sample sizes as in my data (more presences than absences) (Boughorbel, 2017). I used RFs because of the speed, simplicity, tendency not to overfit models and their ability to deal with imbalanced data (Caruana & Niculescu-Mizil, 2006; Liaw & Wiener, 2002), but acknowledge that RFs have their own limitations including poor performance in situations where there is one dominant variable and in making real-time predictions (White and Liu, 1994).

I then analyzed the effects of different predictors in the above three scenarios and plotted their relationships with the response variable based on the generalized linear mixed models (GLMMs) (R packages *lme4* and *MASS*, Bates et al. 2015; Venables & Ripley 2002). I assumed there was a random effect of state because this was where the interviews were conducted and not necessarily where the seahorses were caught and explored the fixed effects of other predictors. For each scenario, I first built simple GLMMs with each of the predictors and examined the improvement of model fit compared with a null model with only an intercept and the random effect (Chi-squared tests). I estimated the best models for my dataset using two criteria: Akaike information criterion (AIC; Akaike, 1973) and Bayesian information criterion (BIC; Schwarz, 1978). The lower value of AIC or BIC, the better the model. I then applied a stepwise forward approach to identify the best model in each of the three scenarios detailed above. I did this by adding the predictor with the lest AIC or BIC in each step and accepted the predictor if it significantly improved the model fit (Chi-squared tests) and its fixed effect was statistically significant (Wald tests) until all predictors were tested.

To avoid Type I error (accepting non-significant effects) in the statistical significance tests, I used Bonferroni Correction on the p-value (0.05 / n, n refers to the number of tests conducted simultaneously or in the same group of hypothesis testing; Cabin & Mitchell 2000; Rice 1989). In each scenario, I treated the process of examining whether adding fixed effects of predictors could increase model fit as the same group of tests (Chi-squared tests, Group I), and significance tests in the stepwise process of identifying the best model as another group (Chi-squared tests, Group II). Therefore, I ended up with seven Chi-squared tests for Group I and six Chi-squared tests for Group II in the 1st scenario, and five Chi-squared tests for Group I and four Chi-squared tests for Group II in the 2nd and 3rd scenarios. I then used p-values of 0.007 (0.05 / 7, Group I) and 0.0083 (0.05 / 6, Group II) as the significance levels for Chi-squared tests in the first scenario; and p-values of 0.01 (0.05 / 5, Group I) and 0.012 (0.05 / 4, Group II) for Chi-squared tests in the second scenario. While examining the significance of the fixed effects within each GLMM, I used Bonferroni Corrections on p-values of 0.005 and 0.006 for the 1st and 2nd scenarios respectively, according to the total number of Wald tests on the fixed effects (n = 10 for the 1st scenario, n = 8 for the 2nd scenario).

I acknowledge that my original sample was not a great representative of the diversity of different elements, particularly with regards to state and hence latitude (skewed towards fisher responses from the state of Tamil Nadu) and gear (skewed towards trawlers), which in turn may have impacted other gear elements (e.g., active or passive). Therefore my results for these variables must therefore be interpreted cautiously. Additionally, when I removed NA from my original sample size, my geographical coverage decreased from the original coverage of 10 regions (9 states plus one Union Territory) to only 8 regions. However, for scenarios 1 and 3, when I removed the NAs from both habitat and depth, I find that my reduced sample sizes were still a good representative compared to removing NAs from habitat (520 vs 698) and depth (520 vs 749) individually.

2.3.6 Fate of seahorses caught in fisheries

I asked fishers to describe what they did with seahorses that got caught in their fishing gear (e.g., sold, thrown back). If sold**,** I then asked fishers the quantities and amount they were paid for individual seahorses or by weight.

2.3.7 Temporal trends

I asked respondents questions about perceived changes in catch, size, and values, not just monetary, based on time scales meaningful to them (e.g., dating from when they first entered the fishery/trade, a decade ago, when the ban was imposed, or any natural disaster).

2.4. Results

2.4.1 Apparent awareness of the ban

During my interviews, most fishers from the locations I surveyed along mainland in India (587 of 961, 61%) did not actively bring up the topic of bans relating to seahorses (Fig. 2.2). I found that 339 fishers (35%) reported being aware of the ban unprompted, while only 35 fishers mentioned being unaware of the ban unprompted (4%) typically after raising the topic of other restrictions). Respondents who stated that they were aware of the bans were primarily from the state of Tamil Nadu (321 of 350 interviewed there or ~92%). In my interviews in the remainder of the country outside of Tamil Nadu, a large majority did not raise the topic of the ban and were willing to answer any questions on seahorses. Overall, from the locations I surveyed in states outside Tamil Nadu, I found that only 18 of 611 (3%) respondents actively brought up an awareness of the bans, while 35 of 611 (6%) stated that they were unaware. The greatest number of respondents from the states outside Tamil Nadu who stated that they were aware of the ban were from locations surveyed in Andhra Pradesh (5 of 54 or 9%) and Kerala (8 of 167 or ~5%). Six of 12 fishers (50%) from locations surveyed in the rest of India who mentioned a reason about how they were aware of the ban on seahorse catch and trade explained their knowledge because they were from Tamil Nadu.

2.4.2 Species composition

I observed five species of seahorses during my surveys namely *Hippocampus histrix, H. kelloggii, H. kuda*, *H. spinossisimus,* and *H. trimaculatus.* All my direct observations of seahorse specimens came from the state of Tamil Nadu (details in Vaidyanathan et al., 2021), other than two specimens of *H. kuda* that were found in Gujarat and Karnataka respectively, and one specimen of *H. trimaculatus* from Kerala.

2.4.3 Catch Monitoring

I generated the CPUE (number of seahorses caught per individual gear unit each year) for eight gear type categories (including divers) for which I had information. Based on respondent data and my extrapolations, I find that the median number of total seahorses caught in a year across all gear types based on areas sampled is around 13 million (~5 to 20 million) (Table 2.3).

2.4.4 Catch Contributions by Gear Type

In the regions I surveyed along Indian coast, most seahorses were caught annually by trawl nets (~54%), followed by seines (~38%) and then gill-nets (~10%) (Table 2.4). In contrast, no fishers operating in the hook and line fisheries in all states sampled (Andhra, Kerala, and

Orissa) (n=22) reported catching any seahorses (Table 2.4). I found that the greatest CPUE was from seines (specifically drag nets) operating in the central region of Tamil Nadu (2.9 * 10^3 seahorses drag net^{-1-} year^{-1}), followed by trawls in the Ramanathapuram region of Tamil Nadu (1.9 *10^3 seahorses trawl net^{-1} year^{-1}, refer to Vaidyanathan et al., 2021) and trawls from regions surveyed in Orissa (1.7*10^3 seahorses trawl net^{-1} year^{-1}). Overall, I found that around 89% of seahorse catches came from active gears that were nonselective.

2.4.5 Catch Contributions by State

Maximum contributions to the annual catch of seahorses in India, based on locations surveyed, were from the state of Tamil Nadu where between 68% and 99.5% (median ~77%) of the annual seahorse catches occurred (Table 2.5). Other notable contributions were from the state of Orissa (15 % of total median seahorse catches) and Andhra Pradesh (3.5% of total median seahorse catches) (Table 2.5).

2.4.6 Important predictors and their relationships with the presence or absence of seahorses catches in fisheries

My results indicated that all variables were generally important predictors for seahorse presence/absence in the RF models. I found that in all scenarios, regardless of sample size or the selectivity of the gear plays an important role, with nonselective fishing gear showing a higher probability of catching seahorses. Although depth and habitat were important predictors from scenario 1, the ranking of the importance of predictors was similar between scenarios 1 and 3, with a switch only in the rankings for gear selectivity (more important in scenario 1) (rank 3 vs 4) and gear type (less important in scenario 1) (rank 4 vs 3). In scenarios 2 and 3, I found the same ranking of the importance of predictors, regardless of sample size (1379 vs 520). Therefore, reducing samples containing ‘NA’ records did not change the conclusion on predictor importance. When I compared my models for scenarios 1 and 3, I find that depth and habitat had a significant effect on seahorse presence in the catch, but the response curves of my best GLMMs were similar. When I compared my models for scenarios 2 and 3, I found that while selectivity was an important variable in my simple

GLMMs in scenario 2, this was not the case in scenario 3. However, my response curves for my best GLMMs resulted in the same conclusion for both scenarios.

When seahorse presence/absence in the catch was used in Scenario 1 (presence/ absence: 428/92), I found that depth, latitude, state, selectivity, gear type and gear category (active vs. passive) were generally important predictors in the RF model, with water layer and habitat of less importance (Fig. 2.3, Table 2.6). All the same predictors were important in Scenario 2 (presence/absence: 1012/ 367) (Fig. 2.3, Table 2.6) and Scenario 3 (presence/absence: 428/92) (Fig. 2.3, Table 2.6), but depth and habitat were not considered because of lower sample sizes. Although all three RFs achieved high accuracy in predicting presences (97%, 94%), the accuracy was relatively lower in predicting absences (48%, 54%, 20%) (Table 2.6). The MCC for scenarios 1 and 2 were similar (MCC = 0.55, 0.55), and even though my MCC for scenario 3 was lower (MCC=0.24), all values were relatively higher than zero suggesting that my RF models performed much better than random classification.

My results about the fixed effects of the predictors in the GLMMs differed between the 1st, and 2nd and 3rd scenarios, although all scenarios suggested that selective gears had a significantly lower probability of catching seahorses (Figs 2.4 & 2.5 and 2.6, Table 2.7).

The 1st scenario indicated that depth, habitat types, and gear selectivity had significant effects on seahorse presence in the catch. Among the simple GLMMs, only the one with the fixed effect of habitat (AIC = 401, BIC = 418) or depth (AIC = 397, BIC = 410) had a significant improvement on model fit (Chi-squared tests, both $p < 0.007$), compared with the null model (AIC = 422, BIC = 430). Depth had a significant negative effect on seahorse presence (coefficient = -0.679, Wald test, $p < 0.001$). Compared with the biogenic habitat, flat habitat had significant negative effect on seahorse presence (coefficient = -1.797, Wald test, $p < 0.005$), rocky / stony habitat had a non-significant negative effect (coefficient = -0.386, Wald test, $p = 0.579 > 0.005$). The best GLMM in this scenario (AIC = 353, BIC = 395) comprised these two predictors (habitat and depth) and another two gear-related predictors: gear selectivity and gear type (Fig. 2.4). Only gear selectivity and depth had significant fixed effects in the best GLMM which showed negative effects of these two predictors (both 365, $p < 0.005$, Table 2.7).

The 2nd scenario showed that gear selectivity, water layer, and latitude had significant effects on seahorse presence in the catch. Among the simple GLMMs, I find only the model with the fixed effect of gear selectivity (AIC = 1256, BIC = 1272) or water layer (AIC = 1268, BIC = 1288) had significantly improved model fit (Chi-squared tests, both $p < 0.01$), in contrast to the null model (AIC = 1277, BIC = 1283). Selective gears had a significantly lower probability of catching seahorses (coefficient = -0.676, Wald test, $p < 0.006$). Compared with gears operating on the seabed, gears operating in water columns had a nearly significant negative effect on seahorse presence in the catch (coefficient = -0.404, Wald test, $p = 0.009 > 0.006$). Meanwhile, latitude (AIC = 1272, BIC = 1282) also had a significant negative effect on seahorse presence (coefficient = -0.224, Wald test, $p < 0.006$), and improved the model fit, although not this improvement was not statistically significant (Chi-squared test, $p = 0.014 > 0.01$). The best GLMM in this scenario (AIC = 1196, BIC = 1232) consisted of fixed effects of two variables, namely selectivity and gear type (Fig. 2.5). The best model indicated that gear selectivity had a significant negative effect on seahorse presence in the catch (coefficient = -3.153, Ward test, $p < 0.001$); two gear types (trawl, seine) had a significantly lower probability of catching seahorse than diving (Wald tests, both $p < 0.006$, Table 2.7).

The 3rd scenario showed that only gear selectivity had significant effects on seahorse presence in the catch. Among the simple GLMMs, I find that none of the models significantly improved model fit in contrast to the null model. The best GLMM in this scenario (AIC = 416, BIC = 445) consisted of fixed effects of two variables, namely selectivity and gear type (Fig. 2.6). The best model indicated that gear selectivity had a significant negative effect on seahorse presence in the catch (coefficient = -2.6248, Wald test, $p < 0.001$ (Table 2.7).

2.4.7 Fate of seahorses caught in fisheries

Of the fishers who provided responses on the fate of seahorses caught in fishing gear (855 or 64%; Table 2.8), the greatest number of fishers reported selling seahorses (328 of 855 responses, or 38%), followed by those who stated they threw seahorses back into the water (237 of 855 responses or 28%) and those who used them for curios and decoration (72 of 855 responses or 8%). When fishers' responses from Tamil Nadu were removed from the analysis (Table 2.8), the story was very different, and only 1% of fishers outside these areas reported selling seahorses. In contrast, the greatest number of fishers (n=186 of 336 responses or 51%) reported throwing seahorses back in the water, and another 8% reported throwing them away with 'waste' or discarded fish. Many fishers reported giving away seahorses (n=41 of 336 responses or 12%), often to children.

Throughout locations I surveyed in India, most fishers who reported throwing back seahorses, or throwing them away, (n=269) explained that seahorses were of no use (60 of 269 or 22%), or that there was no market for seahorses (40 of 269 responses or 15%). Only 6% (15 of 269 responses) reported throwing them back because of the ban, and when fisher responses from the state of Tamil Nadu were removed this number fell further to only 2% (4 of 186 responses). Seahorses were primarily traded in the state of Tamil Nadu (details in Vaidyanathan et al., 2021). Despite fisher reports from Orissa (n=2 of 53) and Kerala (n=2 of 167) about trade existing in these states, I was unable to locate and interview any traders. Researchers reported that live seahorses were traded in the state of Maharashtra, but I was also unable to verify this.

2.4.8 Temporal Trends

2.4.8.1 Fisher perceptions on changes in catches and sizes

In total, 149 fishers in the locations I surveyed along mainland India reported a change in seahorse catch, which may have come from a mixture of personal experience and community narrative. Of this, 77% of fishers (115 of 149 fishers) reported a nearly total disappearance of seahorses in catch (mean=92%, SD=0.23), over the past 2.5 to 55 years (mean=13.98, SD=9.96), although some of these referred to small numbers originally. Only two fishers, or a mere 1%, both from Orissa, reported an increase in seahorse catches over the last decade. However, 21% (32 fishers) stated that seahorse catches had remained the same over the last 5.5 to 20 years (mean=12, SD=4.87).

When I removed fisher responses from Tamil Nadu from my analysis, I find that 77% fishers (70 of 91 fishers) reported a near total loss of seahorse catches (mean=99.93, SD=0.23) over the past 2.5 to 40 years (mean=12.2, SD=9.03). Two percent (the two fishers from Orissa, from above) noted an increase in seahorse catches, whereas 21% (19 fishers) noted that the catches had remained the same over the last two decades (mean=14 years, SD=12.1).

During my interviews in India, only 8 fishers (all from Tamil Nadu) reported a change in size of seahorses caught, with reported declines over the past 12 to 40 years (mean=22.4, SD=12.1).

2.4.8.2 Fisher perceptions on changes in values of seahorses

A total of 54 fishers who used to sell seahorses over the last one to thirty years reported that they no longer did. Outside the state of Tamil Nadu, 39 fishers reported on the changing value of seahorses. While two fishers stated that the price of seahorses had increased over the last five years, 37 fishers who used to sell seahorses over the last 1 to 25 years (mean=9.67, SD=5.1), no longer reported selling seahorses. Of the fishers who provided reasons for no longer selling seahorses (n=12), six fishers stated that there were currently no buyers for seahorses in their locations and two stated that they did not catch enough to trade. However, only four of these fishers stated that they stopped trading because of the ban.

In Tamil Nadu, only 27 fishers quantified changes in prices received for seahorses. Eight respondents stated that prices received for seahorses had decreased 5 to 100% (mean=52.8, SD=38.2) over the last 10 to 20 years (mean=14.1, SD =2.9). In contrast, 10 fishers (of 27) stated that prices they received for seahorses had increased between 4% and 510 % (mean=162, SD=165.3) over the last 6 to 20 years (mean=16.4, SD=4.7). A further 15 fishers stated that they used to previously sell seahorses but did not any longer, two fishers who previously either used seahorses for medicine or threw them back now sold them, and two fishers who had used seahorses for medicinal purposes now threw them back. Based on fisher perception, along the region that has historically traded seahorses in Tamil Nadu, I found that the price of seahorse appeared to have increased in the region over the last 4 decades, though not significantly after accounting for inflation (Fig 2.7).

2.5 Discussion

My study shows that India's ban on catching and trading seahorses in no way ended the extraction of these fishes. I find that the incidental catch of seahorses continued in large numbers, as it has for decades (Perry et al., 2020; Salin, Yohanan & Nair, 2005). The region where seahorses were concentrated was also where fishers most frequently raised the subject of bans unprompted. My analysis indicates that seahorses may most likely have been encountered by nonselective fishing gear operating along the sea bottom, close to the shore, at lower latitudes and shallower depths, particularly in biogenic habitats. That is to say, largely by trawls and seine nets in the southern part of the state of Tamil Nadu. Bycatch of threatened species in other extractive activities certainly adds complexity to the consideration of prohibitions and bans and requires complementary fisheries management measures.

My estimates suggest that – despite the ban – around 13 million seahorses were caught annually, between 2015 and 2017, at the locations I surveyed along the coast of mainland India. This was fewer than the 16.8 million seahorses estimated using a similar methodology, in 1999, during the last comprehensive survey before the ban (Perry et al., 2020). My calculated reduction in overall catches appears to match fishers' general perceptions on declines in their individual catches, but I do not place much confidence on specific declines or timelines provided by fishers because as with all catches, these may or may not reflect population declines, depending on relative effort invested, which I did not probe specifically. However, given that I estimated that more gear units were operating in 2015-2017 (about 70,000) than in comparable areas during 1999 (56,000), my findings of a reduction in overall catch suggest a marked reduction in catch per unit effort over the intervening 16-18 years. I observed a shift in the gear catching seahorses, with a majority (ca 89 %) of the nation's annual catches from my surveyed locations obtained from active nonselective fishing gear such as trawls and seine nets, which was a much greater proportion, and numbers, than the 68% observed in 1999 (Perry et al., 2020). My results also suggest a drastic decline in the contribution of seahorse catches from the highly selective and skilled skin-divers compared to pre-ban catches, which could be attributed to the fewer divers operating. My findings determined that traditional and more passive fishing gears like gill nets, contributed significantly to seahorse catches, primarily because of the large number of units in operation (e.g., Aylesworth, Phoonsawat & Vincent, 2017; Lawson, Foster & Vincent, 2017).

While reflecting best practices in research on illegal wildlife trade, the specifics of my data must be treated with caution because of the extensive and unregulated nature of Indian fisheries, the large number of landing sites, the numerous vessels and gears operating out of numerous locations, and challenges associated with fisher recall. Convenience sampling was an appropriate method for my goal of looking for rough estimates and trends in seahorse catches, particularly given this data-poor context. However, such a broad survey approach may have added error to my estimates (Kelley et al., 2003), including those caused by outliers (Farrokhi & Mahmoudi-Hamidabad, 2012). My catch estimates from a number of locations, particularly where the trade was not perceived as important, may be an under-representation. I found that fishers in locations where seahorses were caught regularly and were of economic importance (Malvan and most landing centres in Tamil Nadu) could more readily quantify their catches or lack thereof. The same was true of locations where fishers caught no seahorses (e.g., most surveyed locations in Gujarat, Karnataka, Daman, and Diu). However, fishers were less likely to report seahorse catches in areas where they worked on multi-day trawlers, in areas with large amounts of bycatch where catch was sold unsorted, or in regions where fishers only occasionally encountered seahorses (e.g., Kerala where of the 204 responses I received, only 54 could be quantified). I found significant seahorse catches in Orissa, a region previously not sampled. It is likely that catches are also high in Andhra Pradesh, the state lying between Orissa and Tamil Nadu. However, logistic issues constrained sampling in the state. Still, my new findings about seahorse distribution and catches should prompt more attention to implementation of management policy.

The argument that bans have value in raising awareness about the conservation status of species for the public and to fishers (Tolotti et al., 2015) may be correct here, without eliciting much conservation response. Evidence from Tamil Nadu, the state with the highest reported catch and trade of seahorses, historically and currently, seems to suggest that the government has been successful in raising awareness about the ban, with greater than 90% of fishers bringing up the topic of bans unprompted. There, increased awareness about the ban is probably offset by the economic importance of the overall catch to fishers, such that compliance with the ban remains low (Roe et al., 2002; Sorice, Oh & Gartner, 2013). This is particularly the case when avoiding a threatened species would restrict overall fishing effort, given the importance of nonselective gear in the state. Wherever I looked, however, the ban was either irrelevant (because of so few seahorses), overlooked or actively ignored.

Given that most seahorses in India were caught by nonselective gear, the ban on capture and trade of seahorses was unlikely to be successful when imposed in isolation. Indeed, it may be futile to ban the use or sale of animals if they will be caught anyway; often individuals of many species may already severely damaged or dead in the fishing gear (Hill & Wassenberg, 2000; Stobutzki et al., 2002). Acknowledging this issue, some jurisdictions elsewhere have allowed use of protected species that are incidentally caught, such as whales obtained as bycatch in South Korea (Macmillan & Han, 2011). By legalizing the trade of these incidentally caught whales, the South Korean government had an opportunity to develop a sustainable management protocol (MacMillan & Han, 2011). However, this was not without its own set of problems as some fishers either targeted them intentionally or did not release whales caught in their net, leading to the issue of “intentional bycatch” (MacMillan & Han, 2011). Booth et al. (2020) found that while a national ban in Indonesia was successful for the conservation of two species of manta rays, they concluded that a complete protection of species and enforcement was not the right management approach for all contexts, particularly for incidentally caught organisms and species of economic importance for livelihoods.

My findings on the attributes determining seahorse catch have management implications for the conservation of seahorses in India. My analysis indicates that seahorses in India were more likely to occur in fishing catches at lower latitudes and shallower depths, similar to findings from Zhang & Vincent, (2017). My results suggest that seahorses were also mostly caught in nonselective fishing gear operating along the sea bottom, close to the shore and particularly in biogenic habitats. This means that operations of nonselective gear need be curtailed in shallow regions, particularly in the Palk Bay region of Tamil Nadu where seahorses are caught in large numbers by drag-netters (traditional modified shrimp trawls) operating on seagrass beds for shrimp, and by trawlers (Vaidyanathan et al., 2021). Given that attempts to reduce bycatch of seahorses would reduce the catch of economically useful organisms (primary or secondary targets), constraints on such nonselective gears might be best implemented through spatial management. One approach would be for traditional draggers in Palk Bay to set up community based protected areas over sensitive seagrass habitats, while curtailing mechanized trawl activities in the state of Tamil Nadu. While trawlers are already banned within three nautical miles of the coast, they still often operate with impunity in inshore areas (Bavinck, 2001), and there are no spatial restrictions on the operation of drag-netters. Moreover, many important areas for seahorses lie outside such inshore regions. Whatever the spatial management plan, the ineffectual implementation of the ban on capturing seahorses makes it clear that community engagement and co-management will be vital if exclusion zones are to be effective; fishers have too many reasons to circumvent prohibitions that they do not support (Vaidyanathan and Vincent, *in revision*).

Banning the catch and trade of seahorses will serve no purpose for their conservation if non-selective fisheries are not managed (Lawson, Foster & Vincent, 2017). India’s trawl fisheries – many of which involve large boats with large engines, greater than permissible under the state Marine Fisheries Regulation Acts (MFRAs) – are exerting unsustainable impacts on marine life and ecosystems (Gupta et al, 2019; Kumar & Deepthi, 2006; Mohamed et al., 2010) and must be managed. Though the ecological benefits of absolute trawl bans remain poorly documented, McConnaughey et al. (2019) predicted a complete recovery of seabeds in the absence of trawling over time. Spatial controls, constraining or eliminating the use of trawl fisheries in near-shore regions or relatively unfished areas, would help minimize the benthic impact on relatively unfished areas, retain the ecological integrity of these regions, result in a potential spillover to fished regions and protect ecologically sensitive habitats

(McConnaughey, 2019). Preventing active nonselective gear from operating in near-shore waters may also benefit artisanal fishers, as in the case of Venezuela where the absence of trawling in in-shore waters resulted in increased catches for small-scale fishers (McConnaughey et al., 2019). Ultimately, modifying the effort of indiscriminate fishing operations in time and space would be of great conservation value for seahorses, while supporting many other species too.

A number of marine species of conservation importance (endangered, threatened or protected) are obtained in fisheries bycatch (e.g., cetaceans, marine turtles, sharks) (e.g., Gopi, Panday & Choudhury, 2006; Oliver et al., 2015; Thompson, Abraham & Berkenbusch, 2013). The opportunistic exploitation of rarer but economically important species while targeting more abundant target species may result in a pathway to extinction (Branch, Lobo & Purcell, 2013). Indeed, what used to be regarded as bycatch is often the target now, with trawl fisheries, and in fact many other fisheries, chasing all marine life indiscriminately (Davies et al., 2009, Lobo et al., 2010). However, forestry and trapping may have the same challenges. In logging an area for the commercially targeted species, trees and other plants of conservation concern may also be incidentally damaged or removed (Panayotou & Ashton, 1992). Similarly, in laying snares, as in the case for bushmeat in Africa, many wildlife species may be impacted including endangered species such as elephants and wild dogs (Becker et al., 2013; Leigh, 2005; Lindsey et al., 2011). A ban as a stand-alone management measure is probably not appropriate for most incidentally caught organisms. Instead, the entire premise of nonselective take needs to be addressed with a shift in focus from combatting illegal capture and towards active management of nonselective gear, gear that also destroy the habitats of many a taxon.

The same concerns about the utility (or futility?) of bans can arise in the context of species affected by non-selective activities on land like logging and trapping. While most studies on logging have focused on the habitat-scale and on the long-term impacts on species, the direct and immediate impacts of logging on individual ETP species have been surprisingly poorly studied. In the case of trapping, use of non-selective gear such as snares are responsible for the take of many ETP species such as the Critically Endangered and (theoretically) nationally protected saola ungulates in Lao PDR and Vietnam (Baillie and Butcher, 2012), and gin-traps in Namibia and South Africa are responsible for the accidental catch of the Vulnerable ground pangolins that are regionally protected by law (Pietersen et al., 2019). Non-selective mantraps used by farmers to protect crops against baboons and wild pigs are also responsible for unintended catches, and often deaths of, the Endangered and legally protected Eastern chimpanzee in Uganda (Mcclennan et al., 2012). Ultimately, nonselective extraction challenges the value of protecting a species on land, just as it does in the water.

Table 2.1 Nine general gear type categories from the Food and Agriculture Organization of the United Nations (FAO), and the corresponding gear types employed by respondents during my seahorse surveys in India.

FAO gear type category	**Reported gear type during my surveys**
-----	Diving
Dredges	NA
Falling gear	Cast nets
Gill/Entangling net	Gill nets Trammel nets Drift nets Fixed nets
Hook and Line	Pole fishing Bait Longlining
Scoop net	Chinese fishing nets
Seine net	Shore seine Boat seine Drag nets
Surround net	Purse seine Ring seine Encircling nets
Trap	Box nets Dol nets (Bag nets)
Trawl net	Trawl

Table 2.2 Response and predictor variables related to seahorse catches based on interviews conducted between 2015 and 2017 along the coast of India.

Type	Variable	Range for continuous variables / Levels for categorical factors	Number of observations
Response	seahorse presence/absence	0/1	1379
Predictor	Latitude	N 10.85 - 22.99	1379
	Gear type	Five types: Diving, Gill net, Seine, Trawl, Other (Falling gear, hook and line, surround and trap)	1379
	Gear operation style	Two types: Active vs. Passive	1379
	Water layer	Two layers: Bottom vs. Water column	1379
	Habitat	Three levels: Biogenic vs. Flat vs. Rocky/stony	698
	Depth	0 - 3656 m	749
	Selectivity	Selective or not	1379

Table 2.3 Approximate estimations of seahorse catches by various gear types and locations along the Indian coast ordered based on location from the northwest to the northeast of the country. All values presented are based on estimates obtained from bootstrapping and running Monte-Carlo simulations for 1000 runs (Canty and Ripley, 2019). Fleet sizes were obtained from local sources, and where unavailable I used either state fisheries census data or CMFRI census of 2010. The top 3 locations and fishing gear in which the most seahorses are caught are in bold.

State or U.T.	Gear	Sample size	No. of gear units in operation	Median CPUE (number of seahorses caught^{-1} gear unit^{-1} year^{-1})	Lower 95% CI annual catch of entire fleet	Median annual catch	Upper 95% annual catch for entire fleet
Gujarat	Gill net	36	8,030	0.5	500	4,000	6,000
	Trawl net	40	8,014	0.5	0	4,500	8,500
Daman and Diu	Gill net	27	759	0.0	0	0	0
	Trawl net	6	537	0.0	0	0	0
Maharashtra	Falling net	2	1,679	4.1	6,500	7,000	7,500
	Gill net	24	1,701	6.2	0	10,500	21,000

Table 2.3 (Con't) Approximate estimations of seahorse catches by various gear types and locations along the Indian coast ordered based on location from the northwest to the northeast of the country.

Maharashtra	Seine	2	35	612.7	20,000	21,500	23,000
	Surround net	17	142	71.8	0	10,000	20,500
	Trap net	17	1,276	1.1	0	1,500	2,500
	Trawl net	13	3,000	6.7	0	20,000	40,000
Goa	Gill net	9	168	8.3	0	1,500	2,500
	Surround net	7	201	3.6	0	1000	11,500
	Trawl net	5	556	245.1	0	136,000	273,000
Karnataka	Gill net	3	2,733	0.0	0	0	0
	Surround net	19	218	2.1	0	500	1000
	Trawl net	51	2,847	3.0	0	8,500	16,000
Kerala	Hook and Line	16	922	0.0	0	0	0
	Gill net	15	3,426	4.7	0	16,000	30,500
	Seine*	8	1,025	0.0	0	0	0
	Surround net	6	233	122.0	0	28,500	57,000
	Trawl net	27	3,989	91.4	0	365,000	721,500
Tamil Nadu**	Diving	8	1,545		36,000	102,000	166,500
	Gill net	78	8,699		175,000	1,126,000	1,886,000
	Seine	**30**	**1,722**		**2,700,000**	**4,900,000**	**6,700,000**
	Trawl net	**252**	**5,728**		**2,100,000**	**3,600,000**	**4,900,000**

Table 2.3 (Con't) Approximate estimations of seahorse catches by various gear types and locations along the Indian coast ordered based on location from the northwest to the northeast of the country

Andhra Pradesh	Hook and Line	4	2,579	0.0	0	0	0
	Gill net	6	2,220	5.9	0	13,000	26,000
	Trawl net	5	1,066	405.9	0	433,000	795,000
Orissa	Hook and Line	2	550	0.0	0	0	0
	Gill net	16	820	143.3	0	117,500	230,000
	Trap net*	3	700	0.0	0	0	0
	Trawl net	**12**	**1,240**	**1659.9**	**0**	**2,100,000**	**4,000,000**
West Bengal	Gill net	3	400	0.0	0	0	0
	Trawl net	11	1,295	0.1	0	150	250
	Total	**780**	**70,055**		**~ 5,000,000**	**~ 13,000,000**	**~ 20,000,000**

* For these gear types, fishers who caught seahorses were not able to quantify the catch, and values were obtained only from fishers who caught no seahorses.

** For the state of Tamil Nadu, I do not include median values per vessel because this varied further by sub-region. Please refer to Vaidyanathan et al., 2021 for a detailed breakdown

Table 2.4 Approximate estimations of seahorse catches per annum (with 95% Confidence Intervals) by gear type arranged from maximum to minimum seahorse catches. Percentage of total catches provided for the median CPUE.

Gear Type	Sample size	No. of gear units in operation	Lower 95% CI annual seahorse catch of entire fleet (in millions)	Median annual catch of seahorses	Upper 95% annual catch of seahorses for entire fleet	Percentage contribution (of the median)
Trawl net	422	28,272	2,100,000	7,000,000	11,000,000	53.85
Seine nets	40	2,782	2,700,000	4,900,000	6,700,000	37.69
Gill nets	217	28,956	175,500	1,300,000	2,200,000	10.00
Diving	8	1,545	36,000	102,000	166,500	0.78
Surround nets	49	794	0	40,000	90,000	0.31
Falling nets	2	1,679	6,500	7,000	7,500	0.05
Trap nets	20	1,976	0	1,500	3,000	0.01
Hook and Line	22	4,051	0	0	0	0.00
Total	**780**	**70,055**	**~ 5,000,000**	**~ 13,000,000**	**~20,000,000**	**100**

Table 2.5 Approximate estimations of seahorse catches per annum (with 95% Confidence Intervals) by state arranged from maximum to minimum seahorse catches. Percentage of total catches provided for the median CPUE.

State	Sample size	No. of gear units in operation	Lower 95% CI annual seahorse catch of entire fleet	Median annual catch of seahorses	Upper 95% annual catch of seahorses for entire fleet	Percentage contribution (of the median)
Tamil Nadu†	368	17,694	5,000,000	10,000,000	14,000,000	76.92
Orissa	33	3,310	0	2,000,000	4,500,000	15.39
Andhra	15	5,865	0	446,000	821,000	3.43
Kerala	72	9,595	0	410,000	808,000	3.15
Goa	21	925	0	138,000	286,500	1.06
Maharashtra	75	7,833	26,500	71,000	114,000	0.55
Karnataka	73	5,798	0	9,000	17,000	0.07
Gujarat	76	16,044	300	8,000	14,500	0.06
West Bengal	14	1,695	0	150	2300	0.001
Daman and Diu	33	1,296	0	0	0	0.00
Total	**780**	**70,055**	**~ 5,000,000**	**~ 13,000,000**	**~ 20,000,000**	**100**

† Annual seahorse catch estimates were obtained using a more detailed calculation, see Vaidyanathan et al., 2021.

Table 2.6 Importance ranking of the different variables and model accuracy for scenario 1 and 2 based on Random Forest (RF) models.

Variable	1st Scenario The rank of importance in RF	2nd Scenario The rank of importance in RF	3rd Scenario The rank of importance in RF
Depth (Log(1+Depth)	1	-	-
Latitude	21	1	1
State	32	2	2
Selectivity	43	4	4
Gear type	54	3	3
Gear operation style	6	6	5
Water layer	7	5	6
Habitat	8	-	-
Presence: Absence	428:92	1012:367	428:92
Model accuracy	0.88	0.84	0.83
Presence accuracy	97%	94%	96.5%
Absence accuracy	48%	54%	20%
Matthews Correlation Coefficient (MCC)	0.55	0.55	0.25

Table 2.7 Generalized Linear Mixed Models (GLMMs) in the first, second and third scenarios using seahorse presence/absence in the catch.

Variable	Category	1st Scenario				2nd Scenario				3rd Scenario			
		Individual GLMM	AIC	BIC	Best GLMM	Individual GLMM	AIC	BIC	Best GLMM	Individual GLMM	AIC	BIC	Best GLMM
State		random effect	421.5	430	random effect	random effect	1272.3	1282.8	random effect	random effect	421.5	430	random effect
Latitude	-	-0.197 (p = 0.019)	419.7	432.5	-	-0.224*	1269	1284.6	-	-0.197 (p = 0.019)	419.7	432.5	
Gear type	Diving	control	427.9	453.5	control	control	1272.9	1304.3	control	control	427.9	453.5	control
	Trawl	0.580 (p = 0.593)			-0.29 (p = 0.839)	0.801 (p = 0.220)			-2.29*	0.580 (p = 0.593)			-1.986 (p=0.125)
	Gill net	0.562 (p = 0.616)			1.693 (p = 0.159)	0.729 (p = 0.270)			0.641 (p = 0.332)	0.562 (p = 0.616)			0.4576 (p=0.683)
	Seine	0.027 (p = 0.982)			-3.859 (p = 0.012)	0.558 (p = 0.440)			-2.593*	0.027 (p = 0.982)			-2.595 (p=0.06)
	Others	0.264 (p = 0.818)			-0.666 (p = 0.618)	0.100 (p = 0.883)			-2.034 (p = 0.007)	0.264 (p = 0.818)			-1.452 (p=0.244)
Gear operation style	Active	control	423	435.8	-	control	1268.5	1299.8	-	control			-
	Passive	-0.221 (p = 0.488)			-	-0.281 (p = 0.073)			-	-0.221 (p = 0.488)	423	435.8	-
Water layer	Bottom	control	423.5	436.2	-	control	1267.6	1283.3	-	control	423.5	436.2	-
	Water column	0.033 (p = 0.910)			-	-0.399 (p=0.009)			-	0.033 (p = 0.910)			-
Habitat	Biogenic	control	401*	418	control	-	-	-	-				-
	Flat	-1.797*			-1.047 (p = 0.138)	-			-				-
	Rocky/Stony	-0.386 (p = 0.579)			0.608 (p = 0.450)	-			-				-
Depth	-	-0.679*	397.3*	410.0	-1.186*	-	-	-	-				-
Selectivity	no	control	420.3	433.1	control	control	1255.7*	1271.4	control	control	420.3	433.1	control
	yes	-0.545 (p = 0.07)			-3.597*	-0.676*			-3.153*	-0.545 (p = 0.07)			-2.6248*

*indicates statistical significance at the p-value with Bonferroni Correction.

Table 2.8 Fate of seahorses incidentally caught in fishing gear based on fisher interviews conducted along the coast of India between 2015 and 2017.

	Responses reporting fate of seahorses (%)	
Fate of seahorse	India	India (Without TN and Puducherry)
Sold	38	1
Thrown back	28	5
For decoration	8	8
Given away	6	11
Medicinal	5	7

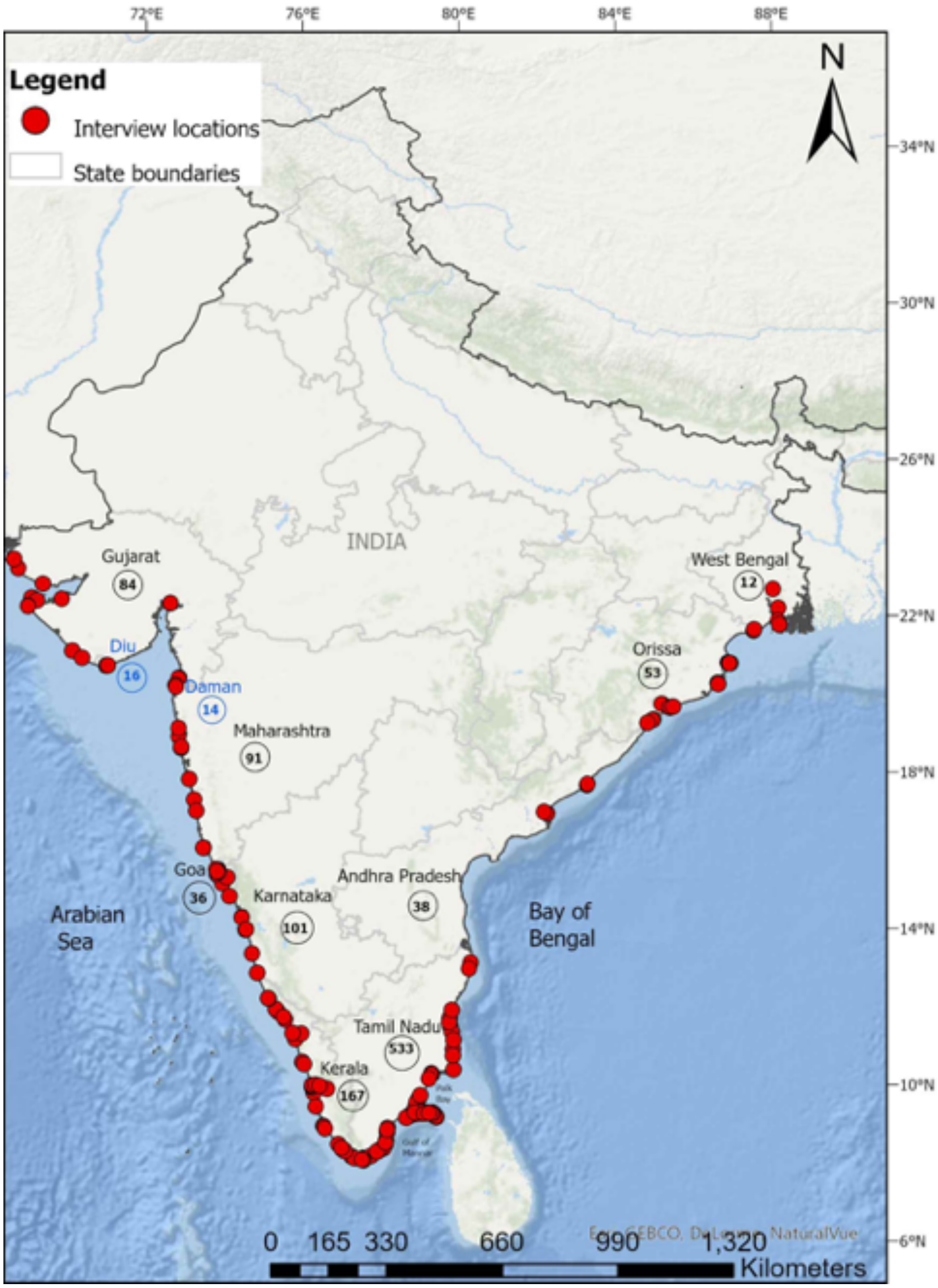

Figure 2.1 Locations where interviews with fishers and seahorse traders were conducted along the coastline of India between 2015 and 2017. Labels in blue indicate the locations of Daman and Diu separately. Locations in the Union Territory of Puducherry are included with Tamil Nadu. Numbers in the bubbles represent the number of interviews conducted in each state.

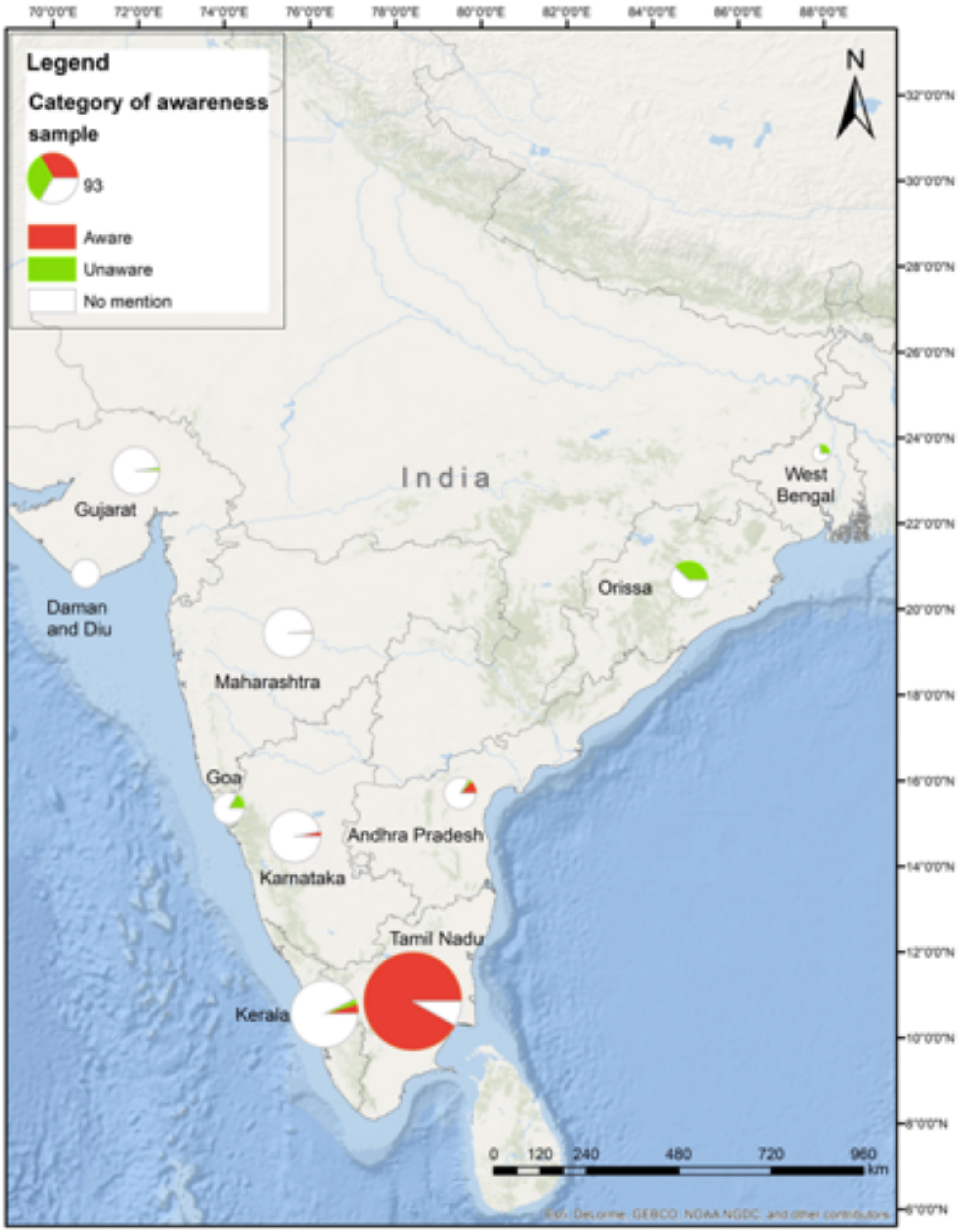

Figure 2.2 Apparent awareness of bans on the exploitation and trade of seahorses in the different states of India. Sample represents the size of a pie chart of sample size 93, white represents proportion of respondents who made "No Mention", green the proportion who stated that they were "Unaware" and red the proportion who were "Aware" of the seahorse ban

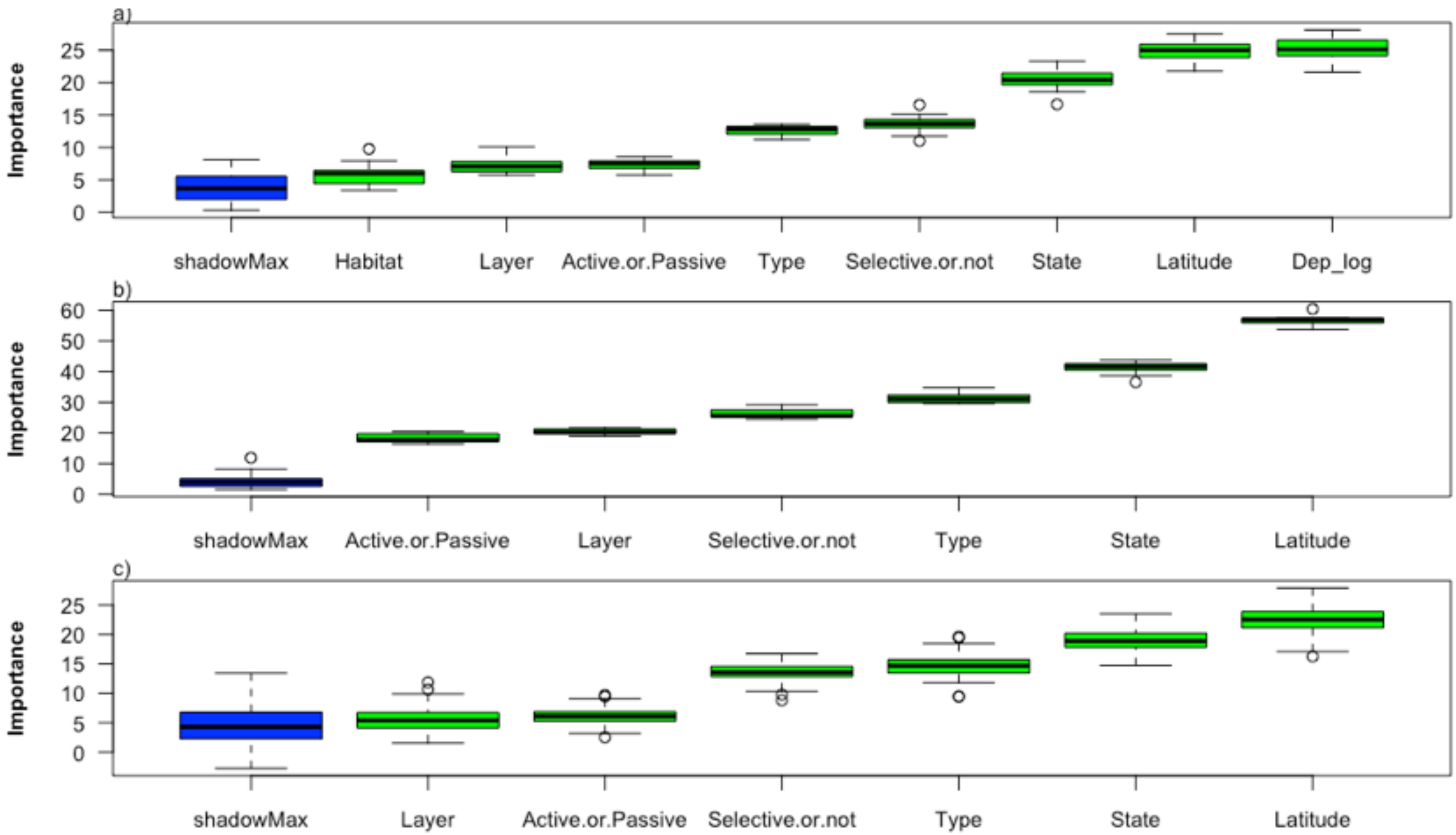

Figure 2.3 Importance of eight predictors for the first scenario and six predictors for the second and third scenarios in the random forest model. Figure (a) depicts scenario 1, Figure (b) depicts scenario 2 and Figure (c) depicts scenario 3. Attributes with green boxes were important.

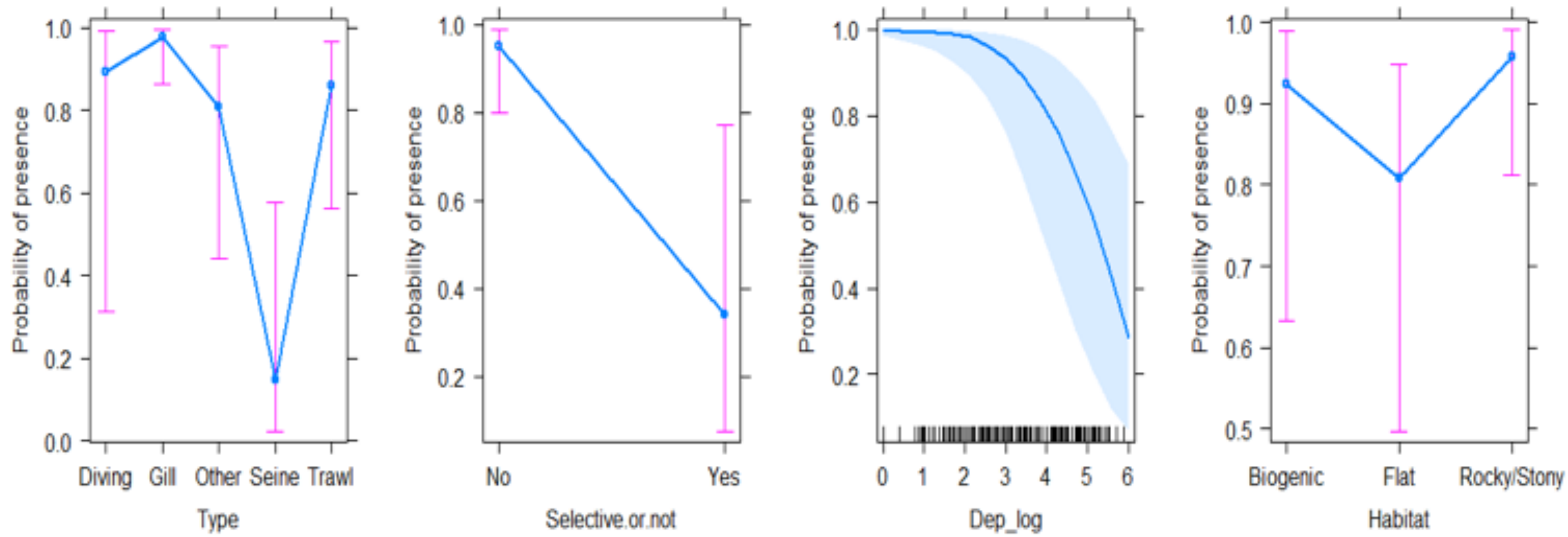

Figure 2.4 Response curves for four important fixed-effect predictors (gear type, gear selectivity, depth (i.e., log(1+depth)), and habitat) identified by the best Generalized Linear Mixed Models (GLMMs) for Scenario 1 with the probability of seahorse presence in the catch on the y-axis. Note that the log of depth (m) was based on the mean value calculated for each fisher's recall.

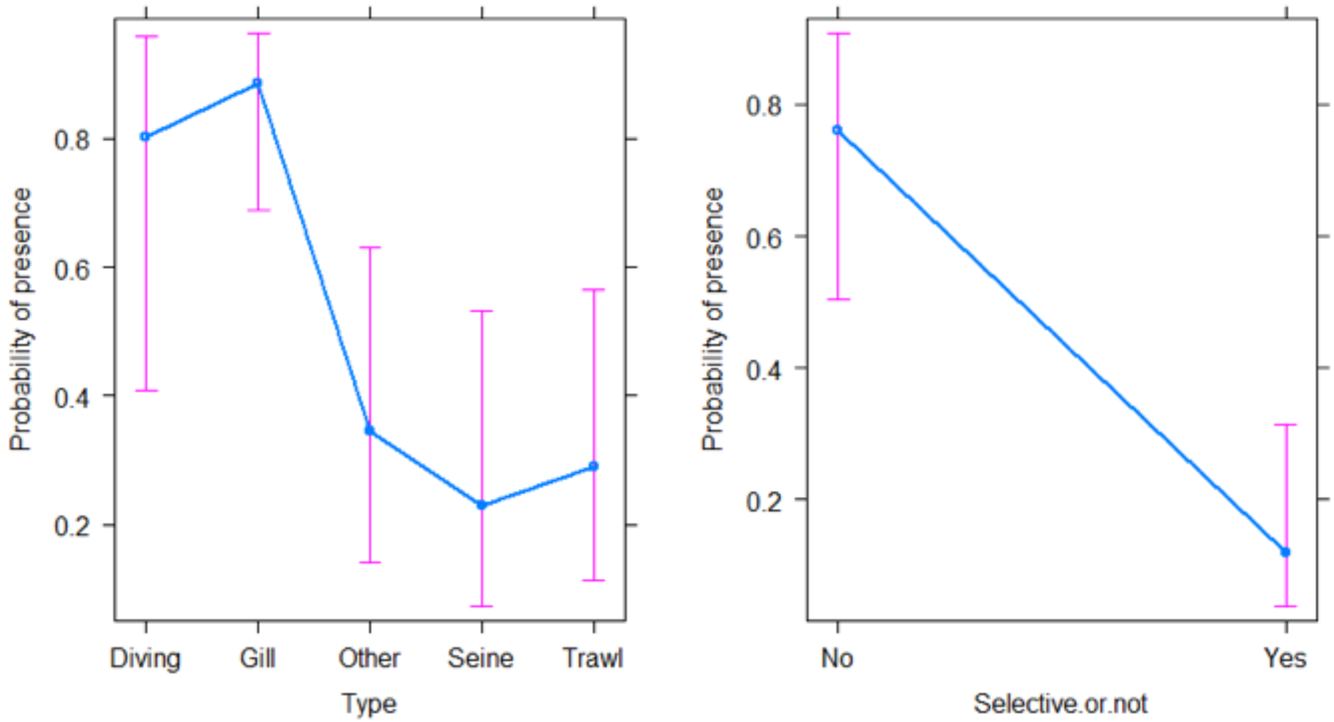

Figure 2.5 Response curves for two important fixed-effect predictors (gear selectivity and gear type) based on the best Generalized Linear Mixed Models (GLMMs) for Scenario 2 with the probability of seahorse presence in the catch on the y-axis.

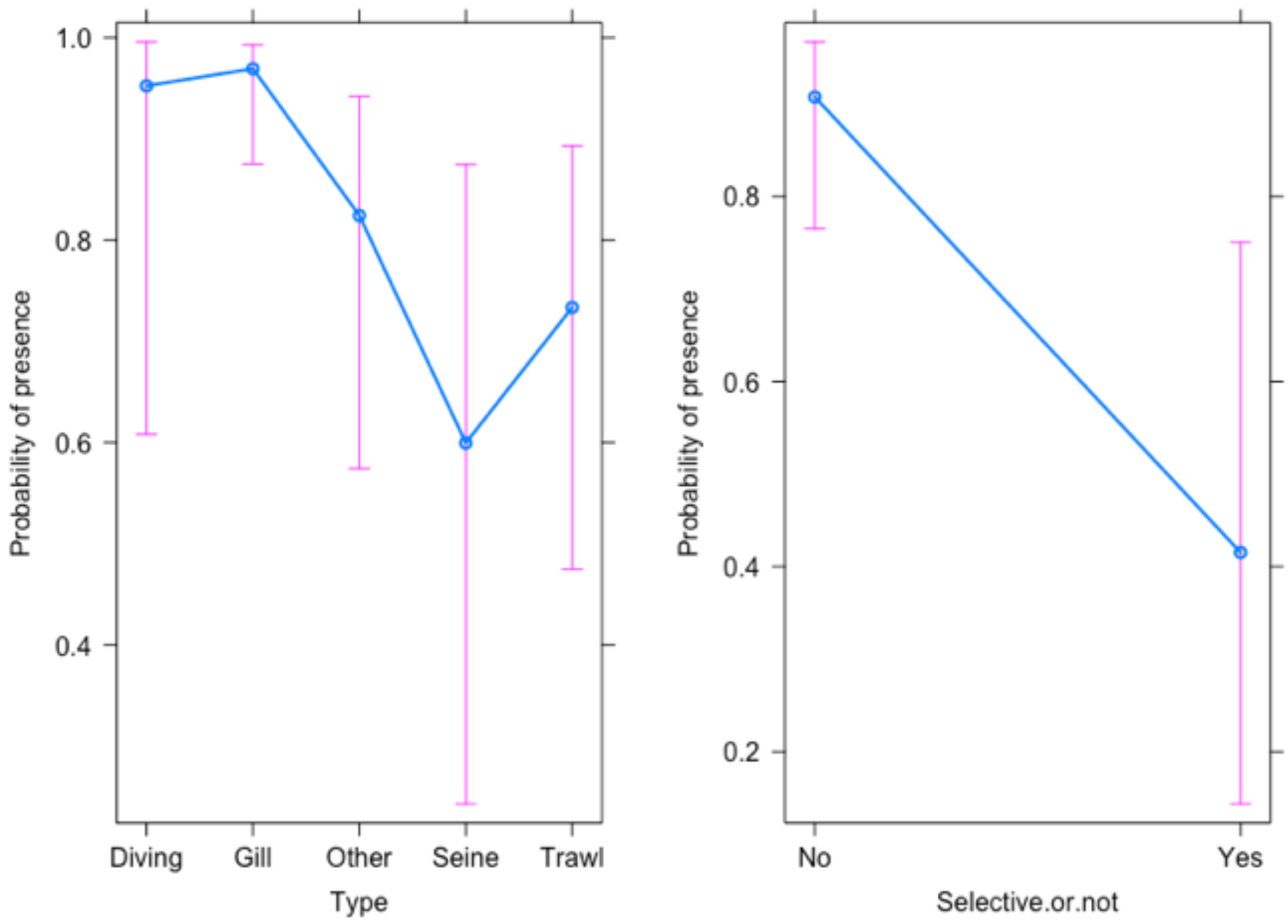

Figure 2.6 Response curves for two important fixed-effect predictors (gear selectivity and gear type) based on the best Generalized Linear Mixed Models (GLMMs) for Scenario 3 with the probability of seahorse presence in the catch on the y-axis.

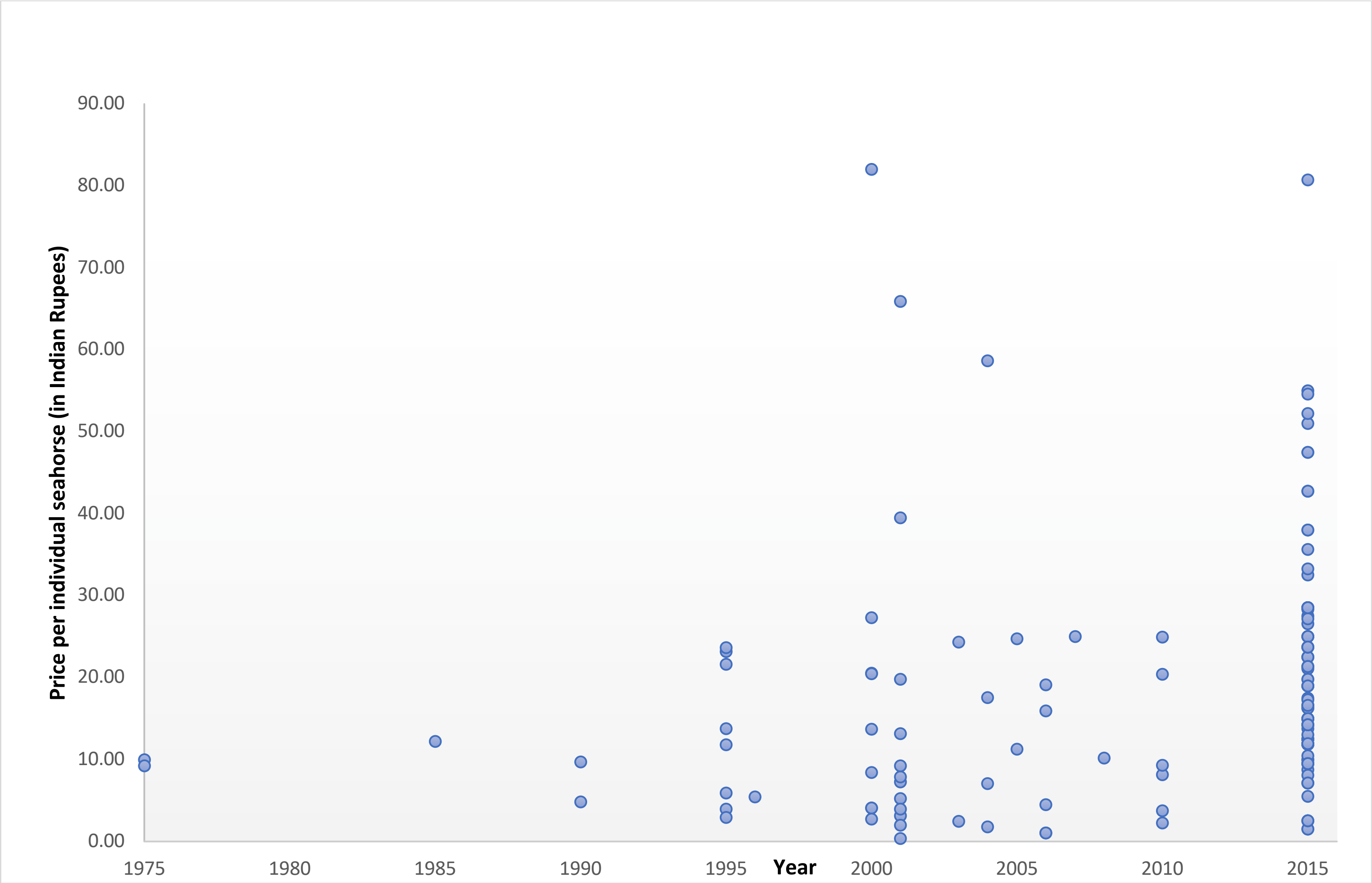

Figure 2.7 Perceived changes in individual seahorse prices over time based on fisher recall from the Palk Bay and Gulf of Mannar regions in the state of Tamil Nadu.

Chapter 3: Catch and trade bans for seahorses can be negated by non-selective fisheries

3.1 Synopsis

Globally, managing bycatch of non-target organisms is a big challenge for marine fisheries and conservation. However, most current management measures are tailored towards the need of targeted species and are often not appropriate for the conservation of species that are incidentally caught in fishing gear. This study investigates the effect of an exploitation and trade ban for seahorse conservation. In the more than 15 years since the ban, little work has been done to assess its effects on seahorse conservation. This work uses the case study of India, where all seahorse species (genus *Hippocampus)* are listed under Schedule I of India's Wild Life Protection Act, making the capture and trade of seahorses illegal. Through surveys carried out between 2015- 2017 it was found that the catch and trade continued, with total annual catches estimated between approximately 5 million and 14 million seahorses. Generalized additive models revealed that seahorse catch per unit effort had non-linear relations with depth and latitude, and were higher in biogenic habitats, with active, bottom-used, and non-selective gears (e.g., trawls). Catch estimates indicated that around 11 to 30 tonnes of seahorses probably entered trade yet interviews with traders only documented trade about 1.6 tonnes. The illegal nature of the trade in seahorses hampered an understanding of trade routes and trade volumes. Fishers reported a decreasing availability of seahorses. Since most seahorses come from bycatch in persistent fisheries that are not directly affected by the ban on seahorse capture, this decline is likely to represent a population decline. A fishery and trade ban for incidentally caught species, particularly in a poorly regulated fishery, appears to add little conservation value. Perhaps a shift in management approach from a blanket ban toward enforced spatial and temporal restrictions would have a better chance of sustaining seahorse populations.

3.2 Introduction

Concerns about excessive exploitation of wildlife have tended to focus on the need to ban exploitation (Lotze, 2010; Tolotti et al., 2015) or regulate the trade (Kuo, Laksanawimol, Aylesworth, Foster, & Vincent, 2018; Rosen & Smith, 2010) of threatened species. The global wildlife trade involves millions of plants and animal species, and estimates place legal wildlife trade values at USD 332.5 billion annually (Engler, 2008). Wildlife trade often can cause declines in wildlife populations, species extirpations, and ultimately disrupt ecosystem functioning (Nijman, 2010; Roe et al., 2002). Trade includes wildlife products for food, but also for many other uses, including medicine, clothing, and curios. High international demand, substantial economic values, poor market regulation, and the open-access nature of these resources can result in a rapid depletion of wildlife (Oldfield, 2003). Unfortunately, the exact extent of the impact of this trade on wildlife conservation remains unclear since a large portion is illegal and undocumented (Oldfield, 2003).

While banning exploitation or regulating trade may provide critical leverage for targeted hunting or fishing, it may do little to reduce impacts on organisms caught incidentally (Foster, Kuo, Wan, & Vincent, 2019). Whether on land or in the ocean, exploitation activities may affect not only the targeted species, but also others that are taken accidentally or opportunistically (Branch, Lobo, & Purcell, 2013). Moreover, exploitation may create conservation concerns by causing physical damage to the environment, affecting other species through cascading interactions, provoking phase shifts in the structure of the ecosystem, and disrupting food webs (Reynolds, Mace, Redford, & Robinson, 2001). Species-specific restrictions are thought to be effective as they protect the exploited species while allowing the continued catch of other simultaneously occurring species at sustainable levels (Shiffman & Hammerschlag, 2016). However, such exploitation bans are of little use when the species are incidentally caught as in the case of the Vaquita porpoise in Mexico (International Whaling Commission. 2017, https://iwc.int/scientific-committee-report-published [6 June 2017]), or with sea turtles that spend much of their time offshore (Lewison, Freeman, & Crowder, 2004).

Bycatch of threatened species is a major concern because it undermines fisheries sustainability, even in cases where effort is well-managed, and the target species are not overexploited. One worry is that mortalities of bycatch are not included in estimates of total fishing mortality of commercially important species (Alaska Sea Grant Program, 2014). Moreover, non-selective fishing often removes juveniles of species of commercial importance in other fisheries. Bycatch also hampers the conservation of non-commercial and protected species when the incidental catch threatens species with vulnerable life histories (e.g., seahorses) and species at low population abundances (e.g., marine mammals) (Alaska Sea Grant Program, 2014). Current solutions for managing bycatch are often technological in nature, and mostly employed in temperate regions, where there is lower biodiversity in the waters (Broadhurst, 2000) and more capacity for bycatch reduction. Such technological fixes are seldom deployed in tropical fisheries where bycatch in indiscriminate gears is highly diverse, management capacity is limited and most incidentally caught species overlap in size with targeted catch (Brewer, Rawlinson, Eayrs, & Burridge, 1998; Cochrane, 2002). Poor management and weak enforcement in developing countries (Worm & Branch, 2012) further undermine conservation measures for bycatch species.

Seahorses (*Hippocampus* spp.) serve as flagship species for a wide range of marine conservation issues, including bycatch (Vincent, Foster, & Koldeway, 2011). The issues facing seahorses, such as overexploitation and habitat degradation, are also major concerns for marine conservation in general (Foster & Vincent, 2004). A large number of seahorses are incidentally caught by non-selective gear such as in the case of trawl fisheries. In addition, a high demand for seahorses in traditional medicine (TM), aquarium trade and curios (Foster & Vincent, 2004) contributes to overexploitation. In light of overexploitation, all seahorses (genus *Hippocampus*) were listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (effective since 2004; CITES, 2002). The global story of seahorse conservation efforts has centered much on regulating trade (e.g., Kuo et al., 2018; Kuo & Vincent, 2018), but needs to focus much more on their exploitation. As an often incidentally caught genus, trade regulations by themselves are unlikely to restrict exploitation unless the unmonitored and unregulated incidental capture of seahorses is restricted.

India was amongst the top four exporters of seahorses, by weight, until 2001 (Salin & Nair, 2006). Seahorses from India were primarily exported in the dried form for TM to Singapore, Hong Kong, and Malaysia (Salin, Yohanan, & Nair, 2005), though dried seahorses were also used in negligible quantities domestically in folk medicine (Perry et al., 2020; Salin et al., 2005). The majority of seahorses in international trade, from India, were derived from the south-eastern coast of India (Tamil Nadu state), particularly from the Palk Bay and the Gulf of Mannar regions (Salin et al., 2005). In 1992, the seahorse fishery and trade emerged along the Palk Bay coast as an alternate fishery to the declining sea cucumber resources (Marichamy, Lipton, Ganapathy, & Ramalingam, 1993). Seahorses in the Palk Bay region were largely obtained by divers targeting them (Marichamy et al., 1993; Perry et al., 2020; Salin et al., 2005) and incidentally by drag nets (Salin et al., 2005)- small-scale, modified shrimp trawls operating in shallow waters and primarily on seagrass beds. Overall, in Tamil Nadu, most seahorses were caught by non-selective gear, largely by bottom trawls targeting shrimp and by drag nets (Perry et al., 2020; Salin et al., 2005).

This research focuses on a particular case study in India where the exploitation of seahorses is prohibited. To combat its substantial trade, in 2001, India placed seahorses (and all other Syngnathid fishes) under Schedule I of the Wild Life Protection Act (WLPA), 1972 (Ministry of Environment and Forests, Govt. of India, 2001), which denotes a ban on capture and trade of these fishes. In the 15 years since the ban on seahorse fishing and trade was declared, no other conservation efforts have been undertaken in the region. This research sought to generate and share knowledge about the current status of seahorse fisheries and trade in Tamil Nadu, and to explore temporal changes in seahorse catches and trade, in the state, since the national ban on catch and trade.

3.3 Methods

To understand the effect of a catch and trade ban on the conservation status of seahorses, semi-structured and structured interviews with fishers, traders, and other stakeholders were conducted. For seahorse catches, important measures included understanding of the species caught, the numbers caught, where they were caught, by what gear they were caught, and the catch per unit effort (CPUE). Where available, seahorse specimens were identified and measured. To understand the status of the seahorse trade after the ban, interviews were conducted with traders to understand the structure, prices, volumes, and routes. To increase reliability of estimates about the magnitude of seahorse catches and trade, the number of locations covered, and number of fishers interviewed was maximized.

Fishery and trade surveys were conducted in the south-east Indian state of Tamil Nadu from July 2015 to April 2016, August 2016 to May 2017, and September 2017 (Figure 3.1). This research covered 97 locations and comprised 605 structured and semi-structured interviews. To understand the current status and trends in the seahorse fisheries and trade in Tamil Nadu, questions were asked about fishing gear, fishing effort, fishing grounds, fishing seasons, seahorse catches, seahorse characteristics (colour, spiny/non-spiny, size), habitats, the season for seahorses, catch location (depth, distance from shore), uses of seahorses, trade, and values. Interviews were conducted across ten of the state's 13 coastal districts (Figure 3.1 & Table 3.1). Data from Puducherry and Karaikal fishing harbour in the Union Territory (U.T) of Puducherry were also included in this study as it lies geographically within the state of Tamil Nadu. For this study, fishers were classified as those who either used gear or gleaned, as well as those people who were boat drivers and/or owners of fishing boats.

Some interview locations were selected based on previous studies (Perry et al., 2020; Salin et al., 2005). Additional locations were then selected based on regions where seahorses could be found, either (i) according to researchers and academics, or (ii) through snowball sampling in which one respondent indicated other potential locations. The study area was broadly divided into five regions, from north to south (see Fig 3.1), based on history of the fisheries, locations fished, local fishing rules and geographical features of the region. Because of the low sample sizes, the west coast was not included in the analysis.

All research received approval from the University of British Columbia's Animal Care Committee (6253-13) and Human Behavioural Research Ethics Board (H12-02731 and H15-00160).

The primary author (herself from the state of Tamil Nadu) conducted each interview in Tamil with the help of seven local field assistants, and questions and answers were translated between Tamil and English. Interviews typically lasted from a few minutes to an hour and a half, depending on the respondents' willingness to answer. Often, more than one participant would take part in an interview. If the other participants explicitly mentioned that they were from different boats and provided answers during the interview, their data were logged separately. During the second and third field season, the research focus was more broadly on trawl fisheries and detailed questions about seahorses were not asked. In addition, during interviews with fishers and traders, where seahorses could be obtained, specimens were identified and measured. Triangulation was used to cross-validate information received within interviews by asking the same questions in different ways and comparing the answers within and among interviews, and across fisheries and trade levels.

3.3.1 Seahorse species and sizes

Seahorse species were identified based on specimens observed during interviews and from traders. Seahorses were weighed and the Standard Length (SL: tip of snout to opercular ridge then to tip of straightened tail) of 368 specimens obtained from fishers' catches (n=32) or traders (n=336) measured. Eight freshly caught specimens were measured, but because of the low sample size these values could not be used to convert catches into biomass. In the absence of sufficient weight measurements from freshly caught species during the study period, the conversion rates were obtained from previous studies or dried specimens collected in this study. For the Central region a wet weight of 6.89 g per individual seahorse was used (Salin et al., 2005). For the Northern region and Rameswaram Peninsula, dried seahorse weights were obtained from the present study and a conversion that dried seahorses weighed 53.45% of wet seahorses was used (Marichamy et al., 1993). Given the small sample sizes of seahorse specimens collected from the Central region (n=8) and the Southern region (n=4), a dried weight of 3.68 g per individual seahorse was used for the Central region (Salin et al., 2005) and a dried weight of 2.5 g per individual for the Southern region based on trade surveys from India conducted in 1999 (Perry et al., 2020).

3.3.2 Catch Monitoring

To estimate the annual catch of seahorses, catch rate as reported by fishers was quantified and multiplied by the number of boats in each location, using data as explained below. For this study, gear catching seahorses were broadly divided into five categories: diving, drag nets, gill nets (including bottom-set gill nets and trammel nets), shore seines, and bottom-trawl nets (including both fish and shrimp nets) (Table 3.2).

To obtain the total annual seahorse catches per individual gear unit, individual fisher reports on catch for discrete time periods (i.e., per haul, per day, per week, trip, month) and mean number of days fished (estimates based on days per week, per month, per year, and months per year they fished) were scaled up to calculate annual seahorse catch. If a fisher reported catching no seahorses, annual seahorse catch for the individual gear unit was treated as zero.

Estimates for catch were obtained using a Monte Carlo bootstrap. Data were categorized by location (Northern region, Central region, Rameswaram Peninsula, Southern region, and West Coast of Tamil Nadu), and by gear type as noted above. Annual CPUE (Catch/gear unit/year) data were bootstrapped for 1,000 runs, resampling with replacement with a sample size equal to the original data to obtain estimates for the median and 95% Confidence Intervals. To scale up for the entire fleet, resulting median and Confidence Interval (CI) from the bootstrap were multiplied by the number of known vessels operating with the gear type only in the landing centres that were sampled. All analyses were run on R ver. 3.5.2, using the *boot* package (Canty & Ripley, 2019; Davison & Hinkley, 1997). Catch estimates were constrained such that the lower confidence limits were set at 0.

Numbers for boats were obtained from local officials, fishers, and state fishery department statistics wherever available, but otherwise depended on the Central Marine Fisheries Research Institute (CMFRI) census, last publicly updated in 2010. Divers from the Central region and the Rameswaram Peninsula were categorized together, based on their mobility and the fact that they switched fishing grounds according to season and catch availability. In the extrapolation, likely seasonal variation in catches, i.e., fisheries closed season, was accounted for.

3.3.3 Important factors related to seahorse catch in fisheries and their relationships

A total of 636 observations of seven predictor variables and two response variables related to seahorse catch were collated based on information that emerged from interviews (Appendix

B.1): one location variable (i.e., latitude), depth, habitat type, and four categorical variables related to fishing gears (Appendix B.2).

Four scenarios of correlative models were built to identify important predictors for seahorse presence/absence in the catch and seahorse CPUE (Appendix B.3). CPUE data were not available (NA) for some observations (n = 178), and data for two variables (i.e., habitat and depth) were also not available for many observations (n = 278 for habitat, n = 373 for depth). In response, the first two scenarios used seahorse presence/absence as the response variable, while the second two scenarios used CPUE instead (with fewer observations than the former). In the first and the third scenarios, observations that contained 'NA' were deleted. In the second and fourth scenarios, those predictors that contained 'NA' were deleted to retain the sample size for other variables. These models were compared to 1) identify predictors which were consistently important across these models, and 2) detect the impact of the four treatments upon response variables.

To detect important factors and their relationships with seahorse presence/absence in fisheries, for the first and second scenarios, random forests (RFs) and generalized linear models (GLMs) were used (Appendix B.4) (R packages 'Boruta', 'MASS', 'randomForest'; Cutler et al., 2007; Kursa & Rudnicki, 2010; Liaw & Wiener, 2002; Venables & Ripley, 2002). For the third and fourth scenarios, generalized additive models (GAM) with a negative binomial distribution to fit the CPUE data were used (Appendix B.4) (R packages 'mgcv'; Drexler & Anisworth, 2013; Guisan, Edwards, & Hastie, 2002; Wood, 2001).

3.3.4 Trade and values

To generate information on the current status of the seahorse trade in Tamil Nadu, participants in the trade were categorized according to their roles: Level 1 included fishers, fish driers and sorters; Level 2 included primary buyers; Level 3 as middle buyers; Level 4 consisted of consolidators; and Level 5 were exporters, with a separate category for brokers. If a respondent played more than one role in the trade chain, the higher of their designations was assigned to them. Fishers, sorters, and traders were asked whether they sold seahorses, to whom they sold the seahorses, and the amounts they were paid for individual seahorses or by weight. Trade data were recorded in units cited by the fishers (i.e., per individual or weight per individual or per gram), and then standardized for analysis. Information was also collected on, but not restricted to, volumes, species of seahorses in trade, size classes, past and present values, and trade routes. However, some stakeholders, particularly traders, were reluctant to provide specimens or information on catches, trade levels, trade volumes and trade routes. The proportion of fishers interviewed who stated that they sold seahorses was assumed to be a representative of the entire fisher population of the state, and their responses were used as a proxy to determine the numbers entering the trade.

Prices for the various regions were calculated separately because of large discrepancies in species and reported sizes and prices. Prices were reported per individual seahorse because fishers only reported prices based on size and not weight, except along the Northern region of the state. All prices were converted from local currency to US Dollars (USD) (https://www.exchangerates.org.uk/) based on the average exchange rate for the year, and also accounted for inflation by scaling with the relative Consumer Price Index (CPI) (CPI of 2015=100, https://www.inflation.eu/inflation-rates/india/historic-inflation/cpi-inflation-india-2015.aspx).

3.3.5 Trends in seahorse fisheries and trade

To understand temporal trends in the seahorse fisheries and trade, respondents were asked questions about the change in catch, size, uses, and number of buyers based on time scales meaningful to them (e.g., dating from when they first entered the fishery/trade, or when the ban was imposed, or the tsunami).

3.4 Results

Since the ban, the catch and trade of seahorses has continued. Most seahorses were caught in bottom operated non-selective gear like drag nets and trawlers. However, information on trade volumes, values, and routes, especially at higher trade levels were difficult to trace. This study did, however, determine that traditional hotspots for seahorse fisheries in the Ramanathapuram District (encompassing the Central region, Rameswaram Peninsula, and parts of the Southern region) persist, with ongoing capture and illegal trade of large numbers of seahorses.

3.4.1 Seahorse species and sizes

Based on port sampling, and specimens obtained from fishers and traders, five species of seahorses (of six reported) were observed along the Tamil Nadu coast viz., *H. histrix*, *H. kellogii*, *H. kuda*, *H. spinossimus* and *H. trimaculatus*. All five species were personally observed by the first and third author along the Northern region of the state, and only three species (*H. kuda*, *H. spinossimu*s and *H. trimaculatus*) along all the remainder of the state.

Based on measurements of seahorse specimens (n=368) (Table 3.3), the mean weight of a dried seahorse was found to be 5.17 ± 4.20g (n=49) in the Northern region, and 2.52 ± 0.80g (n=299) in the Rameswaram Peninsula.

3.4.2 Seahorse catch

Catch per unit effort (CPUE; number of seahorses gear unit^{-1} year^{-1}) estimates were generated for five gear type categories. The CPUE was the highest for drag net in the Central region (3 *10^3 seahorses gear unit^{-1} year^{-1}) and then trawlers in Rameswaram Peninsula (1.9*10^3 seahorses gear unit^{-1} year^{-1}) (Fig. 3.2, Table 3.4). Based on respondent data and extrapolations using descriptor variables from running a Monte-Carlo simulation, the median of total seahorses caught in a year by the entire fleet based on areas sampled in Tamil Nadu was found to be around 10 million individual seahorses or the equivalent of around 60,000 kg of wet seahorses (Table 3.4).

3.4.2.1 Seahorse catches by location

Seahorse catches varied widely by location, with maximum annual seahorse catches occurring from the Central region (~ 3,000,000 -7,000,000 or 57% of total seahorse catches from surveyed areas in Tamil Nadu), followed by the Rameswaram Peninsula (~1,600,000 to 3,900,000 or ~30% of total seahorse catches from surveyed areas in Tamil Nadu), then the

Southern region (~ 150,000 to 1,500,000 or 8% of total seahorse catches from surveyed areas in Tamil Nadu), and finally the Northern region (~222,000-690,000 ~5% of total seahorse catches from surveyed areas in Tamil Nadu) (Table 3.5). Catches could not be extrapolated for the West Coast because of small sample sizes.

3.4.2.2 Seahorse catches by gear type

Across Tamil Nadu, most seahorses caught annually were by drag nets (50%) followed by trawl nets (37%) (Table 3.6) but findings varied between regions.

- In the Northern region, annual catches were greatest in gill nets followed by trawlers.
- In the Central region, the greatest annual catch came from dragnets operating along the central region followed by trawl nets.
- In the Rameswaram peninsula most seahorses were caught by trawl nets followed by gill nets.
- In the Central region and Rameswaram Peninsula, each individual diver caught a substantial number of seahorses (median=$1.7*10^{3}$, n=6) but the relatively low number of divers (n=45) reported to be operating from these landing sites resulted in relatively lower annual seahorse catches compared with all other gear types, except shore seines.
- In the Rameswaram Peninsula, seahorses were also caught by shore seines (median of $1.5*10^{2}$, n=7) but the low number of fishers operating shore seines (around 20) resulted in relatively fewer seahorses being caught yearly by this fishing gear than any other fishing gear in any of the regions.
- In the Southern region, seahorses were caught primarily by gill nets followed by trawl nets.

3.4.3 Important factors related to seahorse catch in fisheries and their relationships

Generally, the RF models and GLMs had very low performance in predicting seahorse presence/absence, while GAMs performed better (PED=72.1%, AIC=2253 in Scenario 3, and PED=46.8%, AIC=5518 in Scenario 4) in predicting seahorse CPUE (Appendix B.5). Therefore, results were only interpreted from GAM models (i.e., the third and fourth scenarios). Correspondingly, it was found that latitude and depth had significantly non-linear effects on the CPUE of seahorses, and both variables while used individually could explain over half of the deviance (56.6% by depth and 65.2% by latitude). From the models, it was observed that a significantly higher CPUE of seahorses were caught by 1) other gears and trawls (vs. gill nets), 2) active gears (vs. passive gears), and 3) bottom-used gears (vs. gears used in water columns; Appendix B.5). Notably, other gears had higher regression coefficients than trawls in the GAMs. Fishing at biogenic habitats also caught significantly more seahorses. Gear-type variable (trawl vs. gill net vs. others) was the best categorical predictor among others in predicting seahorse CPUE in both the third and the fourth scenarios.

3.4.4 Seahorse trade

3.4.4.1 Seahorse species in trade

All five species of seahorses that were observed as catch in the fisheries along the coast of Tamil Nadu also entered trade. Two main species of seahorses were identified in the trade along the Tamil Nadu coast: *H. kuda* and *H. trimaculatus*, with less frequent records of *H. spinosissimus*. *H. kelloggi* was observed only along the Coromandel Coast, although fishers said they were available further south off Kanyakumari, and only two specimens of *H. histrix* were observed in the catch and trade.

3.4.4.2 Trade structure

At least five levels of trade were observed for dried seahorses along the Tamil Nadu coast, with individuals often occupying more than one level in the trade chain. Fishers/sorters (Level 1) sold seahorses to primary buyers (Level 2) located nearby, or directly to secondary buyers/middle-buyers (Level 3). Primary buyers only purchased seahorses directly from the fishers/sorters and appeared to be the most numerous, though it is hard to estimate how many. Secondary buyers in turn either sold seahorses to tertiary buyers/consolidator (Level 4) or in one case directly exported the seahorses themselves. Tertiary buyers/consolidators reported selling seahorses to exporters (Level 5), but over the course of this study no exporter could be interviewed. Because of the illegal nature of the trade, upper-level buyers (>Level 3) north of Karaikal along the Northern region or below Ervadi in the Southern region could not be accessed, despite information about their presence from fishers and middle-buyers.

3.4.4.3 Trade routes

According to a Level 3 trader in the Northern region, a Level 2 and Level 4 trader in the Rameswaram Peninsula, and a Level 4 trader from the Central Region, dried seahorses were generally sent to larger cities such as Bengaluru and Chennai normally by road. The same Level 4 trader in the Rameswaram Peninsula, stated that seahorses were also sent to traditional seahorse hubs such Ervadi, and Keelakarai, while two other Level 4 traders from the Central region stated that they only transported seahorses locally to seahorse trade hubs such as Thondi and Keelakarai. A broker from the Rameswaram Peninsula stated that seahorses were at times then sent from these cities to a large port city like Mumbai. According to the same Level 3 trader from the Northern region and the Level 4 trader from the Rameswaram Peninsula, the seahorses were apparently then exported, by ship and by air, to countries including China, Myanmar, Singapore, Thailand, and Sri Lanka (Fig. 3.3).

3.4.4.4 Trade volumes based on survey

3.4.4.4.1 Estimated trade volumes based on catch statistics

Based on seahorse catch estimates, and assuming that the proportion of fishers who reported selling seahorses (67.3%, n=286 of 425 responses) represent the entire population, it is estimated that approximately between 3 million and 9 million (median 6.5 million) seahorses enter the trade each year in Tamil Nadu. Based on dried weight estimates of seahorses, this equates to between around 11 and 30 tonnes (t) (median 22 t) of dried seahorses being traded annually.

3.4.4.4.2 Estimated trade volumes based on interviews with traders

Solely based on the volumes and number of buyers known to be operating at their level, as reported by the highest-level buyers that could be located and interviewed in all the surveyed regions, it is estimated that at a minimum 1,565 kg (~1.6t) or ~750,000 dried seahorses are found in the trade each year (Table 3.7).

3.4.4.5 Price of seahorses

Prices reported showed no noticeable pattern in the average size class, or in the smaller and medium size classes, with higher level buyers often stating that they sold seahorses in these size classes at lower prices than reported by fishers or lower-level traders (Appendix B.6a-d). However, in the larger size classes of seahorses, a discernable trend was observed, and in three of the four regions for which data were obtained, prices increased around one to two times between fishers and consolidator.

3.4.5 Trends in seahorse fisheries and trade

3.4.5.1 Changes in seahorse catches

Based on fisher responses (n=52), most fishers (n=41) stated that seahorse catches had declined. Fishers reported declines in catches varying from between 32% and 100% (mean=87%, median=93.5%, n=22, standard deviation = 18.1) over a time period varying from between 5 and 50 years ago (mean=17.3, median=15, n=34, standard deviation=10.95). Eleven fishers stated that seahorse catches had remained the same over the last six to 26 years (mean=15.1, median=14, n=7, standard deviation=6.4). Only one fisher stated an increase in the catch of seahorses compared to the year 2000, which he attributed to a technological change in fishing gear.

3.4.5.2 Changes in size of seahorses caught

All respondents who provided an answer (n=8) stated that the size of seahorses had decreased. All eight fishers were based in the Central region and Rameswaram Peninsula. Seven of nine fishers stated that they used to get 20-30 cm seahorses between 12 and 40 years ago (mean=23, SD =11) but this was no longer the case. Based on measurements in this study, the average SL of seahorses was 13.5 cm in the Rameswaram Peninsula (n=299) and 14.2 cm in the Central region (n=16).

3.4.5.3 Changes in uses of seahorses

Of the 19 fishers who stated that they had changed the way they handled seahorses over the last five to 30 years (mean=14.6, SD=6.1), 15 fishers stated that they used to previously sell seahorses but did not any longer, two fishers who previously either used seahorses for medicine or threw them back now sold them, and two fishers who had used seahorses for medicinal purposes now threw them back. Of the 12 fishers who provided reasons for the change in use, three fishers stated that they no longer found seahorses, while nine of the 12 fishers stated that they no longer sold seahorses because of the ban (including strict enforcement, fewer buyers because of the ban or the risk of recrimination). However, 26 fishers who used to sell seahorses over the last 6 to 74 years (mean=14.9, SD=4.1) continued selling seahorses even after the ban.

3.4.5.4 Changes in number of seahorse buyers

Only 16 fishers provided responses to the change in number of buyers. All stated that the number of Level 2 buyers had decreased over the last 5 to 30 years (mean=14.92, SD=7.53), though they could not quantify the decrease. Only one Level 2 buyer reported changes in the number of buyers at his level and he stated that it had increased over the last two years.

3.5 Discussion

Exploitation of seahorses in large numbers continues despite the 2001 catch and trade ban on seahorses imposed by the Indian government. The majority of seahorses (~87%) caught in Tamil Nadu came from two non-selective fishing gears: trawls and drag nets. Tracing traders, trade routes and trade volumes proved to be challenging because of the illegal nature of the trade. Nonetheless, estimates from this study suggest that between 2015-2017 a median of around 9.7 million seahorses were caught annually along the Tamil Nadu coast, as compared to an estimated median of 13.4 million seahorses from Tamil Nadu during the last comprehensive survey before the ban (1999-2000; Perry et al., 2020). Because these animals are obtained as bycatch, any decline in total obtained is almost certainly unrelated to the catch ban and should raise conservation concerns about seahorse populations in India. I find that the catches of seahorses from target fisheries by divers has drastically reduced compared to before the ban (Table 3.8), which could be because of the fewer known divers operating in the Palk Bay region. While seahorse catch estimates from this study are greater than most other previous studies (Table 3.8), differences in the extent of geographical region sampled and methodology used makes direct comparisons difficult. Moving away from the ocean, most trade could not be traced, probably because it was illegal; it seems that about 11 t of dried seahorses destined for the export markets, to be used in traditional medicine, enter trade in a year. However, only about 1.6 t entering trade could be traced in this study, far less than previous estimates (Table 3.9).

This study highlights the need to move beyond trawlers in assessing bycatch, despite how non-selective and devastating trawler catch has become. The tendency to focus on trawl bycatch is probably due to the greater access to trawl vessels and trawl data (Davies, Cripps, Nickson, & Porter, 2009; Kelleher, 2005). Indeed, hundreds of non-target species are caught by trawlers and other non-selective fishing gears such as beach seines, boat seines and push nets, both large- and small-scale. However, the impacts of traditional fisheries are often underestimated, similar to models in this study which suggest that 'other gears' (most were active, non-selective, bottom-used gears used by small-scale fishers) could catch more seahorses than trawls in terms of catch per unit effort. Employing over 230 million people globally (Teh &Sumaila, 2013), small-scale fishers have often shifted to unsustainable fishing methods that have resulted in catch declines (Jennings & Polunin, 1996). Destructive bottom fishing gears like drag nets are often employed by small-scale fishers, resulting in damage to marine habitats and the incidental catch of non-target species and juveniles (Hicks & McClanahan, 2012; Mangi & Roberts, 2006). Even when banned, use of such gears often persists, sometimes because of a lack of capacity to invest in less destructive fishing gear (Cinner, 2011).

This study adds to the growing literature about the massive impacts that small scale fisheries can have on marine life, including seahorses (Aylesworth, Phoonsawat, & Vincent, 2017; Lawson, Foster, Lim, Chong, & Vincent, 2015; Hawkins &Roberts, 2004). When poorly managed, small-scale fisheries may irreparably damage vulnerable marine species, fish stocks, and habitats (Alfaro-Shigueto et al., 2010). In Tamil Nadu, local fishers interviewed during this study reported that the number of traditional yet destructive drag nets in operation had increased exponentially over the last two decades. The operations of these drag nets are also problematic because they operate directly over seagrass habitats (BOBLME, 2015) targeting juvenile shrimps. Similar to this study, other researchers have found that small-scale drag net fisheries caught more seahorses per vessel than the larger trawls in the Palk Bay and Gulf of Mannar regions of Tamil Nadu, India (Vinod et al., 2018). It would help to expand the focus from just trawlers to other non-selective fishing gear, as the impact that these traditional non-selective gears have on resources is often unknown (Chuenpagdee, Liguori, Palomares, & Pauly, 2006).

This study confirms that many of India's fisheries and ocean regulations are poorly enforced, if at all. Protecting near-shore waters from non-selective bottom-gear can help ensure habitats retain their structural complexity (Pilskaln, Churchill, & Mayer 1998), and provide a refuge for juvenile fish and shrimp (Kumar & Deepti, 2006) so that they can continue to grow, while also benefiting traditional communities employing selective fishing methods. In India, each state developed its own Marine Fisheries Regulation Act (MFRA) to manage their fisheries within 12 nm. One of the provisions under this act prevents the use of bottom-trawls within about 3 nm (or up to 5 nm depending on the state). Yet implementation of these MFRAs is virtually non-existent (Pramod, 2010), and trawlers in Tamil Nadu continue to illegally fish within 3 nm because of poor enforcement (Bavinck, 2001). Such trawlers are also bigger and more powerful than allowed by law (Stephen, 2014). According to some sources (Rajagopalan, 2008; Vinod et al, 2018), it may also be that drag nets are actually illegal in Tamil Nadu, although this could not be independently verified by the authors. Further challenges come from the large number of unregulated and unlicensed fishing boats that operate in India's large-scale and small-scale fisheries (Pramod, 2010). While India has had great success with compliance to the closed season during the sixty-day monsoon ban, wherein mechanized boats such as trawlers are prohibited from fishing, this has not been the case with most of their other marine fisheries regulations (Gunakar, Jadhav, & Bhatta, 2017).

Findings in this study reinforce arguments that a simple ban on extraction or use may do little for conservation, particularly for incidentally caught species (Foster et al., 2019, Tolotti et al., 2015), such as seahorses. Despite the imposition of trade bans, local people are often driven to obtain wildlife illegally, because they are readily available and offer a source of secondary income (Pires & Moreto, 2011). While there have been no complete prosecutions, fishers in certain regions of Tamil Nadu were more apprehensive to provide information about seahorse catches and trade because of the possibility of being apprehended and fined by local officials. On the other hand, traders in the region faced a greater risk of recrimination by government officials, and findings from this study are in agreement with other studies that found that tracing trade of illegal wildlife is complicated, and that trade bans often push the trade underground (e.g., Rosen & Smith 2010; Underwood, Burn, & Miliken, 2013). Fishers in this study reported that the illegal trade was profitable, though mostly for buyers, as in illegal trade in other wildlife products (Wyatt, 2009; Zimmerman, 2003). In India, although no official estimates of seahorse trade exist after the ban, trade has certainly continued, driven by the non-selective take and the importance of seahorses for fisher livelihoods particularly for drag net fishers (Vaidyanathan & Vincent, *in revision*). Interviews with fishers and traders in this study indicated that smuggling of seahorses was facilitated by their small sizes, allowing them to be hidden easily. Illegal catch and trade persist in the absence of enforcement (Phelps & Webb, 2015; Underwood et al., 2013) or a dearth of economic incentives for conservation, exacerbating population decline (Conrad, 2012).

Ultimately, it appears that catch of seahorses by non-selective fishing gear drives the trade and not vice-versa. Solutions for the conservation of small incidentally caught fishes may benefit from a move toward managing fishing gear, including phasing out non-selective bottom-gears, and enforcing spatial measures. The problems faced by seahorses provide a great insight into the issues faced by other bycatch species in poorly regulated fisheries. Rather than taking a species-specific approach, it may be more effective to set spatial restrictions on bottom gears and place more management effort in regions with biogenic habitats, such as the Palk Bay region of Tamil Nadu. It is vital to implement and enforce current protected areas in India and trawl exclusion zones, ensure that banned gears are not used, and to involve and incentivize communities to take conservation actions. While there are challenges associated with enforcing existing regulations and the ban (Vaidyanathan & Vincent, *in revision),* working with fishing communities to achieve greater compliance is key to seahorse conservation.

Table 3.1 Respondents interviewed during field surveys between 2015 and 2017 along the Tamil Nadu coast. Note that key informants may have been interviewed more than once over the course of my field seasons.

Designation	**Number of Interviews**
Fishers (men/women)	533 (527/6)
Women sorters, driers	24
Seahorse Traders	22
Researchers	6
Fisheries and Forest Officials	6
Others (Fish buyers, fish exporters, fisher heads, fisher worker forum members, former traders, net menders)	14
Total Interviews Conducted	**605**

Table 3.2 Description of gear types catching seahorses along the Tamil Nadu coast, based on interviews conducted between 2015 and 2017.

Gear	**Description**
Diving	Divers in the Ramanathapuram region free dive, normally diving for 50 seconds to a minute and then surfacing for about a minute between dives to rest. On a given day, divers tend to fish for between 1.5 to 3 hours, and during unfavourable seasons often work as crews in other kinds of fishing. In the Thoothukudi district, many fishers dive with compressed air from bicycle pumps. On every boat, there are normally five divers, with 4 helpers remaining on top to ensure the diver's safety.
Drag nets	Drag nets (*Thallu valai/Thallu madi*) are mostly wind-operated fishing gear, known as modified trawl nets or country trawls. Unlike the trawl net, the dragnet is operated off the side of the boat, with wooden poles from the side and back of the boat keeping the net propped open for maximum coverage. Being wind-driven, these nets are operated with the mouth facing the direction of the wind, and the boat moves laterally forward, at an approximate speed of 1km/hr. The boats from which these nets are operated are usually on 15 to 25 feet fishing boats ('vallams'), which may have engines. Drag nets became popular in the late 1970s to catch prawns (Sam Bennett & Arumugham, 1989), and are primarily operated in the shallow waters of the Palk Bay and Gulf of Mannar at depths between 4 to 7m. Nets are typically around 10m in length and 5 m width, and mesh sizes may between 10mm and 35mm. In the Palk Bay region these nets operate exclusively on seagrass beds (Murugan, E et al. 2008, Murugan et al., 2011), and primarily target the juveniles of green prawns (*Penaeus semisulcatus*) (CMFRI, 2012). In the Thoothukudi district, drag nets often bring up seagrass, and sponges as bycatch (Sivaramakrishnan, Samuel, & Patterson, 2013). Fishers head out for about 6 hours per trip, the length of each may vary from 15 minutes to even up to an hour and a half, and fishers employ anywhere between one and 12 hauls per trip. Fishers may go alone on the boat, or in groups of two or three. In Ramanathapuram district, boats using these nets may not operate during the monsoon ban (April 15th to June 15th) but drag nets may currently operate through the year in the Thoothukudi district.

Table 3.2 (Con't) Description of gear types catching seahorses along the Tamil Nadu coast, based on interviews conducted between 2015 and 2017.

Gill nets	Gillnets may be operated from larger mechanized boats or smaller traditional crafts. Gears are passive, and normally just set either in the water column or touching the bottom (bottom-set gill nets). Fishers catch both invertebrates and vertebrates using gill nets, and mesh sizes are normally upwards of 28 mm. Fishers may leave the nets overnight, and return the next morning to retrieve them, or may remove them immediately after. Nets may either be placed in a straight line or in an encircling fashion. Fishers also may use multi-layered gill nets or trammel nets.
Trawl nets	Bottom trawls in India operate off mechanized boats, by dragging a net along the seabed, destroying bottom habitats, and catching everything in its path. Trawl fishing in India started in 1956, and initially resulted in greater commercial fish landings (Devraj & Vivekanandan, 1999). Target catch for trawl fishing includes cephalopods, crustaceans, and fish, but over the years stocks of exploited species have declined so badly that many trawl fisheries have shifted to catching all species with no distinction (Lobo, 2010). A large diversity of engine power, boat lengths, duration of trips, number of hauls and people employed, are observed in trawl boats operating along the Tamil Nadu coast. Mesh sizes vary from 10 mm upward at the mouth end to as much as 5000 mm to 7000 mm at the cod end. The engine speeds are also diverse, varying from 50 hp to 500 hp. The length of the net may be anywhere from 15 m to 35 m, and the width anywhere from 6 m upwards. Trawl boats may be a single day or multi-day, towing the net upward of two hauls per day, with each haul around two hours in duration. Trawl boats could have as few as two to three fishers on board, but in larger operations may have even 15 fishers on board. Trawl boats along the coast of Tamil Nadu are not allowed to fish within 3nm of the coast, or from April 15th to June 15th, during the monsoon ban.

Table 3.2 (Con't) Description of gear types catching seahorses along the Tamil Nadu coast, based on interviews conducted between 2015 and 2017.

Shore seines	Traditional fishing gear, whereby fishers operate seines from the beach/shore. A boat with around four fishers' heads to sea, with a net around two km long. When the boat is around 1 to 5km from the shore, the boat circles back, and the two ends of the net are handed to two groups of around 10 to 25 people each, standing in two lines. Fishers then spend anywhere from 1.5 hours to the whole day pulling the nets in. Nets are operated in relatively shallow waters (5 to 10 m), but mesh sizes are decreasing. Difficulties in finding enough people to operate the nets have resulted in the decline in the number of operational shore seine units. It is not uncommon to watch both men and women operate this kind of fishing gear.

Table 3.3 Measurement of the Standard Length (in cm) and weight (in g) of 368 seahorse specimens, separated by sex, and obtained from fishers (n=32) and specimens in trade (n=336) at different locations along the coast of Tamil Nadu.

Location	Species	Sex	Sample size	Mean Standard Length± SD (cm)	Mean Weight± SD (g)
Northern region	*H. histrix*	Female	2	15.71 ± 0.99	3.45 ± 1.34
		Male	0	-	-
	H. kelloggii	Female	18	20.81 ± 3.28	8.04 ± 4.05
		Male	4	21.93 ± 3.46	11.08 ± 3.46
	H. kuda	Female	4	13.8 ± 0.69	3.15 ± 0.88
		Male	1	16.	3.70
	H. spinossisimus	Female	5	13.68 ± 1.16	2.78 ± 0.61
		Male	4	12.95 ± 1.21	2.28 ± 1.06
	H. trimaculatus	Female	9	11.48 ± 3.07	1.33 ± 0.88
		Male	2	13.25±1.06	3.05± 0.92
Central region	*H. kuda*	Male (Wet)	5	15.14 ± 0.72	9.36 ± 2.95
		Unknown (Wet)	2	14.35 ± 1.63	7.55 ± 1.34
		Unknown	7	13.38 ± 0.78	3.66 ± 0.64
	H. spinossisimus	Unknown (Wet)	1	13.6	6.6
	H. trimaculatus	Female	1	15.6	8.1

Table 3.3 (Con't) Measurement of the Standard Length (in cm) and weight (in g) of 368 seahorse specimens, separated by sex, and obtained from fishers (n=32) and specimens in trade (n=336) at different locations along the coast of Tamil Nadu.

Rameswaram Peninsula	*H. kuda*	Female	100	13.88 ± 1.05	2.51 ± 0.71
		Male	49	13.60 ± 0.82	2.50 ± 0.55
	H. spinossisimus	Female	4	12.73 ± 3.23	3.28 ± 1.88
		Male	0	-	-
	H. trimaculatus	Female	102	13.18 ± 1.87	2.42 ± 0.87
		Male	44	13.30 ± 1.63	2.71 ± 0.91
Southern region	*H. kuda*	Female	1	5.3	2.8
		Male	0	-	-
	H. spinossisimus	Female	2	11.90 ± 0.71	1.3 ± 0.57
		Male	0	-	-
	H. trimaculatus	Female	1	12.8	2
		Male	0	-	-

Table 3.4 Approximate seahorse catches by various gear types and locations along the coast of Tamil Nadu. All values presented are based on estimates obtained from bootstrapping and running Monte-Carlo simulations for 1000 runs (Canty and Ripley, 2019). Biomass is based on calculations of wet weight of seahorse individuals based on calculations from my measurements or previous studies. Fleet sizes were obtained from local sources, and where unavailable I used the state fisheries census data or CMFRI census data of 2010. Locations and fishing gear in which the most seahorses are caught are in bold. I could not estimate catches from the West Coast of Tamil Nadu because of low sample sizes. Final values rounded to the nearest whole number.

Location	Gear Type	Original Sample	Median CPUE (seahorse catch/gear unit/year)	Number of vessels operating in surveyed locations	Lower 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas	Median of annual seahorse catch for the entire fleet in sampled areas	Upper 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas	Median values as wet biomass (in kg)	Overall Ranking based on median contribution to total seahorse catch
Northern region	Gill net	27	62	4,385	61,000	271,000	421,000	2,600	6
	Trawl net	158	95	2,294	161,000	217,000	268,500	2,100	8
Central region	**Drag Net**	**20**	**2,988**	**1,600**	**2,700,000**	**4,100,000**	**6,600,000**	33,000	**1**
	Gill net	6	598	462	0	276,500	505,000	1,900	5
	Trawl net	13	822	509	300,000	400,000	500,000	2,900	4

Rameswaram Peninsula	Drag Net	1	755	2		1,500		10	14
	Gill net	27	144	922	50,000	133,000	206,000	650	9
	Shore seine	6	154	20	0	3,100	6,100	15	13
	Trawl net	**39**	**1,933**	**1,426**	**1,600,000**	**2,800,000**	**3,700,000**	13,000	**2**
Central region and Rameswaram Peninsula	Diving	6	1,736	45	36,000	78,000	120,000	500	10
Southern region	Diving	2	16	1,500	0	23,500	47,000	100	12
	Drag Net	3	721	100	0	72,000	139,000	350	11
	Gill net	18	152	2,930	66,000	446,000	755,900	2,100	3
	Trawl net	42	156	1499	45,500	234,000	389,000	1,100	7
Total		**368**			**~5,000,000**	**~10,000,000**	**~14,000,000**	**~60,000**	

Table 3.5 Approximate estimated seahorse catches per annum (with 95% Confidence Intervals) by location, from maximum to minimum seahorse catches, in the study area. Percentage of total catches provided in brackets for the median. Catches from divers were split evenly between the Central Region and Rameswaram Peninsula. Due to low sample sizes, I was unable to estimate seahorse catches for the West Coast of Tamil Nadu.

Location	Lower 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas	Median of annual seahorse catch for the entire fleet in sampled areas	Upper 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas
Central region	3,000,000	5,500,000 (57)	8,000,000
Rameswaram Peninsula	2,000,000	3,000,000 (30)	4,000,000
Southern region	147,000	778,000 (8)	1,500,000
Northern region	222,000	488,000 (5)	690,000

Table 3.6 Approximate estimated seahorse catches per annum (with 95% Confidence Intervals) by gear type arranged from maximum to minimum seahorse catches. Percentage of total catches provided in brackets for the median CPUE.

Gear Type	Lower 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas	Median of annual seahorse catch for the entire fleet in sampled areas	Upper 95% Confidence Interval of annual seahorse catch for the entire fleet in sampled areas
Drag net	2,700,000	5,000,000 (50)	7,000,000
Trawl net	2,000,000	4,000,000 (37)	5,000,000
Gill net	176,000	1,000,000 (12)	2,000,000
Diving	35,900	102,000 (1)	167,000
Shore seine	400	3,000 (negligible)	6,000

Table 3.7 Volumes of seahorses smuggled by buyers at different levels from different landing centres in various regions along Tamil Nadu, from North to South based on interviews conducted with buyers between 2015 and 2017. For my total volume calculations, I include only the highest level interviewed at every landing site.

Location	Region	Level	Number of buyers known to be operating at the same level	Volume for all known traders (kg)	Individuals
Pazhayar	Northern	2	Unknown	23	5,323
Karaikal	Northern	2	5	7†	1,574
Nagapattinam	Northern	2	Unknown	44†	10,266
Nagapattinam	Northern	3	2	100	14,000
Thondi	Central	4	Unknown	70	45,240
Devipattinam	Central	4	3	539	248,363
Mandapam	Rameswaram Peninsula	4	1	143	72,667
Rameswaram	Rameswaram Peninsula	4	2	471	246,527
Ervadi	Southern	3	2	219	109,500
Grand Total				**1,565**	**743,194**

† Volumes from these traders are not included as they sell to the secondary traders in Nagapattinam.

Table 3.8 Comparison with previous studies along Tamil Nadu that estimated annual seahorse catches.

Year	Location	Region as categorized in my study	Major gear	Number of seahorses caught	Volume of seahorses caught (dried) (t)	Contribution from the Central Region	Reference
1993	Morpannai, Mullimunai, Thirupallaikudi, Thondi	Central	Diving	924,000	3.696†	100%	Marichamy, Lipton, Ganapathy, & Ramalingam, 1993
1999	Entire coast of Tamil Nadu	Northern, Central, Rameswaram Peninsula, Southern and West Coast	All major gear	~ 3.5 – 21million	--	28% (only divers and dragnets)	Perry et al., 2020
2000-01	Gulf of Mannar, Palk Bay, Coromandel Coast	Northern, Central, Rameswaram Peninsula, Southern regions	No mention	~ 104,018	1.456	~50%	Murugan, Dhanya, Rajagopal, & Balasubramanian, 2008

Table 3.8 (Con't) Comparison with previous studies along Tamil Nadu that estimated annual seahorse catches.

2001	Palk Bay and Gulf of Mannar	Central, Rameswaram Peninsula, Southern regions	Divers, drag-nets, trawls	2,648,179	9.75	76% (divers and drag nets)	Salin, Yohanan, & Nair, 2005
2002-2003	Pamban, Rameswaram, Mandapam	Rameswaram Peninsula	Drag-nets, shrimp trawls, shore-seines	17,266			Murugan et al., 2011
2015	Palk Bay and Gulf of Mannar	Central, Rameswaram, Peninsula, Southern regions	Drag-nets,trawls	369,338†		91% ‡	Vinod et al., 2018

† Values extrapolated to a year based on estimates from the study

‡ Demarcation of study regions vary from my current study

Table 3.9 Comparison with previous studies along Tamil Nadu that estimated annual seahorse trade volumes (t).

Year	Location	Number of seahorses traded	Volume of seahorses traded (t)	Reference
1993	Palk Bay	924,000	3.696†	Marichamy, Lipton, Ganapathy, & Ramalingam, 1993
1995	Palk Bay		3.6	Vincent, 1996
1999	Tamil Nadu and Kerala (mostly from Tamil Nadu)	5 million	12.5	Perry et al., 2020
2000-2001	Gulf of Mannar, Palk Bay, Coromandel Coast	104,018	1.456	Murugan, Dhanya, Rajagopal, & Balasubramanian, 2008
2001	India		5.24†	Anon, 2003
2001	Palk Bay and Gulf of Mannar	2,648,179	9.75	Salin et al, 2005
2001	Palk Bay		5.3	Lipton and Thangaraj, 2002
2002	Palk Bay		0.11‡	Lipton and Thangaraj, 2002

†Estimates included both seahorses and pipefish

‡ Estimates were based on only a month into the season

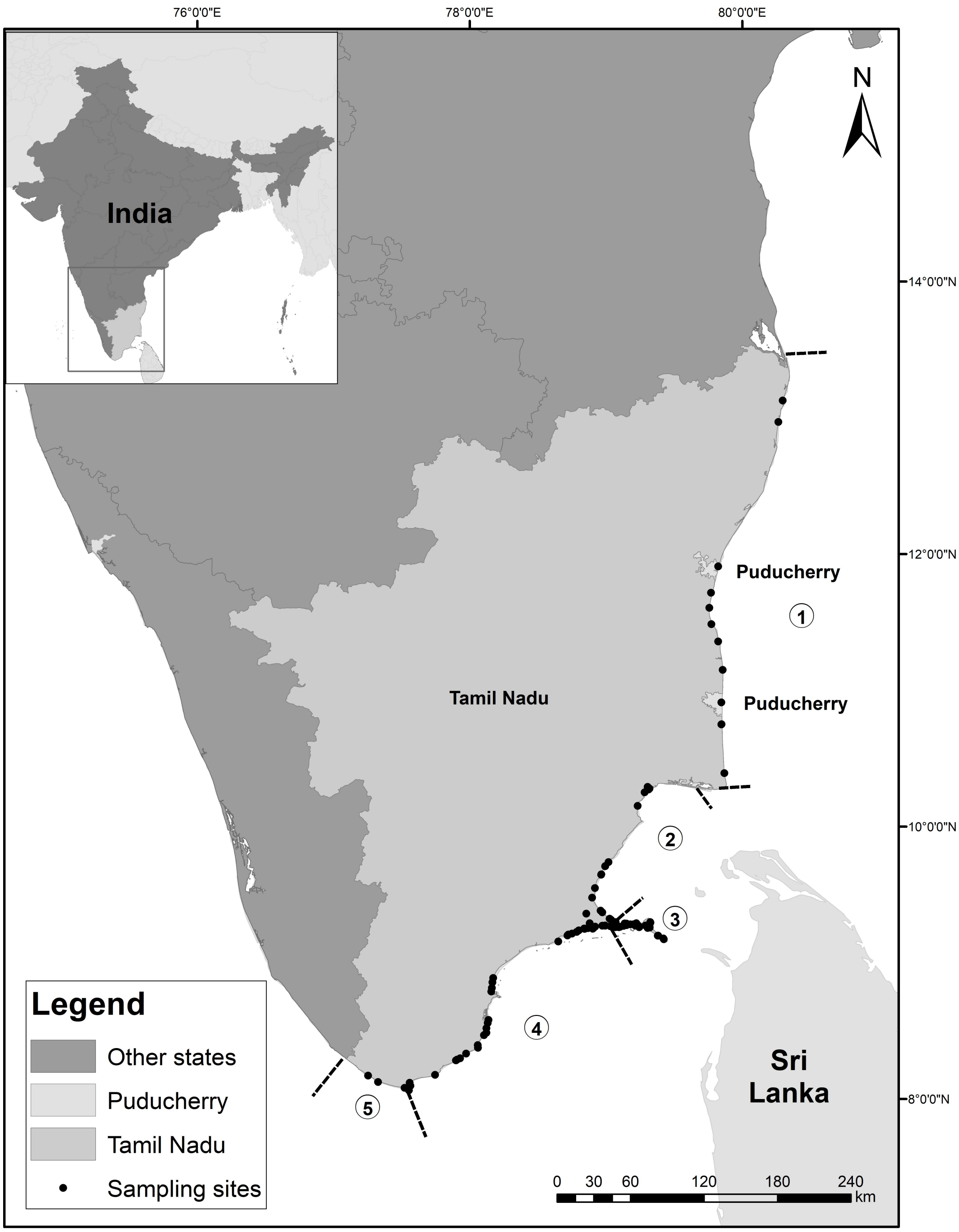

Figure 3.1 Map of the study area where field surveys were conducted between 2015 and 2017. The study area was divided into 5 regions (numbered 1 to 5 from North to South in the map); 1. Northern region, corresponding to the Coromandel Coast 2. Central region, which covers the Palk Bay region 3. Rameswaram Peninsula 4. Southern region comprising the Gulf of Mannar region and 5. West Coast of Tamil Nadu.

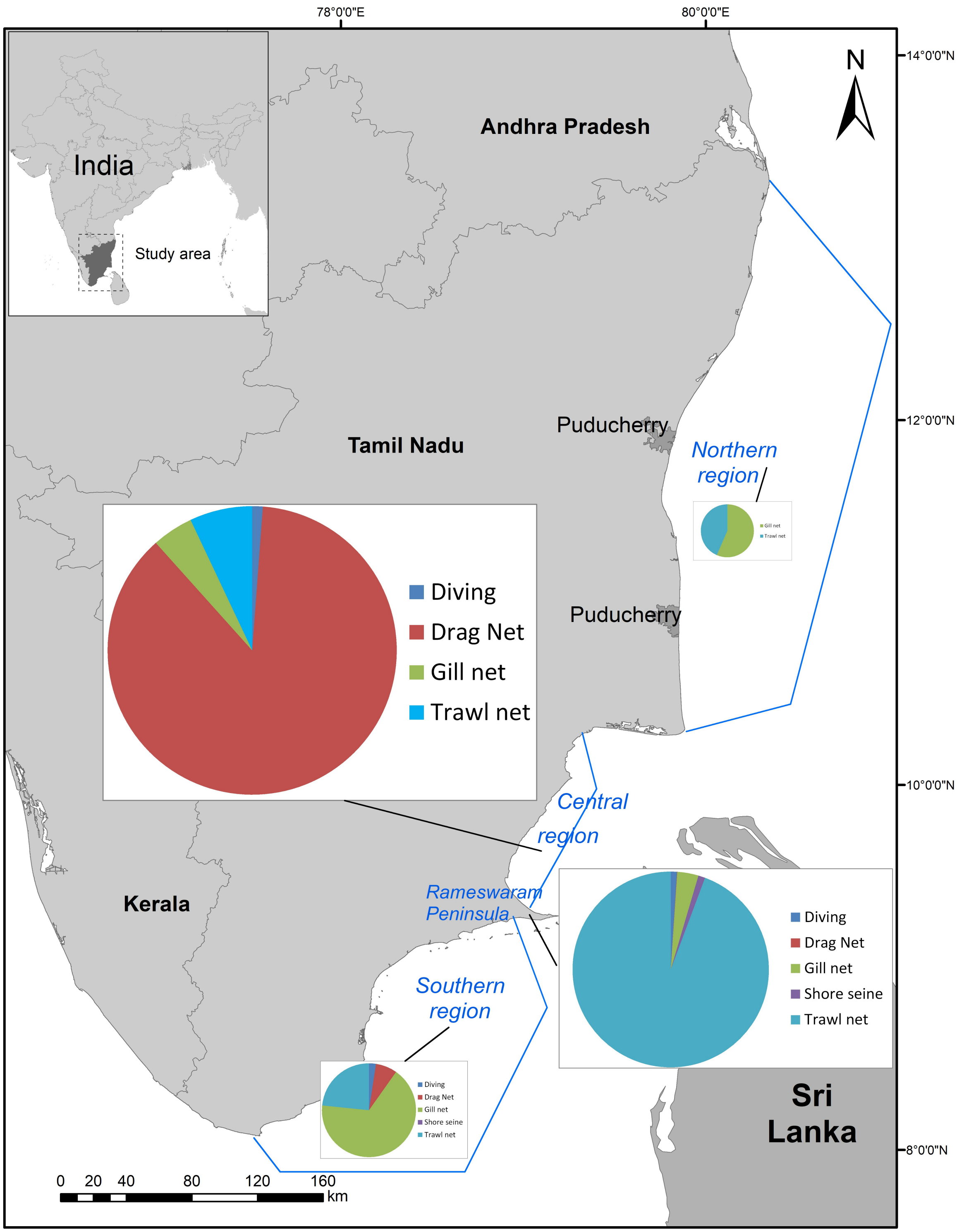

Figure 3.2 Breakdown of seahorse catches by location and gear type along the coast of Tamil Nadu, based on catch estimates from interviews conducted between 2015 and 2017.

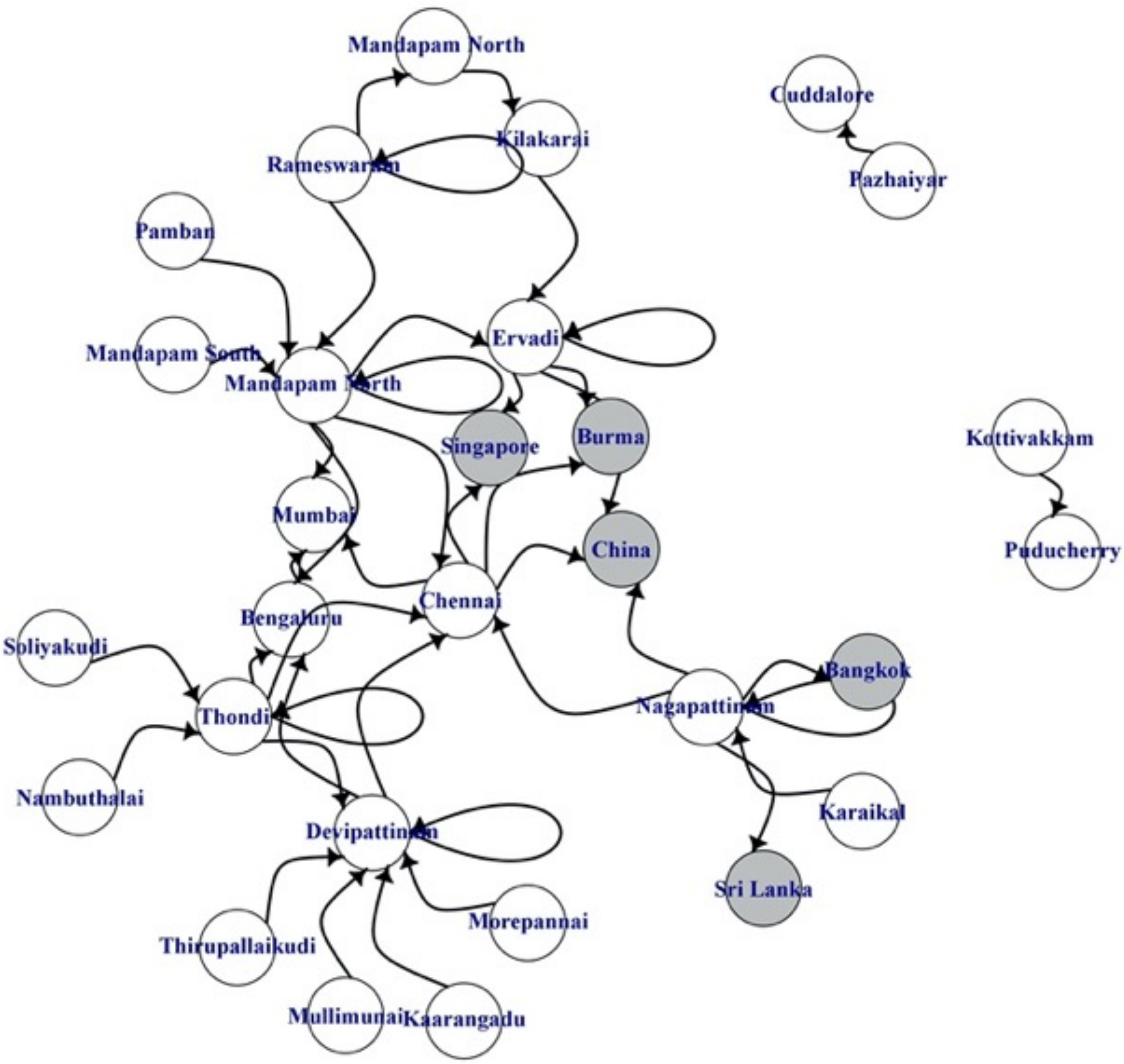

Figure 3.3 Trade network based on interviews with seahorse buyers during field surveys conducted in Tamil Nadu between 2015 and 2017. Areas in grey represent international destinations.

Chapter 4: Benefits of catching banned species exceed the costs: a case study of seahorses and trawl fishing in India

4.1 Synopsis

The success of bans on wildlife trade depends on the balance between compliance and enforcement, which in turn is determined by the relative commitment of stakeholders. Such commitment depends on variables that include the economic value of species, stakeholder consultation in decision making and the consideration of costs and benefits of violating the ban. Through 304 semi-structured interviews with fishers and sorters, I investigated why fishers continued exploiting protected species, using the case study of seahorses (*Hippocampus spp*.) in Tamil Nadu, India. I found that economic contributions from seahorses was greatest for drag-net crew in the Palk Bay region, despite these fishers neither catching the greatest number of seahorses nor receiving the greatest price per seahorse in the regions surveyed. The greatest benefits accrued to owners and crew of dragnet boats, where seahorses could significantly supplement owner income (mean = 340%) and crew income (mean =111%) and cover the operating costs of a dragnet, particularly during times of low income from target species. For trawlers, economic contributions from selling seahorses were negligible compared to boat incomes (0-1.75%). Contributions from seahorses did not provide economic benefits to owners of bottom trawlers because money from selling seahorses typically went to the crew, supplementing their income by up to 19% of during times of low fish catches, who then often spent it on supporting their recreational activities. Fishers expressed frustration that the ban had been imposed without consultation, given their long history of landing seahorses, and noted that enforcement was too lax to deter sale of seahorses. Fishers also commented that they might as well sell seahorses, despite the ban, since the animals had already been caught. Given the challenges of regulating trade in incidentally caught species, conservation efforts need to focus on restricting the extent to which they are obtained in the first place, particularly through spatial restrictions on indiscriminate gear.

4.2 Introduction

Ultimately, the success of any regulation is measured by what it achieves (OECD, 2000). This pattern applies to policy measures relating to natural resource management. In most parts of the world, formalized regulations to protect natural resources are a relatively recent phenomena, gaining traction over only the last halfa c (Acheson, 2006). Despite the burgeoning legislation for the management of resources, many regulations achieve little and amount to intentions rather than policy (Acheson, 2006). Natural resource regulations are perceived to fail either because they are ill-defined or insufficient, or because they are poorly followed (Shirley and Gore, 2019). The many regulatory failures include numerous designations of "paper-parks", protected areas that exist only in official documents (Taylor, 2015), which local communities are unaware (Reading et al., 2016), and the continued overexploitation of forests and fisheries in many parts of the world despite regulations to manage them (Ascher, 1995; McGoodwin, 1990). While the reasons for regulatory failure are plenty, ultimately a successful regulation requires strong leadership, working for the larger interest of the public and determined political will, actively supporting the regulation (Wellenius and Stern, 1994), as has been identified in the case of successful co-managed fisheries (Gutierrez et al., 2011).

Enforcement must be a part of the plan for any regulation, where obedience to rules is monitored, and wrongdoers penalised (Kahan, 1999; Nagin, 1998; Tyler, 2008). Strong environmental laws and consistent enforcement have been identified as key components of sustainable pathways (Chapman et al., 2019). Enforcement has played a critical role in conservation and natural resources management (e.g., Hilborn et al., 2006; Jachmann, 2008). Strong enforcement against poaching was an important factor in the case of increasing populations of elephants and black rhinos in the Serengeti National Park in Tanzania (Hilborn et al., 2006). The corollary is that, in regions with a lack of enforcement, increased poaching has been observed (Leader-Williams et al., 1990; Di Minin et al., 2015; Poudyal et al., 2009). Good enforcement has been crucial in Marine Protected Areas (MPAs) for the recovery of target fish stocks (Guidetti et al., 2008) and in reef fish assemblages (Floeter et al., 2006). However, enforcement issues include prohibitively high costs (Balmford et al., 2002) and ongoing mistrust between locals and authorities (Infield and Namara, 2001).

Because enforcement of regulations is often restricted by limited capacity and resources (Keane et al., 2008), the degree of compliance is a key factor affecting the success of a regulation (Thomas et al., 2016). Compliance may be considered either on a dichotomous scale (compliance vs non-compliance) or as a range of behaviours (weak to high) (Arias, 2015). A simplistic approach to compliance suggests that a willingness to comply may be achieved by an individual commitment to doing the 'right' thing (Robinson and Darley, 2004, Tyler, 2006), economic incentives (OECD, 2000), or an acceptance of the goals of the reform (OECD, 2000). However, this assumes that people are rational actors maximizing utility through costs and benefits, which is quite the opposite of observed behaviours regarding decision-making about natural resource use (Siebenhuner, 2000, Levine et al., 2015). It is increasingly acknowledged that generating compliance involves a better understanding of non-economic factors such as norms (measures largely accepted in a group) (Ramcilovic-Suominen and Epstein, 2012)- including social and personal norms (Oyanedel et al., 2020), and non-economic values (e.g., intrinsic, social, cultural, and relational) that people associate with resources (Chapman et al., 2019). As a result, there is now a greater push for conservation research to draw from multiple disciplines such as sociology, psychology and behavioural theory, all fields in which compliance is of great relevance (Arias, 2015). To deter non-compliance, economic incentives such as alternative livelihood schemes and payments for ecosystem services have also gained popularity (Duffy et al., 2015). However, even these initiatives have been met with a fair share of criticism, including amplifying inequalities resulting in greater non-compliance at a local scale (Gibbes and Keyes, 2010). Ultimately, for many management authorities, compliance with rules remains a significant concern and or/challenge (Hauck and Kroese, 2006).

Compliance is essential in situations where the actions are well beyond the range of most government scrutiny, as in the case of activities in the ocean. In fisheries, as in many other natural resource contexts, a lack of compliance with rules has been quite prevalent (Nielsen and Mathiesen, 2000, Arias et al., 2015). Studies on fisher compliance have often taken an economic standpoint to suggest that fishers may violate rules when economic gains are greater than potential fines if caught, and/or the probability of being caught is low (Sutinen and Kuperan, 1999; Sumaila et al., 2006). However, given the large context in which illegal, unreported, and unregulated (IUU) fishing occurs, including regulations, gear types, species (Arias et al., 2015), it is key to understand the local socio-economic and institutional settings in which the fisheries is situated (Waylen et al., 2010). Within these settings, understanding and promoting factors that increase compliance may help curtail IUU through many well-designed and locally suitable measures (Petrossian 2015). However, this is still complicated, and even within the same fishery, different motivations (e.g., normative vs instrumental) at different levels (within individual vs between individuals) have been observed with regards to compliance with various rules (Oyanedel et al., 2020). Ultimately, while generating fisher compliance, it is critical to understand that one solution does not fit all and that no solution is likely permanent (Ostrom, 2007).

Compliance also plays an important role in situations where implementation has distinctive challenges. In fisheries regulation, implementation is particularly complicated when managing nonselective fishing gears and the species they catch (Keledjian et al., 2014). Most bycatch regulations have primarily focused on ensuring that fishers use mitigation measures (e.g., Alverson et al., 1994, Hall et al., 2000) but have done little to address the actual fishing method. In many countries, particularly in south and southeast Asia, overfishing and dwindling profits means that many fishers often no longer target specific species, instead targeting all fish (Lobo et al., 2010). As a result of the increasingly blurred lines between target and bycatch species, fishers may be more opposed to regulations banning the catch of specific species or species-specific quotas (Karnad et al., 2014); species that were bycatch have now evolved into secondary targets or become just one more element in a catch that is sold without discrimination. In such situations, compliance is hugely difficult, and enforcement is unlikely. While enforcement has successfully regulated bycatch quotas in some parts of the world, such efforts have proven to be expensive and intensive in terms of person-power (Diamond, 2004), and therefore not what most countries in the developing world choose to prioritize.

In principle, we might expect better enforcement of laws affecting marine species of iconic or charismatic value, because of the greater research, funding, and public support directed towards the conservation of these species (Verissimo et al., 2011). Seahorses (*Hippocampus* spp.) are an incidentally caught genus of fishes that serve as flagship species for a wide range of marine conservation issues (Vincent et al., 2011), and are in unsustainably high demand for Traditional Medicine (TM), aquarium trade, and curios (Foster and Vincent, 2004). Considering the threats they face, all seahorses were listed on Appendix II of the Convention on International Trade of Endangered Species of Flora and Fauna (CITES) in 2002, with implementation since 2004). Seahorses were the first marine fishes to be listed on Appendix II since the Convention's inception. Appendix II does not impose a ban but requires 183 Parties to ensure that wild populations are not affected detrimentally by international trade. An inability to meet these obligations has led many countries to suspend exports, sometimes because of CITES reviews of their regulations (Foster, 2016). Such export suspensions may, however, have little impact on the sustainability of wild populations where incidental fishing continues unabated, and where enforcement of the ban is weak (Foster et al., 2019).

My research focuses on regulations affecting seahorse catch, exploring difficulties associated with their enforcement. I use the particular case study of seahorses in India where, in 2001, the exploitation of seahorses (and all other Syngnathid fishes) was prohibited through its inclusion under Schedule I of the Wild Life Protection Act, 1972 (Ministry of Environment and Forests, Govt. of India, 2001), which denotes a ban on capture and trade of these fishes. Despite this ban, the catch and trade of seahorses continue at a large scale, mostly from the Southeastern coast of India (Tamil Nadu state), particularly from Palk Bay and the Gulf of Mannar region (Vaidyanathan et al., 2021; Vinod et al., 2018). It seems probable that the lack of compliance with the ban is because seahorses are obtained incidentally in non-selective fishing gears, whatever the prohibitions, and because the people involved may benefit from the income from seahorses. While the penalty for catching and trading seahorses is a three to seven-year prison term, with fines ranging from ₹10000 (~USD 137) to ₹ 25000 (~USD 342) (1USD= ₹73.13 at the time of writing), and though fisher apprehensions have taken place, never has a court case met a logical completion (D.Bilgi, Former Wildlife Warden, Gulf of Mannar National Park, *personal communication*). In this paper, I estimate and examine the economic value of the seahorses relative to the income of boats from targeted catch and unsorted bycatch, and people involved in the fisheries that obtain seahorses. I also address fishers' comments about why they continued exploiting and trading protected species. By incorporating the fishers' thoughts (stakeholders who directly extract the species), this paper seeks to develop better conservation measures for seahorses.

4.3 Methods

To meet my objective, which was to understand why fishers continued catching and selling species despite protection in place to prevent such activities, I conducted semi-structured and structured interviews with people whose work was related to seahorse fisheries and trade (e.g., fishers and sorters, government). My data for this study came from larger surveys I conducted in the state of Tamil Nadu to understand the status of seahorse fisheries and trade two decades after an extraction and trade ban (Vaidyanathan et al., 2021). During these surveys, I conducted interviews over three time periods, using convenience sampling because my intention was to have the greatest coverage in terms of both location and respondents interviewed. From these surveys, I found that the catch and trade of seahorses continued in large numbers, which lead me to the question- does supplemental income from trading a protected species explain why people continue participating in this banned activity? To answer this, I used information I had collected from my interviews on variables such as seahorse catches, prices received, fishing effort, and the economics of boat operations, which I used to estimate the benefits and risks associated with catching protected species.

4.3.1 Data Collection

To understand why fishers continued catching and trading protected species, I selected three coastal districts – from North to South: Nagapattinam, Ramanathapuram and Thoothukudi (Tuticorin) district (Figure 1) – for which, from my larger surveys conducted in Tamil Nadu, I had the greatest amount of data (n >40) from trawlers and drag-netters, totaling 304 interviews with fishers and fish sorters (Table 1).

I conducted interviews along the coast of Tamil Nadu state during three time periods: (i) July 2015 to April 2016, (ii) August 2016 to May 2017 and (iii) September 2017. Field research was led by the senior author, a citizen of India from Tamil Nadu. I focused on these two gear types because they caught most seahorses in the state (Vaidyanathan et al., 2021). I selected some interview locations based on locations with high levels of reported seahorse catches and trade from previous studies in India (Salin et al., 2005, Perry et al., 2020). I then selected additional locations based on regions where seahorses were found, 1) according to researchers and personal communications with academics, and 2) through snowball sampling within this study in which one respondent indicates other potential locations. All research was approved by the University of British Columbia's Animal Care Committee (6253-13) and Human Behavioural Research Ethics Board (H12-02731 and H15-00160).

Interviews were conducted in Tamil with the help of three local field assistants (fluent in Tamil) and for the semi-structured interviews, questions and answers were translated between Tamil and English. My interviews lasted anywhere from a few minutes to an hour and a half, depending on the respondents' willingness to answer. I asked questions about fishing gear, fishing effort, fishing grounds, fishing seasons, seahorse catches, habitats, uses of seahorses, trade, and prices obtained for seahorses (Appendix A.1). During my second and third field season, my research focus was more broadly on trawl fisheries, and I asked questions about their role in the crew, boats operating costs, catch composition and values during different seasons, boat incomes, crew, and owners, seahorse catches and values per trip, and the split of income obtained from the illegal trading of seahorses (Appendix C.1). I used triangulation to cross-validate information received within interviews by asking the same questions in three different ways and comparing the answers within and among interviews (Patton, 1999).

4.3.2 Data Analysis

For this study, in the Nagapattinam district, I selected the Nagapattinam Fishing harbour as the representative location for three reasons: (i) trade in the district was found to be centred here (Vaidyanathan et al., 2021), (ii) I obtained a large number of interviews (n=101) from the region, and (iii) fewer seahorses were reportedly caught in the region compared with the Ramanathapuram district, but the seahorse species here were larger with noticeably greater prices obtained for each seahorse. In Thoothukudi district, I included the only major trawl landing centre, where fishers reported landing fewer seahorses, as a comparison for the other landing sites in this study.

In Ramanathapuram district, I combined the data collected from fishers on various aspects such as seahorse catches, prices received and operating costs from eight trawl landing centres (described in Appendix C.2) into five areas as follows. I considered trawl data from Soliyakudi and Thondi together (Palk Bay trawlers), and for Ervadi and Kilakarai together (Ervadi and Kilakarai), in both cases because of the proximity of the two locations and the similarity of their fishing operations (time of fishing, seasons, type of fishing and fishing grounds). I also analysed data from Mandapam north and south together (Mandapam trawlers) because the same trawl boats often shift operations between these two landing centres, and seahorses were sold to a common set of traders. I treated the data from the two other trawl landing centres, viz. Pamban and Rameswaram fishing harbour, in

Ramanathapuram district separately because of the different locations in which they primarily fished (the deeper Gulf of Mannar vs the shallower Palk Bay region).. In this district, I combined data from fish and shrimp trawls even though crew on fish trawls were likely to be paid a greater amount because they hauled more often in each trip.

I treated the data from drag nets across the Palk Bay region of the Ramanathapuram district as one (hereafter referred to as Palk Bay drag nets), based on (i) similarity in habitats and depths that they fished and (ii) low sample sizes obtained from six landing sites (M.V. Pattinam, Thondi, Soliyakudi, Morepannai, Kaarangadu and Mullimunai). I also obtained data from shore-based workers (henceforth referred to as 'sorters'), but only in the Mandapam region of the Ramanathapuram district.

To supplement and cross-validate my own findings on boat operating costs, boat income, or crew income, I used data from local fisheries officials and researchers, along with previously published literature in the region that provided income breakdowns (e.g., Stephens et al., 2013; Johnson and Narayanakumar, 2016) (Appendix C.3). To account for variability in catches, I created three scenarios for boats in every landing centre: (i) boats operating at a 50% loss; (ii) boats operating at operating costs; (iii) boats operating at 50% profit. I then calculated the various crew income scenarios based on these values.

I classified the salary structure for crew who received a fixed salary or a percentage of the catch as low risk to crew and for those who received a salary as a percentage of the profit as medium risk to crew (Appendix C.4). I did not include a category for high risk because all crew I interviewed reported receiving at least a basic stipend even when catches were poor and were not wholly dependent only on profits for their income. For the Palk Bay trawl locations, I was unable to obtain operating costs of trawlers and therefore used mean operating costs based on all the other landing centres in the Ramanathapuram District.

I accounted for inflation by scaling all values to prices in 2016, the year when I had the most interview data, with the relative Consumer Price Index (CPI) (CPI of 2015=100, https://www.inflation.eu/inflation-rates/india/historic-inflation/cpi-inflation-india-2015.aspx). I converted all values to the US Dollar (1USD= ₹67.07) based on yearly averages for 2016-2017 (https://www.rbi.org.in/scripts/PublicationsView.aspx?id=17923).

4.3.2.1 Catch per unit effort and prices of seahorses across gears and locations

To calculate the number of seahorses caught per day, I took individual reports on landings from fishers for discrete-time periods (i.e., per haul, per day, per week, trip, month, or year) and then scaled them to the daily catch of seahorses per boat (seahorses per boat per day). I calculated prices received for individual seahorses in the various regions separately because of large geographic discrepancies in the type of species and their reported sizes and prices. The prices paid to fishers per seahorse differed according to the size of the seahorse, but I was unable to obtain a breakdown by number of seahorses per size class that were caught, so I took the mean of the price across all reported size classes.

I summarized and plotted the CPUE (seahorses per boat per day), prices received per seahorse, the absolute prices obtained from seahorses per boat per day, and the price obtained from seahorses per crew member or per sorter per day from different locations. The amount each boat earned from seahorses per day was calculated as:

Price from seahorses/boat/ day = mean number of seahorses obtained/day * price/seahorse (1)

and daily value of seahorses to crew was calculated as:

Price from seahorses/crew/day = total price of seahorses / number of crew operating on the boats (2)

In drag netters, drivers and owners normally received a portion of the profits from seahorses, but this was not the case in trawlers.

For locations which had sample sizes greater than ten, I ran a non-parametric Kruskal Wallis (K-W) test (Daniel, 1990) to compare differences between CPUE (seahorses per day), prices received per seahorse, total prices obtained from seahorses per boat per day, and the prices obtained from seahorses per crew or per sorter per day. I did not include sorters in my comparisons for prices obtained from seahorses per boat per day. I chose the K-W test because of the low sample sizes and non-normal distribution of my data. If the K-W test showed significant differences, to understand which locations were significantly different, I then ran a post-hoc analysis using the less conservative post-hoc Conover-Iman test of multiple comparisons (‘conover.test’ package in R; Dinno, 2017), with the Benjamini-Hochberg (bh) adjustment method to reduce possibilities of a false positive (Benjamini and Hochberg,1995).

4.3.2.2 Income from seahorses relative to overall boat and crew income

I compared the amount of money contributed by seahorses relative to reported boat income that included only the income from target catches/unsorted bycatch, and crew income among locations and over the three boat income scenarios. I then summarized the supplemental contribution of seahorses for each boat scenario and each wage structure.

For respondents who stated that they sold seahorses, but either did not provide a price obtained and CPUE, or provided only one of these variables, I used the mean value from respondents in the same location to fill in blanks. I followed a similar protocol concerning information about the number of crew on boats and the operating costs. My small sample sizes ($n < 10$) in many locations meant that I used the means rather than the medians to assign equal importance to every value.

I provide all calculations per day and not per trip because while the length of a trip was a day in Ramanathapuram district (up to 28 hours for trawlers) and Tuticorin district (5 am to 9 pm the same day), the length of a trip was approximately 5 days in the Nagapattinam district.

4.3.2.3 Factors determining relative value of income from seahorses

I analyzed the effect of different predictors on the daily boat income (Appendix C.5) and crew income (Appendix C.5), using a Gamma distribution, based on linear mixed models (R packages ‘stats’ and ‘lmer’, Venables & Ripley 2002, R Core Team 2019). To fit a gamma regression model, I added a constant value of 0.00001 to all 0 values as gamma is only defined for values greater than 0. I identified the best model, which explained the most variance with the least number of predictors, based on the Akaike information criterion (AIC; Akaike, 1973). The lower value of AIC, the better the model fit for the given dataset.

4.3.2.4 Owner income

Only in Palk Bay dragnets were income obtained from seahorses reported to contribute to owners' income. I calculated the percentage supplemental income that seahorses contributed to reported owner income in this location across the three different boat scenarios.

4.3.2.5 Sorter income and comparisons with boat crew income

I obtained shore-based worker (sorter) income only from my interviews in the Mandapam region (Mandapam and Munairkadu). For this area, I calculated the supplemental contributions of seahorses to the income of sorters. I then ran an unpaired two-tailed t-test with an unequal variance to compare the supplemental income of seahorses to sorters with that of fishers in the income scenario from the Ramanathapuram District where supplemental income from seahorses to the legal income of crew was the lowest.

4.3.2.6 Fisher perception about continued catch and trade of seahorses

I collected qualitative information to help us understand why fishers continued illegally trading seahorses despite a catch and trade ban. All data were obtained through unprompted comments made during my interviews for which I did a post-hoc analysis.

4.4 Results

Overall, I found that despite the catch and trade ban, seahorse trade could provide a significant supplemental income to drag-net crew (up to 80%) in the Ramanathapuram district when boats were breaking even (Appendix C.7). While the supplemental contribution was lower for trawlers (~1% in Ervadi and Kilakarai to 20% in Pamban South), income contributions from seahorses was near zero for the sorters, and for crew in the Tuticorin fishing harbour (~ 0.01%) (Appendix B.6) where the CPUE was relatively low (Fig. 4.2a). The supplemental income from seahorses was of greatest value to drag netters, more than for trawl crew who received greater salary, with both drag-net crew (Appendix C.7) and owners (Fig 4.3) benefiting from their trade. Supplemental income from seahorses helped offset the relatively low operating costs of drag-netters, particularly during periods of low catches.

4.4.1 Catch per unit effort and prices of seahorses across gears and locations

Fishers in the Palk Bay region, particularly drag-netters, reported receiving the greatest incomes from seahorses despite neither catching the largest number of seahorses per day nor receiving the greatest prices per seahorse compared to other landing centres (Figs. 4.2a-d).

4.4.1.1 Catch per unit effort

I found significant differences in the seahorses caught per boat per day across locations (Fig. 4.2a) (chi-squared=158.67, df=6, p -value< 2.2 e-16). On running the Conover-Iman post-hoc analysis, I found that the CPUE was significantly lower in Tuticorin fishing harbour (Appendix C.6a), a large harbour, with large trawls, where all boats land their catch at around the same time each night, compared to the other locations (Appendix C.6a). Sorters in the Mandapam region and multi-day trawlers in the large bustling Nagapattinam fishing harbour, where seahorses were openly auctioned, also obtained significantly fewer seahorses than all other regions except the Tuticorin fishing harbour (Appendix C.6a). I did not find any significant differences in the catches of seahorses between the trawl and drag landing centres of the Palk Bay region where boats fish in shallow seagrass beds, the Mandapam landing centres in which trawl boats often fish interchangeably between the shallow waters of the north and the deeper more biodiverse waters of the south, and the Rameswaram harbour where trawl boats frequently cross the international border with Sri Lanka (Appendix C.6a).

4.4.1.2 Price obtained per seahorse

Prices obtained per individual seahorse differed significantly by location (Fig.4.2b) (chi-squared = 149.03, df = 6, p-value < 2.2e-16). On running a post-hoc analysis, I found that prices obtained in the large bustling harbour with open auctioning of seahorses (Nagapattinam fishing harbour) were significantly greater than in all other locations (Appendix C.6b). Sorters at the Mandapam region and fishers at the night-time trawl landing harbour (Tuticorin fishing harbour) received significantly lower prices per seahorse than other locations, but comparisons between these two harbours showed no significant differences (Appendix C.6b). Amongst the landing centres of the Ramanathapuram District, I discovered that trawl and drag net crew in the landing centres of the Palk Bay region received significantly greater income per seahorse than fishers in the two landing centres of Mandapam and the Rameswaram fishing harbour where boats frequently strayed into Sri Lankan waters (Appendix C.6b). No significant differences in prices were observed between the trawl and drag net fishers of the Palk Bay region (Appendix C.6b).

4.4.1.3 Income received from seahorses per boat

The income received from seahorses per boat per day differed significantly by location (Fig. 4.2c) (chi-squared = 86.40, df = 6, p-value < 1.7e-10). My analysis showed that fishing boats in the night-time landing centre (Tuticorin fishing harbour) received significantly lower income from seahorses than all other locations (Appendix C.6c). Dragnet boats from the Palk Bay region earned more from seahorses than fishers from multi-day trawl fishing boats at Nagapattinam fishing harbour and the trawl landing centres of Mandapam. Trawl boats from the Palk Bay region received a significantly greater income compared to the trawl boats of the Rameswaram fishing harbour. However, no significant differences were observed between the trawl and drag landing centres operating in the shallow, seagrass rich Palk Bay region (Appendix C.6c).

4.4.1.4 Income received from seahorses per crew member

I found significant differences in the income obtained from seahorses per crew member per day across the different locations (Fig. 4.2d) (chi-squared = 95.6, df = 6, p-value < 2.2e-16) and types of boats (drag-netters vs trawlers). Overall, income from seahorses received per crew were significantly greater for the Palk Bay drag net fishers than in any other location (Appendix B.5d). Fish sorters in the Mandapam region received significantly less money from seahorses than all locations except fishers in the nighttime fish landing centre (Tuticorin fishing harbour) (Appendix C.6d). Crew members working in the Palk Bay region receive greater incomes from seahorses comparing to in other regions, for both drag-net fishers and trawlers. Fishers in the Mandapam landing centres, in the Rameswaram fishing harbour where trawls frequently crossed the Sri Lankan border, and the bustling Nagapattinam fishing harbour did not receive significantly different incomes from seahorses.

4.4.2 Income from seahorses relative to boat income

For trawlers, I find that the income from seahorses relative to boat income was negligible even when the boats were running at a 50% loss (Fig. 4.3). In some cases, such as the nighttime trawl landing centre (Tuticorin fishing harbour), seahorses did not contribute to income (n=37, mean=0, SD=0.006). The maximum relative value from seahorses to boat income was only around 1.75% in the 50% loss scenario in trawlers operating along the shore in the Palk Bay region (n=25, SD=1.71). As the income of the boats increased, potential relative contributions of seahorses to boat income decreased, and in the 50% profit scenario, seahorses contributed between 0% at the Tuticorin fishing harbour to a maximum of 0.6% in the trawl boats operating in the Palk Bay region (Fig 4.3).

However, when I considered the case of drag-netters, a different picture emerged. During times of low fish catches, when drag-netters were running at a 50% loss with regards to income from their targeted and unsorted bycatch, the relative income from seahorses (mean=109.79, SD=111.29, n=24), may have helped subsidize the operating costs of the boat and even when drag-netters ran on a 50% profit, the income from seahorses was sizeable compared to the overall income (mean=36.60, SD=37,10, n=24) (Fig 4.3).

4.4.3 Income from seahorses relative to crew income

Supplemental income from seahorses was negligible in the nighttime landing centre of Tuticorin fishing harbour (mean=0.01, SD=0.02, n=37), but potentially provided a considerable supplement relative to the other incomes of trawl crew (Appendix C.6). This supplemental income was notable particularly during times of low fish catches when boats were running at a 50% loss, or just breaking even, and for certain salary structures for crew in the landing centres of Mandapam (mean = 16.77, SD=15.77), Rameswaram (mean= 14.89, SD= 12.69) and Pamban (mean= 18.92, SD= 11.01) (Table 4.2). However, once again, the contributions of seahorses to crew income remained the largest for drag-nets, providing the crew with a supplemental income ranging from 51% of other income (SD=98.76, n=24) when the boat was doing running on a 50% profit, to about 111% of other income when the boat was running on a 50% loss (SD=110.99, n=24) (Table 4.2).

4.4.4 Factors determining relative value of income from seahorses

I found that for vessel income, the best model includes two of three predictor variables, namely location and gear type (Appendix C.8), and for crew income, I find that the best explanatory model determining the contribution of seahorses to crew income included all four predictor variables viz. location, boat profit scenario, gear type and income scenario (Appendix C.8).

4.4.5 Income from seahorses for owners

"We (fishers) get only seahorses for ourselves, so we collect all and sell. Owner gets no share, the crew takes and sells."- Trawl fisher, Rameswaram fishing harbour

Owners in the Ramanathapuram district stated, unprompted, that seahorses belonged to the crew. For example, during my semi-structured interviews in the Mandapam region, nine respondents who provided details (4 of 12 crew and 5 of 6 owners) stated that seahorses belonged to the crew. Similarly, in the trawl landing centre where the boats operated in the Gulf of Mannar region, the only respondents who provided any details (3 of 12 crew and 3 of 5 owners) also stated that seahorses were solely for the crew while the others did not respond. In the landing centre where boats frequently crossed the Sri Lankan border, only two (of 5) owners provided responses, both stating that seahorses belonged to the crew. In the smaller Palk Bay trawl landing centres, all three owners interviewed stated that only the crew benefitted from seahorses, and so too in the landing centres in the south of the district where both owners interviewed responded that seahorses were for the crew. In the Nagapattinam fishing harbour during my semi-structured interviews (n=5 of 101). three owners who stated that seahorses were sold said that seahorses were for the crew, and one owner stated that they got a share only if the seahorse catch for a trip exceeded a certain amount (~USD 75-150). From my semi-structured interviews with drag-net fishers (n=5), only two fishers explicitly mentioned how income from seahorses was shared and stated that the owner would sell the seahorses and split with the crew members. For drag-nets, seahorses could supplement owner income by up to 340**%** when the boat was running at a 50% loss (SD=105.4, n=24).

4.4.6 Income from seahorses for sorters

I found that seahorses contributed about 1% of the sorters' incomes (SD=0.93, n=23). I compared this with the scenario where seahorse contribution to crew income in the Ramanathapuram District was the lowest (Mandapam, boat running at a 50% profit and crew excluding the driver paid 20% share). This comparison revealed that crew still received a significantly greater relative supplemental income from seahorses than for sorters (t-test, $p < 8.1e\text{-}05$).

4.4.7 Fisher perception about continued catch and trade of seahorses

While I did not ask fishers why they continued catching and selling seahorses illegally, some fishers provided insights about potential reasons without prompting. I broadly identified four recurring themes about why seahorses continued to be caught and traded.

a. Nothing can be done as seahorses are obtained as bycatch

" Seahorses are not targeted, but caught incidentally"- Drag net fisher, Kaarangadu.

In the Ramanathapuram District, fishers claimed not to target seahorses, although a couple of fishers stated they would not return incidentally caught seahorses to the sea. In the case of trawl boats, one owner noted there was no use in throwing seahorses back because they were anyway caught dead. Though seahorses were not targeted, crew members stated that catching seahorses was entirely based on the luck of the crew, with good luck bringing more seahorses.

b. Seahorses are important for livelihoods

"The daily expense of a family is Rs.500 (~$7.5), but income is not proportionate. However, a seahorse sells at Rs.70 (~USD 1)."- Drag net fisher, Thirupallaikudi

In Ramanathapuram district, both drag net fishers and trawl net fishers felt that seahorses supported their livelihoods. However, the most common comment from fishers in the Nagapattinam and Ramanathapuram district was that they used money from seahorses to buy alcohol. Fishers commented that seahorses and sea cucumbers were lifelines of the fisheries, and while sea cucumbers contributed to the well-being of the owners, seahorses were an important income source for the crew. Trawl fishers in locations such as Tuticorin stated that seahorses had no value, unlike other fish, and so were discarded.

c. The risks of catching and trading seahorses are very low

"The trade is as good as open. Seahorses are dried and openly sold"- Trawl fisher, Rameswaram fishing harbour

Trawl fishers in the bustling harbours of Mandapam, Pamban and Rameswaram never mentioned fear of recrimination as a reason to avoid seahorse catch or trade. No trawl fisher I interviewed in these harbours mentioned having been apprehended with seahorses. However, this perception of risk seemed highly variable across locations. Drag net and trawl net fishers in the Palk Bay region were more anxious about government officials. That said, respondents in this region stated that officials overlooked fishers who collected few seahorses and had only warned them against hoarding large quantities of seahorses in their houses. In the southern part of the district, fishers were mostly unwilling to talk about seahorses and on more than one occasion crowds dispersed when I raised the topic. Seahorses were openly auctioned in Nagapattinam fishing harbour while operations in Tuticorin fishing harbour were more clandestine and information less forthcoming.

d. Fishers were not consulted before prohibiting the exploitation of seahorses

"People (other researchers) talked to us and the next thing we know they (sea cucumbers, seahorses) were banned. You talk to us we do not know what (fishery) will be banned next."- Trawl fisher, Ervadi.

Fishers in the Ramanathapuram District had not been consulted before the listing of seahorses under India's WLPA. Respondents were made aware of the ban only after its imposition only when they heard from other fishers who had gotten in trouble, while others heard it on the radio, news, or when boards were installed in the case of the Gulf of Mannar region. Fishers in the Tuticorin District were aware of the ban and were less forthcoming with information about the trade. However, I could not obtain data on fisher awareness from the Nagapattinam District.

4.5 Discussion

My research showed that, despite the bans on extraction and trade, fishers continued selling seahorses because of their persistent economic value, set against the low cost of obtaining these animals (as bycatch species), and the poor enforcement of the ban. I found that seahorses were particularly important to fishers when primary fish catches were low and may have helped offset operating costs to drag-net fishers during these lean times. Fishers appeared to continue catching seahorses because it involved no extra time or effort while fishing, given their non-selective fishing gears, and no extra time costs to crew or owners as the sorting occurred between hauls. In the face of declining fishery resources, seahorses provided an additional source of income for crew, particularly in situations where their salaries were dependent on the profits. I found extensive fisher non-compliance with regulations, where they actively sought to avoid detection. Current laws do little to deter illegal seahorse catch and trade, and a better solution may be to work with fishing communities to constrain effort and effectively manage ocean spaces.

I observed a shift in individuals benefiting from the sale of seahorses. In the 1990s, the main people who supplemented their income through the sale of seahorses in the Palk Bay region were women, who picked them out of the piles of miscellaneous fish (Vincent, 1996) and skilled divers, who targeted them for livelihoods (Marichamy et al., 1993). I found that crew on boats sorted out the seahorses and sold them, in line with other studies from the region (Perry et al., 2020, Salin et al., 2005). Fishing crew apparently began making this effort as seahorses became more valuable. This shift in who benefits from seahorses has significant implications. Because earnings from women largely go towards household costs while men commonly regard extra income as theirs to spend (Bennett, 2005), seahorses went from supplementing family needs to providing small luxuries to men. While there may have been other non-economic values associated with seahorses, I was unable to draw any conclusions as I did not explicitly explore these aspects. In my experience, a further concern is that the ban on fishing sea horses (and, simultaneously, sea cucumbers) primarily affected the livelihoods of the skilled skin divers in the Ramanathapuram region, who targeted particular species and removed them very selectively. However, many such fishers then moved to bigger fishing boats, including the bottom trawlers that continued catching seahorses in their indiscriminate and destructive fisheries (Vinod et al., 2018).

I found that seahorses provided supplemental income for dragnet and trawl net crew members, particularly during times of low fish catch. Income from seahorses could keep drag net fishers afloat financially during poor fishing seasons; values obtained from seahorses were greater than boat operating costs, thus buffering owners from potential losses. The relative importance of income from seahorses derived from at least four characteristics of the drag-net fishery: (i) relatively lower operating costs of drag net fishers compared to trawl fishers, (ii) fewer crew on board, reducing costs and maximizing value of the seahorses, (iii) operation of these nets on key seahorse habitats producing many seahorses, and (iv) a long history of seahorse trade. The absolute mean income received by drag net crew from seahorses per day was quite substantial (~USD 2.5), providing fishers with the power to purchase around 6.5 kg of wholesale rice; slightly less than the 8.7 kg per capita monthly consumption of rice in rural Tamil Nadu in 2011-12 (National Sample Survey Office, 2014). However, as discovered for other taxa and other places (Coad et al, 2010), I determined that the money earned from the illegal transactions of selling seahorses were actually more likely to be spent on recreational goods, particularly in the case of trawl fishers, including local cigarettes and alcohol. This supplemental income from seahorses could provide fishers in some regions with the purchasing power of up to about 17 packs (of 20 each) of local cigarettes, or a 180 ml bottle of brandy, on an average fishing day.

Persistent illegal capture of banned seahorses is not a surprise in fishing communities with a high dependence on marine resources (e.g., those of drag-netters) and a lack of other livelihood options (Busilacchi et al., 2018). Given scarce resources and poor incomes from legal catches, fishers commonly engage in illegal activities that bring personal benefits (Sumaila et al., 2006). In Tamil Nadu, fishers continued to deploy destructive dragnets, probably because of their poor economic conditions and the dearth of reasonable loans to transition from this fishery to a less destructive one or to other income earning activities (Nithyanandam et al., 2003). Ever more intensive resource extraction generates increased dependence on illegal take of economically important protected species, eventually leading to depletion of all the resources in the region (Pauly, 1990; Steneck, 2009), including threatened species.

My findings of low compliance with the ban may partly derive from fishers' views that seahorses extraction for personal use and the sale of seahorses are legitimate based on their long history exploiting the resource, whatever the official illegality of the take (Marks, 2014). Non-compliance may also arise when fishers question the legitimacy of the ban because of apparently flimsy premises (Nielsen and Mathiesen, 2000); fishers in this region mentioned that they were informed about the ban after the fact, and to them when seahorses often come up dead in their fishing nets, throwing them back made little apparent sense. The failure to involve fishers in the development of the regulation – with information only reaching them after it had been imposed – further undermines the legitimacy of the ban (Jentoft,1989). The criminalization of catch and trade of seahorses that have traditionally been exploited, may result in the disenfranchisement of local fishers from their natural resources, and a general mistrust of conservation measures and authority figures (Marks, 2014; Walters et al., 2015). Given that many fishers reported catching and selling seahorses, it appears that the act may be socially acceptable, which could explain the continued involvement in the illegal activity. Ultimately, regulation is likely to be ineffectual, if the authorities have little understanding of the fishery or the fishers (Shirley and Gore, 2019).

I find that enforcing bans is particularly challenging for species like seahorses, where the small size of the organism and their dried state makes them relatively easy to trade (Foster et al., 2016). During interviews, fishers noted several strategies to avoid authority and detection while trading seahorses, as has elsewhere been observed in the case of illegal fisheries, even with increased enforcement (Kuperan and Sutinen, 1998). Despite high penalties (USD 500 and up to 7 years imprisonment) for catching and trading a seahorse, I confirm previous results (Sumaila et al., 2006) that the low probability of detection, the ability to avoid being caught, and the fact that fishers have never actually been penalized to the full extent have resulted in fishers continuing these illegal activities. Ramping up enforcement may merely create a somewhat futile arms race with drag netters and trawlers

A more manageable and cost-effective response to conservation concerns would be to shift the focus away from combatting illegal fishing of seahorses (and other threatened species) and towards active management of nonselective fishing gear, which also destroy the habitats for seahorses and other marine taxa. Fishers in Tamil Nadu continue adopting illegal fishing practices – many of which involve larger boats and engines than are permissible under the Tamil Nadu Marine Fisheries Regulation Act (TNMFRA) – because of the perceived income from the increased catches (Karnad et al.,2014). In the state, and particularly in the Palk Bay region, fishing fleets are overcapitalized with too many boats chasing too few fish (Sathyapalan et al., 2008). There is a need to tip the balance towards conservation of ocean resources in Tamil Nadu. While it may be costly to enforce laws at sea, many of these violations such as the use of boats greater or more powerful than permissible limits, and the use of banned fishing gear, maybe detected and enforced from land. Implementation of existing legislation such as actively preventing fishing with banned fishing gear or prohibiting trawlers in in-shore areas would help conserve not only seahorses but other hundreds of other incidentally caught species from shallow, coastal waters.

Implementing a successful exploitation and trade ban is challenging at the best of times (e.g., Challender et al., 2011; Moyle, 2003, Rivalan et al, 2007), but when layers of complexity are added (such as economically useful threatened species that are incidentally caught), it compromises the success of these blanket bans, which then require a more thoughtful approach (Booth et al., 2020). Given the severely constrained capacity to enforce these bans in many countries, which results in non-compliance, combining a top-down approach with a bottom-up one may be worth pursuing. Formal laws explicitly granting legal rights to local communities for the protection of certain wildlife was found to be successful in Namibia (Chan et al., 2019). In the context of the Palk Bay region, this combined approach would be at a more local level. An important ally would be the head of administration in each district (District Collector), given their proximity to the fishing villages, and the fact that they have executive powers to implement rules (Salagrama, 2015). Some of the key rules in the region have been a result of decisions implemented by the District Collector, based on concerns raised by fisher groups, such as the three nautical mile trawl exclusion zone and agreements on fishing days between traditional and trawl fishers (three-four day rule) (Salagrama, 2015). Community-based institutions like panchayats (elected representatives of the village) could play a crucial role in the management of resources given their ability to effectively enforce rules, an aspect that formal and informal legal systems frequently lack success with (Bavinck and Vivekanandan, 2017). Community measures could work even in open access systems, as in the case of the Coromandel Coast of Tamil Nadu, where fishing communities pushed for regulatory action for the larger good of the community (Bavinck, 1997).

My findings in this study have implications far beyond the marine environment. Bytake is not limited to fisheries, of course. A wide range of species are taken while engaging in indiscriminate removal of wild resources, including, for example, inadvertent capture in snares and traps. Bytake in snares and traps includes endangered, threatened, or protected (ETP) species such as the ground pangolin (Pietersen et al., 2016) and the Edward's pheasant in Vietnam (Brickle et al., 2008). A great many of these species are found in regions where conservation funding is low (Mittermeier et al. 2003), and enforcement capacity limited (UNEP-WCMC, https://wedocs.unep.org/bitstream/handle/20.500.11822/17554/FINAL_%20UNEA2_Inf%20doc%2028.pdf?sequence=2&isAllowed=y, accessed Oct 10,2020; Wittemyer et al. 2014). Where the snares and trapping provide economic benefits, any ban on capturing ETP species in bytake will likely prove as futile as the bans on seahorse capture. Indeed, bans may disadvantage selective and targeted take and instead promote trapping that removes animals indiscriminately. As in the case of trawling, the focus in such situations needs to be on reducing the toll and impact of the nonselective gear that operates unfettered and not on meaningless declarations of bans. I need to move away from deceptively simple and futile options and towards solutions that truly reduce pressures on wild populations.

Table 4.1: Locations and number of respondents interviewed along three districts in Tamil Nadu where interviews on seahorse fisheries and trade were conducted between 2015-2017.

District	Location	Landing Site Acronym	Number of respondents
Nagapattinam	Nagapattinam fishing harbour	NFH	101
	Palk Bay drag-netters	PBD	24
	Palk Bay trawlers	PBT	26
	Mandapam	Mn	36
	Pamban South	PNS/PnS	17
	Rameswaram fishing harbour	RMM	24
	Ervadi and Kilakarai	EandK	11
Ramanathapuram	Mandapam shore-based workers	Sorters	24
Tuticorin	Tuticorin fishing harbour	TFH	41
		Total	304

Table 4.2: Supplemental percentage income from seahorses to crew in different boat scenarios and wage structures where contribution is greatest.

Location	Pay Structure		50% loss	Operating Costs	50%profit
Palk Bay dragnets (PBD)	1 share for boat, 1 for owner and 1 for crew	Mean	111.29	76.48	50.98
		SD	111	148.15	98.76
		Count	24	24	24
Nagapattinam fishing harbour (NFH)	Flat rate (but only % of catch if boat makes no money)	Mean	6.4	6.4	2.36
		SD	7.97	7.97	3.13
		Count	90	90	90
Palk Bay trawlers (PBT)	20% catch divided by labour and driver	Mean	10.73	5.37	3.58
		SD	11.11	5.55	3.7
		Count	21	21	21
Mandapam (Mn)	Basic allowance+20% profit	Mean	16.77	16.77	5.39
		SD	15.77	15.77	5.03
		Count	32	32	32
Pamban South (PnS)	Basic allowance+22.5% profit	Mean	18.92	18.92	5.68
		SD	11.01	11.01	3.27
		Count	11	11	11
Rameswaram (RMM)	Basic allowance+20% of total catch (7.5-8% for drivers, 4-5% for crew, 6-7% for second drivers)	Mean	14.89	10.57	7.37
		SD	12.69	9.11	6.41
		Count	21	21	21
Ervadi and Kilakarai (EnK)	20% catch divided by labour and driver	Mean	3.35	1.67	1.12
		SD	1.88	0.94	0.63
		Count	10	10	10
Tuticorin Fishing Harbour (TFH)	Flat rate	Mean	0.01	0.01	0.01
		SD	0.02	0.02	0.02
		Count	37	37	37

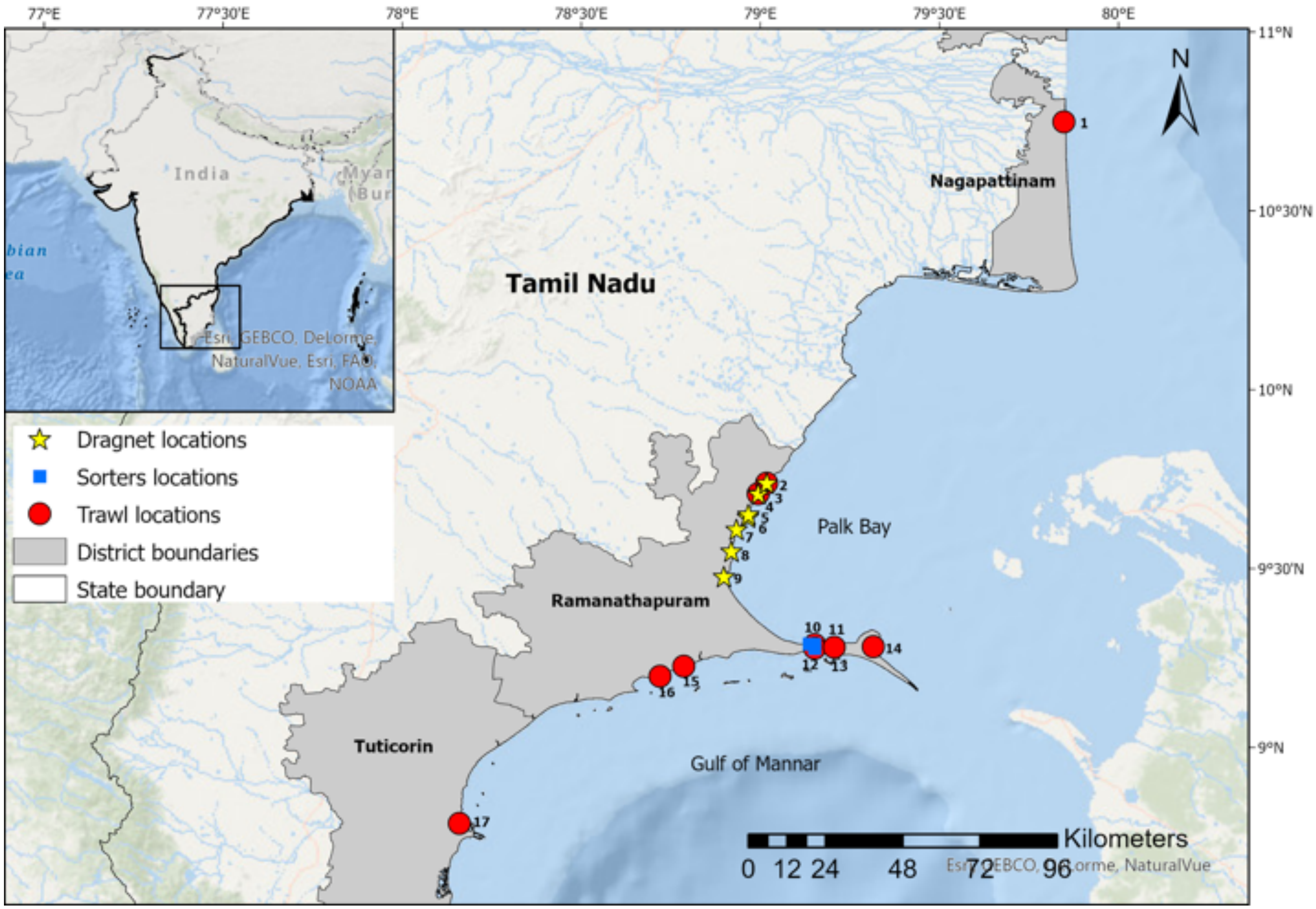

Figure 4.1 Locations in which field interviews were conducted between 2015-2017 along three coastal districts of Tamil Nadu. Locations from North to South are 1- Nagapattinam fishing harbour (NFH), 2&3 - Palk Bay trawlers (PBT), 2-9 - Palk Bay dragnetters (PBD), 10-12 - Mandapam shore-based workers (Sorters), 11-12 - Mandapam (Mn), 13- Pamban South (PnS), 14- Rameswaram fishing harbour (RFH), 15-16 Ervadi and Kilakarai (EandK), 17- Tuticorin fishing harbour (TFH).

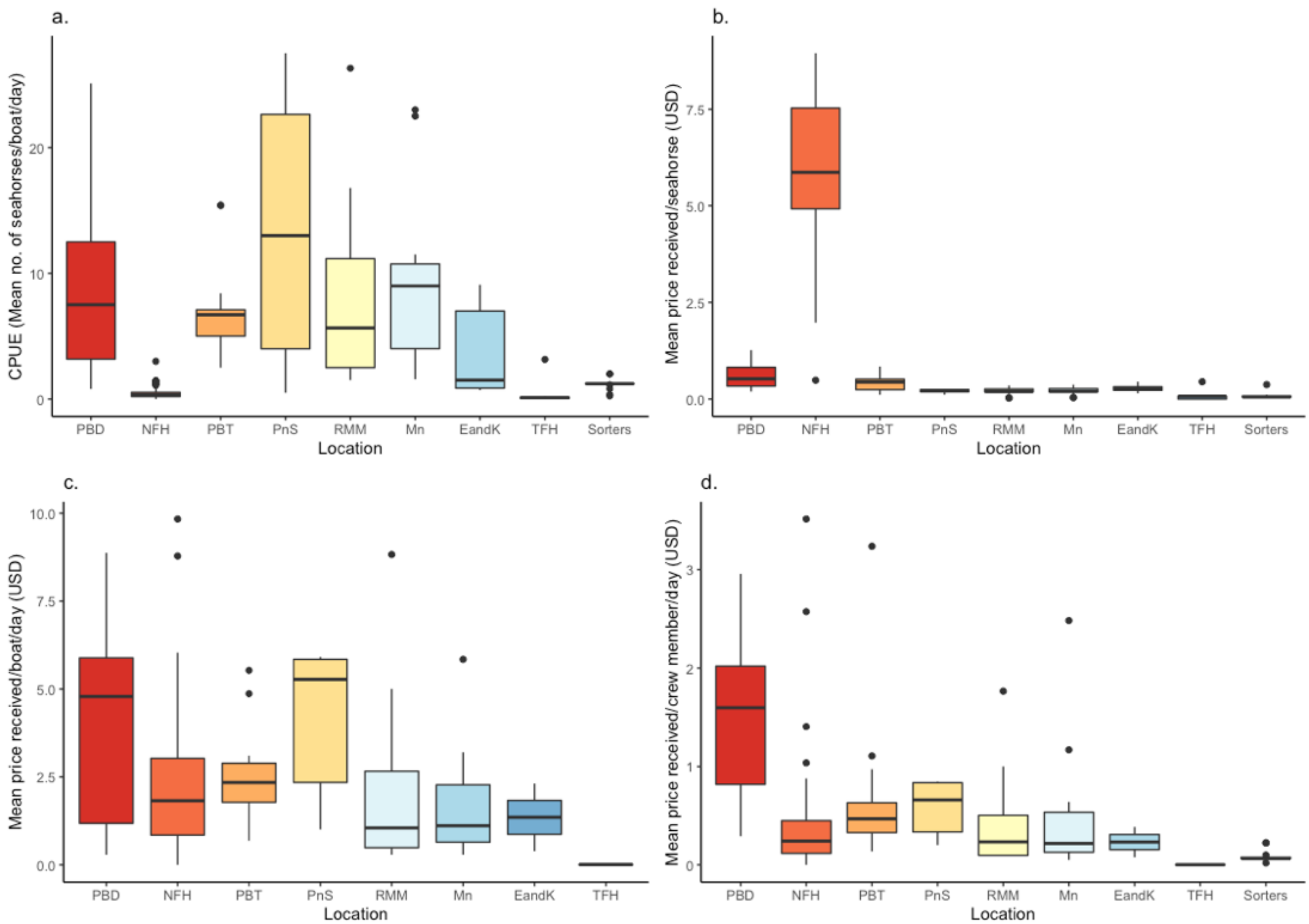

Figure 4.2 Comparison of a) mean seahorse catch per boat per day b) mean prices received per seahorse c) of mean value received from all seahorses caught per boat per day and d) mean value received from seahorses per crew member per day across different locations and gear types along the Tamil Nadu coast. Locations begin with drag-netters, followed by trawl locations arranged from North to South, and end with sorters of the Mandapam region. I plotted all values from the different variables but ran a K-W only for those variables with a sample size > 10 and found significant differences across all variables. I subsequently ran a post-hoc Conover test for multiple pairwise comparisons (Appendix C.6 a-d).

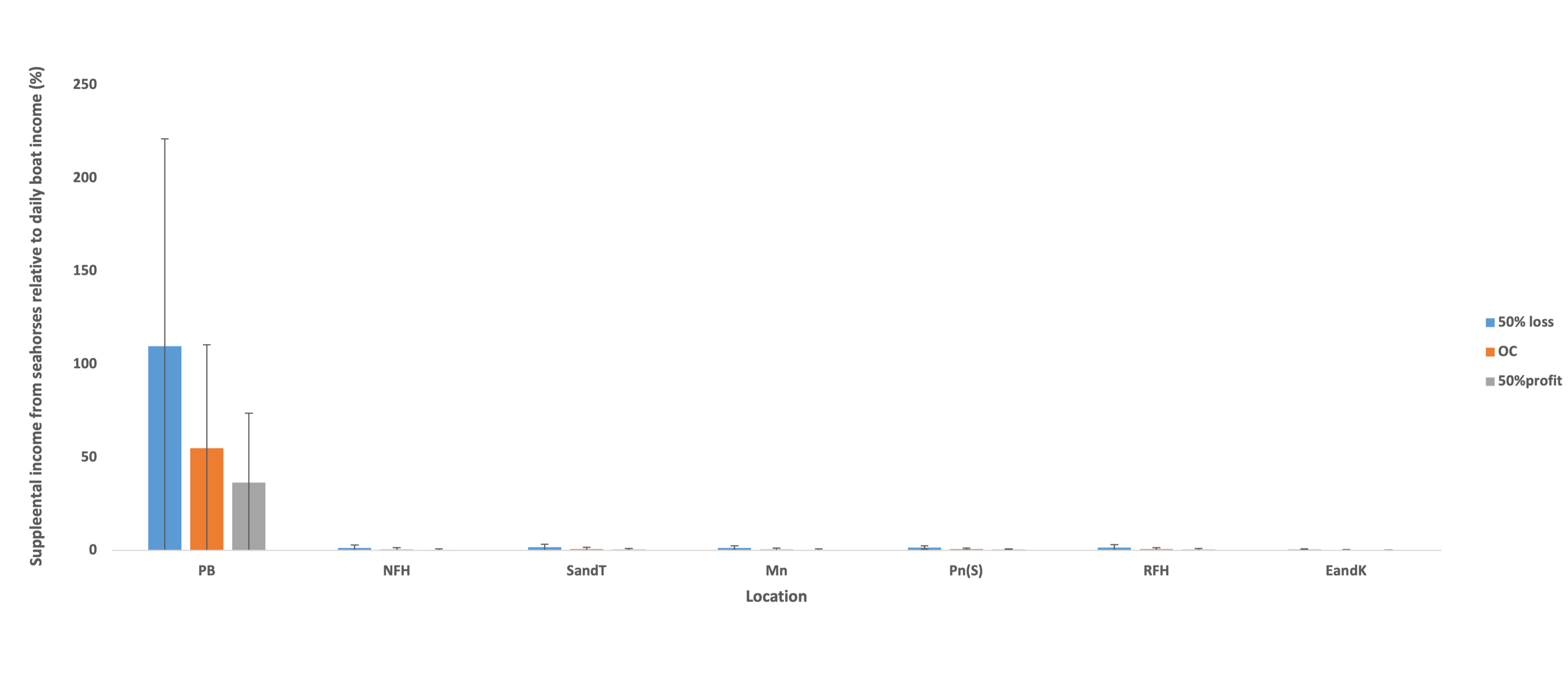

Figure 4.3 Mean supplemental contribution percentage from seahorses (±SD) relative to the daily reported income of the boat from targeted catches and unsorted bycatch, in three different operating scenarios- 50% loss, while breaking even (OC) and at 50% profit, across eight locations. Locations are arranged starting with the Palk Bay drag-netters and trawl locations are arranged from North to South (L-R). Values in the Tuticorin fishing harbour (TFH) were near 0 and have not been included in this graph.

Chapter 5: A practical approach to meeting national obligations under CITES

5.1 Synopsis

Reconciling conservation and resource use requires adaptive management. The Convention on International Trade of Endangered Species (CITES) is a key tool in species conservation, regulating international trade for a list of species (Appendix II) that are or may become threatened by trade. To export such species, CITES member countries are required to confirm that their exports are not damaging wild populations (dubbed making positive 'Non-Detriment Findings'). When countries find this challenge too great, they often default to banning international trade, thus imposing economic costs on stakeholders. What, then, are the easiest ways for countries to make positive NDFs? I examine the case study of India, which has banned catch and trade of seahorses (Hippocampus spp.), but where rampant illegal trade continues. I drew on fishers' knowledge and published literature to determine whether management was working. My approach involved four layers of spatial assessment to help assess the status of seahorse populations: (i) where they live (ii) where pressures are exerted on the species; (iii) where management exists; and (iv) where management is effective. From this information, I can identify the areas of seahorse vulnerability, where they are threatened by fishing and not supported by good management. My findings identify gaps along the southeast coast of India, precluding positive NDFs. Overall, reported seahorse presence was greatest in the southern Palk Bay region. This region theoretically offers protection through a 3nm trawl exclusion zone and a 60-day closed season. However, implementation was problematic, with three-quarters of trawl fishers reportedly catching seahorses in the trawl exclusion zone, though both trawl and drag fishers reported respecting the closed season. Such pragmatic analysis provides managers in India with a tractable route towards regulating exports at sustainable levels as an alternative to the current futile bans and can be deployed broadly in assessing sustainability of exploitation.

5.2 Introduction

Reconciling conservation with resource use is currently a major challenge. Conflicting mandates are observed in many cases, such as the Sustainable Development Goals (SDGs), where goals include protecting and improving the status of life both on land and in the waters (Griggs et al. 2014), while also aiming to eradicate hunger and poverty by 2030 (United Nations, 2017). This tension seems particularly challenging because of conflicts that arise between protecting biodiversity and converting land to agriculture for greater food production (Gao and Bryan, 2017; Phalan et al., 2011). In the marine realm, for example, seagrasses are vital habitat for many endangered, threatened and protected (ETP) species, but their presence close to human populations and their importance as fishing grounds (Unsworth et al., 2018) results in these habitats being seriously damaged by trawlers and other non-selective fishing gear. Integrated approaches, such as ecosystem-based management (EBM) that factor in multiple perspectives and reconcile divergent interests have been increasingly touted as solutions to maintain the integrity of ecosystems (Cavanagh et al., 2016; Levin et al., 2020). However, in many places and systems, wholly implemented EBMs remains largely aspirational (Link and Browman, 2014). There is now a need for a sweeping transformative change across diverse factors (e.g., technological, social and economic), including goals and values, that may then help reduce trade-offs and maximize synergies, and reverse existing environmental trends (Diaz et al., 2019; UNEP,2021).

When governments struggle to reconcile species conservation and resource use, they tend to default to one or the other. If the focus is on conservation, governments sometimes ban exploitation and/or trade as a management measure for the protection of species (Moyle, 2003). Bans may take several forms, including i) the creation of fully protected areas (e.g., Lubchenco & Gorud- Colvert, 2015), ii) precluding certain extractive activities such as hunting and logging (e.g., Blackie & Casadevall, 2019), iii) preventing harmful methods of extraction (e.g., McConnaughey et al., 2020) or iv) protecting certain threatened species while allowing more extensive exploitative activities (e.g., Collins et al., 2020). Though these restrictions appear to address problems associated with declines, rarely is it so straightforward (Moyle, 2003). Bans on extraction are often met with resistance because they may result in a loss of revenue to local communities (e.g., Lindsey, 2010) and reduced revenue for conservation (e.g., Mbaiwa, 2018) potentially resulting in local communities partaking in the illegal activity (e.g., Deere, 2011). In their turn, bans on trade can provoke (1) an increase in black market prices, which may actually prompt more illegal extraction (Abensperg-Traun, 2009), (2) emergence of underground markets, which makes it challenging to track and enforce a trade ban (Martin, 2000), (3) a loss of livelihoods for local communities, thereby taking away incentives for these communities to be invested in conservation initiatives (Broad et al., 2003), and (4) presence of unregulated domestic markets that undermine the utility of export bans (Lemieux & Clarke, 2009). Finding ways to sustainably manage extraction and wildlife trade has become an urgent conservation challenge.

One key instrument used to reconcile conservation and resource use through trade is the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), a process in which bans are often deployed (e.g., Challender et al., 2014). CITES aims to ensure that international trade in specimens of animals and plants does not threaten their survival in the wild by providing a framework to be respected by each member State (Parties, 183 at the time of writing, https://www.cites.org/eng/disc/parties/index.php). International trade is banned for species listed on Appendix I, whereas it must be regulated to ensure sustainability and legality for those on Appendix II. Parties wanting to export an Appendix II species must first provide evidence that such exports will not be detrimental to wild populations, called making a non-detriment finding (NDF) (CITES, 2016). Many CITES Parties struggle to meet their obligations for exports of Appendix II species to be sustainable, often turning to bans as seemingly more straightforward than developing appropriate management protocols (Foster et al., 2020). In a first set of cases, countries may declare stricter domestic measures than required by CITES (examples in Vincent et al., 2014). In a second set of cases, countries that are asked to justify the scale and nature of their exports (in a process called Review of Significant Trade (RST) defined in https://cites.org/eng/imp/sigtradereview) sometimes turn to bans as a way of avoiding scrutiny of their exports (e.g. Foster 2016). In a third set of countries, a Party's difficulties in meeting its obligations may lead CITES to impose a trade ban (called a suspension: e.g., Foster 2016).

Although trade suspensions have sometimes been effective in improving the implementation of CITES listings (UNEP-WCMC, 2016), incomplete enforcement of such bans often leads to illegal trade and higher black-market prices (Abensperg-Traun, 2009). CITES generally lacks both the data and the enforcement capacity to address black market trade. For example, CITES records only cover exports that went through airports, leaving most other trade undetected.

(Phelps et al., 2010). In addition, Parties that have imposed a national ban on capture or trade tend to do little else, feeling that they have met the provisions of CITES, and thus fail to engage with any illegal trade.

An important step toward sustainable trade under CITES would be to simplify advice on how Parties might more easily balance export and the health of wild populations, thereby supporting NDFs.Parties have expressed concern that existing documents and frameworks for making NDFs are too complex, requiring too much information or too many steps (S.F., personal observation). Making an NDF requires substantial data on factors such as the magnitude of trade, the population status, pressures faced at the level of the species and on their habitats, and management possibilities (Foster and Vincent, 2016) (Appendix D.1). However, Parties often lack the resources, capacity, and information to undertake the detailed work required under most current protocols (e.g., Rosser & Haywood, 2002).

I propose that CITES authorities could achieve adequate analysis of NDFs – helpful, even if not perfect - from merely overlaying four sets of information: (1) where species are found; (2) where pressures are being exerted; (3) where management is being undertaken; (4) apparent effectiveness of such management measures (Figure 5.1). Core data on the first two sets of information – spatial distribution of species and threats – can be generated relatively rapidly, cheaply, and with few technical challenges using local/traditional ecological knowledge (Berkes, 1993; Huntington, 2000). For the third and fourth sets of information, authorities can draw on their own management protocols and experiences in time and space (Mundy-Taylor et al., 2014; Aylesworth et al., 2020). The resulting NDF evaluation, although imperfect, will enable Parties to make progress in assessing the status of wild populations under their regulatory regimes and to move towards adaptive management (Fig. 5.2) (Meffe & Viederman, 1995; Smith et al., 2011).

Seahorses (*Hippocampus* spp.) provide a well-documented example of the challenges of managing species under CITES Appendix II. They were the first marine fishes to be included on Appendix II of CITES since its inception, the first marine fish for which an NDF framework was created (Foster & Vincent, 2016), and the first to go through the RST (Foster 2016). Further capacity building has included the development of monitoring protocols, simplified identification guides, and the generation of information on seahorse distribution, fisheries, and trade in most key source countries, *inter alia* (CITES CoP18 Doc 72). Nonetheless, the seahorse listing has ultimately resulted in export bans from most countries that historically exported the most seahorses (CITES CoP18 Doc 72; Foster et al., 2019). Such bans have been ineffectual, with persistent illegal, unregulated, and unreported (IUU) exports of dried seahorses. Indeed, it was estimated that almost all dried seahorses in Hong Kong SAR (95%) in 2016-17 had been imported from source countries with export bans in place, indicating a widespread lack of enforcement (Foster et al., 2019). Supporting Parties to make meaningful NDFs for seahorses would refocus their attention on doing the management that is needed to reduce pressures on wild populations, and that is required by CITES. Such NDFs might be somewhat tentative at first but could be strengthened in an adaptive management approach as information improves through monitoring.

I use a case study in India for testing my concept of simplified NDFs. India banned all exploitation and trade of seahorses in 2001, under Schedule I of its Wild Life Protection Act (WLPA), 1972 as a result of its involvement in the consultations that led to the CITES Appendix II listing for these fishes in 2002. Nonetheless, the catch and trade of seahorses has continued virtually unabated (Vinod et al., 2018; Vaidyanathan et al., 2021). Fisher compliance was low, partly because they were not involved in the decision-making process and questioned the legitimacy of the law, but mostly because the seahorses were caught incidentally during their other fishing activities, primarily with drag nets and trawlers (Vaidyanathan and Vincent, *in revision.*).

Using data generated from fisher interviews that I conducted and from existing published literature, I probed the viability of my proposed four step mapping approach to making NDFs. First, I identified seahorse locations by generating distribution maps based on fishers reports of seahorse presence/absence in their catches. Second, I identified threats to seahorses from fishing by generating a map on fishing effort using the active number of fishing hours per day by different boat types. Third, I overlaid the distribution of existing spatial management efforts. Finally, I evaluated whether existing management was sufficient to mitigate the pressures on the seahorses. My findings may help India understand how its' existing management measures would help conserve seahorses should they lift a ban and help guide other countries with their conservation policy and action in data-poor situations.

5.3 Methods

To test my concept of a simplified NDF, my assistant and I conducted fisher interviews to collect spatial data on fishing grounds, depth, and distance from shore that fishers operated, and occurrence of seahorses in catches. I also used published literature from my study area as a secondary source of information on seahorse distributions.

5.3.1 Study Area

My research is anchored in an area of the southeastern state of Tamil Nadu called Ramanathapuram District (Fig. 5.3), a hotspot for illegal seahorse catches and trade (e.g., Salin, 2005; Murugan et al. 2011; Perry et al., 2020).

5.2.2 Data Collection

Information on seahorses for my framework from this District came from fishers' knowledge and published literature. I used information at the genus level (*Hippocampus* spp.) because i) that was the level for which fishers' knowledge was available, and ii) all species of *Hippocampus* are protected under India's WLPA and listed under Appendix II of CITES.

5.2.2.1 Fishers' knowledge (FK)

I obtained fisher knowledge for this study as part of larger surveys I conducted in the state of Tamil Nadu between 2015 and 2017. The purpose of my larger surveys was to understand the extent of seahorse fisheries and trade in the state two decades after a ban, and therefore to increase the reliability of my estimates, I tried to maximize coverage, in terms of both geographical coverage as well as the number of respondents interviewed. During these surveys, my research assistant and I conducted 228 semi-structured interviews at 56 locations in the Ramanathapuram District. Locations included fish landing centres, eight of which were trawl landing centres, and fishing villages.

For this study, from my larger surveys, I obtained information on seahorse species distribution and fishing pressure from 118 and in 29 locations in the district. My other interviews failed to generate spatial data because fishers were unwilling to provide such detailed information, either because they were aware of the ban on catching seahorses or because they did not want to reveal information on their fishing grounds in general. Fishers from 19 locations reported primarily fishing in the shallow, seagrass rich Palk Bay region of the state, and fishers from 15 locations reported fishing along the highly biodiverse Gulf of Mannar region. Note that some fishers in the Ramanathapuram peninsula reported fishing in both the Gulf of Mannar and Palk Bay regions.

I chose interview locations based on where seahorses were reported according to published literature (Marichamy et al., 1993; Murugan et al. 2008; Perry et al., 2020), information from local colleagues or snowball sampling (in which one respondent indicated other potential locations). At each location, my assistant and I spoke with respondents recommended by local researchers and those I encountered haphazardly. We conducted interviews with fishing crew, boat drivers and boat owners across five types of fishing methods: diving (n=4), drag nets (n=16), gill nets (including trammel nets and bottom-set gill nets) (n=20), shore seines (n=12) and trawls (n=69). I obtained a higher proportion of responses from trawl fishers because my second field season, beginning in 2016, focused on the pressures of trawl fisheries in Tamil Nadu. We conducted all interviews at landing sites, allowing for multiple fishers from the same boat to participate and providing opportunities to cross validate within the boat. In some landing sites, fishers from different boats took part in the mapping process, allowing for cross-validation amongst fishers and across boats. All research received approval from the University of British Columbia's Human Behavioural Research Ethics Board (H12-02731 and H15-00160).

During interviews, fishers were asked to draw regions where they caught and did not catch seahorses on nautical charts. We sometimes guided mapping efforts by pointing out features on the map (e.g., islands). In interviews where fishers could not draw because of time constraints or other reasons, I used their narrated details to draw polygons for seahorse presence or absence (Zhang and Vincent, 2017). We asked fishers to identify locations in which they (a) fished and caught seahorses (i.e., presences) and (b) fished but did not catch seahorses (i.e., absences). We also asked about the depth, distance from shore and habitat in which they caught seahorses, and the fishing gear, fishing effort and fishing seasons. I collected all datasets in the WGS 1984 datum, and georeferenced and analyzed using ArcGIS pro.

5.2.2.2 Published literature

I extracted available data about seahorse distributions and fishing effort in the Ramanathapuram District from published literature (Table 5.1). If specific localities were not documented, I included the entire study/sampling area described in the paper as part of the species' range. All species maps from the validated records in literature were digitized using ArcGIS Pro.

I attempted to obtain seahorse sightings (SS) from online biogeographic databases including the Global Biodiversity Information Faculty (GBIF, www.gbif.org), Oceanic Biodiversity Information System (OBIS, www.iobis.org), FishNet2 (www.fishnet2.net), FishBase (www.fishbase.org) and iSeahorse (www.iseahorse.org). However, the only records of seahorse sighting within the coordinates of my study sites were located on land and hence could not be used.

5.2.2.3 Habitat Data

I only considered documented seahorse habitats, including corals, dead corals and seagrass (Murugan et al., 2008; Vinod et al., 2018). I extracted seagrass occurrence data originally published by Geevarghese et al. (2017) that used Landsat 8 OLI imagery to map seagrass distribution in the Palk Bay region (Geevarghese et al., 2017). For the Gulf of Mannar Marine National Park (GoMNP), I used habitat data (coral and dead coral with algae, dead corals and seagrass beds) from Mathews et al. (2010), which used Line Intercept Transect methods to map the habitats. My habitat data has a high degree of uncertainty associated with it but is the best available at this time. I had to extract seagrass habitat data for Palk Bay from a low-resolution image (Fig 3. in Geevarghese et al., 2017), and as a result, my estimate of seagrass coverage was greater than that reported by the authors. Additionally, the resolution of data for the Gulf of Mannar was limited and combined live coral cover with dead coral covered with algae and seagrass habitats with sand. I was unable to include data for other habitats where fishers reported seahorse presence, such as sponges, sandy and rocky habitats, because I could not source spatial data at the appropriate scale.

5.2.2.4 Management measures

I considered three existing management measures: (i) The GoMNP – a no-take marine protected area of 560 km^2 site, forming the core of the Gulf of Mannar Biosphere Reserve; (ii) trawl-exclusion zones – a three nautical mile limit from the coastline where trawlers are not allowed to operate, but traditional fishing gears including drag-netters may; and (iii) seasonal closures – a 60-day period from April to June, when a majority of the important fish species are believed to spawn , during which trawlers and drag-netters in the District are not allowed to operate. I mapped the no-take protected area and no-trawl zones in ArcGIS Pro.

5.2.3 Data analysis

5.2.3.1 Seahorse locations based on fisher reports

To create maps of seahorse distribution (occurrence), I used fisher reports on the presence or absence of seahorses from my interviews and published literature. I created presence/absence maps by overlaying individual fisher's maps showing where they caught (presence) or did not catch (absence) seahorses. I then calculated (i) the number of fishers reporting presence/absence of seahorses in a given location and (ii) the proportion of fishers reporting presence/absence of seahorses of the total number of fishers reporting to fish in either in Palk Bay or Gulf of Mannar. I used these two metrics to understand the extent of spatial agreement on seahorse presence among fishers. To maintain data quality, I only kept areas in the maps that included at least two observations of fishers reporting presences or absences (as per Zhang and Vincent, 2017).

I identified seahorse priority habitats by overlaying seahorse presence maps, generated from fisher reports, over my layers of natural/biogenic habitats to estimate the proportion of seahorse presence in coral and seagrass bed habitats compared to these habitats' overall extent. My estimates were done for each distinct habitat type, and also for the Palk Bay and Gulf of Mannar region separately.

5.2.3.2 Threats to seahorses from fishing

To estimate the fishing pressures that seahorses faced, I mapped fishing effort for the fishing grounds in the district as measured by the duration that fishing gear was actively employed. I obtained information on the mean number of hauls in a fishing day and each haul's duration from my interviews. I then overlaid the effort data obtained from the individual fishers to obtain the cumulative number of hours spent fishing in a day. For interviews where information on either the number or duration of hauls was missing, I filled the gap using either published literature (Table 5.1) or by using information from fishers using similar gear from the same location. However, in the case of the highly variable and diverse gill net operations, if I could not obtain information from other fisher interviews in the same location, I ignored the data altogether. I acknowledge limitations of using this method (e.g., fishing-gear bias, sampling effort limitation), particularly given the variety of gears and vessels used in this region.

5.2.3.3 Existing spatial management

I executed a simple geospatial analysis to calculate the overlap (percent coverage) of existing management measures (no-take MPA and trawl exclusion zone) with my seahorse presence and habitat maps.

5.2.3.4 Analyzing the implementation of existing management

To address this dimension of my framework, I analyzed management violations in two ways: (1) total area that trawlers reported seahorse catches within the trawl exclusion zone; (2) total areas that fishers reported catches from the no-take MPA. For trawlers, I had to analyze the protection offered by the 3 nm trawl-exclusion zone and MPA together because of overlaps in the boundaries (overlap of ~158 km^2 or 9% of the total area protected). To understand the effect of the closed season, I compared the overall area covered by traditional fishers (without drag-netters) throughout the year with the overall area that trawlers and drag-netters reported operating in. I acknowledge limitations in my comparisons as I only compared the overall area fished by the different gears over the year and did not compare the effort among the gear types.

5.3 Results

My proposed approach to assessing sustainability of exploitation depends on assessing four sets of data, that I now examine and bring them together.

Overall, I observed both the greatest number of fishers reporting seahorse presences in their catches, and the greatest fishing effort, in the southern Palk Bay. This is a region rich in seagrass habitats, an area that has a closed season for fishing, and a 3 nm trawl exclusion zone, although where drag-netters may still operate. The entire district of Ramanathapuram in principle is protected by a 3nm trawl exclusion zone while also having one marine protected area. Trawls and dragnets threatened both the species and the seahorse habitats, with fishing operations on large tracts (~90%) of critical seahorse habitats in this study. Throughout the district, fishers reported respecting the closed season everywhere but continued to catch seahorses in the trawl exclusion zone outside that closed period. Finally, my analysis indicates large violations of protected areas, and continued catches of seahorses from these regions.

5.3.1 Seahorse locations based on fisher reports

Overall, my analysis showed that seahorses were caught in 68% of India's EEZ considered for this study (7746/11357 km2), and at least 88% of areas (7746/8807 km^2) in which respondents stated they fished within the EEZ.

My interviews with fishers along the Ramanathapuram Coast indicated that more fishers caught seahorses in the southern Palk Bay region, extending from Devipattinam to Thondi (Fig. 5.4). In the Gulf of Mannar, a greater number of fishers reported catching seahorses closer to the shore, near the southern portion of the Rameswaram Peninsula and along the northern section of the Gulf of Mannar (Fig. 5.4). The distribution pattern of seahorse presence was similar whether maps were generated using the number of fishers reporting seahorse presence in their catches in that location (Fig. 5.4) or using fisher presence data scaled by the number of fishers who reported fishing in either Palk Bay or Gulf of Mannar (Appendix D.2).

Overall, only nine fishers reported locations where they did not catch seahorses, with never more than three fishers per location (Appendix D.3). These locations occurred across 11 fishing areas compared with the 196 fishing grounds where fishers did catch seahorses. Locations with absences must be treated with caution, and not as true absences, given that in some of these areas many more fishers reported presences (Fig 5.4 and Appendix D.3), which could potentially be attributed to the fishing gear being operated (e.g., passive nets like gill nets may be less likely to catch seahorses).

When I separated fishers by gear type (trawlers vs traditional), I found that fishers still reported catching the greatest percentage of seahorses in the Palk Bay region (Appendix D.4 and Appendix D.5). The greatest percentage of trawl fishers (~43%) and traditional fishers (~26%) reported presences of seahorses along the Devipattinam coast and the northern part of the Gulf of Mannar in the case of trawl fishers. Distinguishing among gear types, it appears that the absence of drag-netters and the smaller areas fished by other traditional fishers in the Gulf of Mannar region drove the observed patterns.

I found that fishers reported catching seahorses in ~ 90% (483/536 km^2) of seagrass and coral habitats in the Palk Bay and Gulf of Mannar regions (Fig. 5.5). Fishers reported catching seahorses in 90% of seagrass bed (316/350 km^2) and 92% of seagrass beds with sand (155/169 km2) in Palk Bay and Gulf of Mannar, respectively (Fig. 5.5). However, fishers reported catching seahorses in only 70% (14/20 km^2) of the area covered by coral (alive, dead, or covered with algae). This difference may be because corals were only found only in the Gulf of Mannar region (Fig. 5.5), where fewer people reported fishing (n=49).

5.3.2 Threats to seahorses from fishing

I found that the fishing pressure (measured by the cumulative hours spent actively fishing per day across all fishers) was greatest in the entire Palk Bay region, in shallow waters and near the coastline (Fig. 5.6). Within this region, the greatest effort (197 combined active fishing hours/day) was reported off the coast of Devipattinam, primarily from non-selective drag-netters and trawlers. I found a similar trend in effort when I removed traditional gear (other than drag-netters) from this analysis (Appendix D.6), probably because I had less information on these gears than active non-selective fishing gears. Altogether, fishers reported operating in more than 94% of seagrass and coral reef habitats in Palk Bay and Gulf of Mannar (505/539 km^2).

5.3.2 Existing spatial management

I found that around 1727 km^2 of my study area (15% of the total 11357 km^2 of ocean within

India's EEZ considered for this study) was covered by either the no-take MPA (404 km^2 or 3.5% of ocean within India's EEZ considered for this study) or the trawl-exclusion zone (1481 km^2 or 13% of study area falling with India's EEZ), amounting to ~ 81% of seagrass and coral habitats (435/539 km^2) (Fig. 5.7). However, only ~ 13% of these habitats lay within no-take areas and were, in theory, completely protected from fishing pressure (72/539 km^2).

Overlaying seahorse presence maps with MPA boundaries and the 3nm trawl exclusion zone revealed that fishers reported catching seahorse in 85% (around 1476/1727 km^2) of the combined protected area (Fig. 5.7). I further found that fishers reported catching seahorse in 92% of the area covered by no-take MPAs (370/504 km^2).

5.3.2 Analyzing the implementation of existing management

When I considered fishing pressure from trawls, I found that it was greatest in the Palk Bay region off the coast of Devipattinam, including in the large seagrass beds in this region and within the trawl exclusion zone (Fig. 5.8).

Overall, I found that trawl fishers reported fishing in about ~90% of the protected areas (1548/1727 km^2) and reported seahorse presence in their catch in about 90% of the area they fished (~1388/1548 km^2) in these supposedly protected areas.

My findings indicate that trawl fishers operated within on almost all the seagrass and coral habitat that was theoretically protected (91%, 394/435 km^2; see above). When I assessed the violations separately, I discovered that trawlers reported fishing in 98% of the MPA (396/404 km^2) and reported catching seahorses in 91% of the MPAs (366/404 km^2). They further reported operating in 88% of the trawl exclusion zone (1303/1481 km^2) and reported catching seahorses in 78% of this area (1149/1481 km^2). In contrast, traditional fishers reported operating in only about 44% and seahorse presence in 39% of the no-take MPA (178 and 158/404 km^2, respectively); that said, I interviewed fewer traditional fishers (n =19) in the Gulf of Mannar region.

Overall, I found that ~18% of areas with reported seahorse catches within India's EEZ were violations of existing management measures (1392/7746 km^2). Seahorse conservation was further undermined by illegal, unregulated, and unreported (IUU) fishing outside India's EEZ. About

16% of the total area where respondents reported fishing lay within Sri Lankan waters (~1627/10434 km^2). Such Sri Lankan waters comprised about 11% of the entire area where fishers reported catching seahorses (~ 946/8692 km^2).

The only fisheries management measure that may have been effective for seahorse conservation was the 60-day fishing ban on the use of trawl and drag nets, both significant pressures, which is highly enforced. During the ban, the remaining fishers use more selective and/or less damaging methods such as passive fishing gear (gillnets), targeted active fishing methods (diving) or non-selective gear more constrained in its extent of operation (shore-seines). Such traditional fishers also reported operating in only 19% of the area where trawl and drag-netters fished within India's waters (1544/7936 km^2) through the year. As such, the temporal closure should effectively eliminate a great deal of the fishing pressure where seahorses live.

5.4 Discussion

I here identify a simple four-step mapping process that produces a general sense of the well- being of wild populations – as is needed for making NDFs – even while being imprecise in details. Such a process is generally helpful for all taxa but is of value when dealing with ETP marine species in developing countries. Overlaying spatial data of animal or plant locations with threats and existing management addresses the core question of sustainable exploitation – and most certainly the core question of an NDF – as to whether management is sufficient to avoid detrimental effects on wild populations (Foster & Vincent 2016). Such a pragmatic approach provides a first and useful approximation of where – and indeed how – managers might improve the status of wild populations. In the case of seahorses, I found notable levels of concern, with fisheries clearly operating within areas that had banned the gear. My intention is for managers and policy makers to use such broad analyses as starting points, and then to refine layers of data, reduce threats and enhance implementation. Such an approach, when married to stakeholder engagement in an explicitly experimental framework, constitutes adaptive management, a paradigm that is increasingly advocated in both conservation and resource exploitation. In conservation, as in so much else, the perfect is the enemy of the good.

In the case of seahorses, my process was clear in its general revelations even while it was imprecise in its detail and identified much cause for concern about wild populations. I found that fishers reported seahorse presence more frequently close to the shore and in shallower waters, commensurate with where their critical seahorse habitats are found. Given that my observations were based on fisher catch, fishers are clearly operating extensively in these areas. My findings suggested that seahorses faced immense pressure from active, non-selective gear such as drag-netters and trawlers. In addition to the threats to the species because of these fishing gears, I found that seahorse habitats also faced great stress, with destructive fishing operations on large tracts (~90%) of critical seahorse habitats such as corals (dead and live) and seagrasses.

Once I consider all four steps of my analysis together, it not surprising that fishers reported during interviews that seahorse populations in the Ramanathapuram region (and surrounding districts) had declined; they made this deduction from assessing their seahorses catches over the 20 years since the ban was implemented (Vaidyanathan et al., 2021; Vinod et al., 2018). I calculated that some form of protection had been declared for about 15% of the districts' EEZ, with all fishing banned (in theory) in less than 5% of the entire area. However, I found large violations of existing spatial measures despite such theoretical protection for seahorses and their habitats. Indeed, about 18% of the area where fishers reported catching seahorses was ostensibly "protected". Even had all management measures been fully enforced, there would have been notable concerns in Palk Bay, where the only year-round spatial management measure banned trawls but not the drag-netters. Though deployed by small-scale fishers, drag-nets can be destructive because their target of juvenile shrimp (Sampson Manickam et al., 1989) leads them to operate directly over seagrass beds and to catch seahorses and numerous other non-target species incidentally.

My conservation assessment identified the serious need to better implement existing management measures as well as the need for further management action. Authorities in India need to enforce and enhance existing management measures such as preventing the operation of trawls within the trawl-exclusion zone, providing official demarcation of the MPA boundary, and actively preventing fishing within the MPA. Such implementation measures would alleviate some of the pressure faced not just by seahorses and numerous other species obtained as bycatch, but also on their habitats.

Given that the ban on seahorse exploitation was being ignored by most fishers, India needs to rethink its approach to protecting these animals. My findings add support to the growing arguments that constraining non-selective fishing gear in terms of effort, extent, and areas of operation – from both the traditional and mechanized sector – is key to conservation efforts in the region (Vaidyanathan et al., 2021; Vinod et al., 2018). It is vital to protect the vast seagrass beds of the Palk Bay region, particularly given that protection of at least 20% has been suggested as a conservation target for marine habitats to reduce the risk of over-exploitation and safeguard against stochastic events (Beck and Odaya, 2001). The protection of these seagrass beds is also a recommendation also made to support the conservation of other charismatic species such as the dugong which are found there in great numbers (Anand, 2015). One encouraging step for seahorse conservation efforts in this region lies in the recent formation of an exclusive marine agency in this district, armed with dedicated staff, to enforce regulations and prevent illegal fishing, including the use of destructive fishing methods and banned fishing nets (Tamil Nadu Fisheries Policy Note, 2020, accessed online at https://cms.tn.gov.in/sites/default/files/documents/fisheries_e_pn_2020_21.pdf).

As well as highlighting the need for more management action, my approach to collecting the data had benefits in generating dialogue that is needed to improve such management change. Deployment of local knowledge has been strongly advocated, especially in the case of co-management (Smith, 1995; Grafton & Silva-Echenique, 1997), with the contribution of data by fishers helping increase the legitimacy of management regimes in the long-run (Neis et al., 1999). Through my interviews, I initiated the conversation with fishers about their thoughts on the ban, what worked, what did not, and ways forward for seahorse conservation. Communities often possess a wealth of knowledge about management structures that may be effective within their belief systems, on practical approaches on improving compliance, and about fishing methods that may work well (effective/conservative) in a local context (Charles, 2001). During my interviews, I found that fishers largely agreed that non-selective fishing gears were particularly damaging and probably caused the decline in seahorse fisheries. They also noted that implementation of existing rules such as enforcing the trawl exclusion zone was essential for conservation. Other studies from the region have also reported that fishers advocated the use of gear limitation (reducing bottom-trawl numbers), no-take zones and enforcing prohibitions on banned gear were key to seahorse conservation (Vinod et al., 2018). Management authorities will do well to focus on this commonality of views about necessary steps for marine management and conservation, and work with stakeholders to create the conditions for collective action on such measures.

My pragmatic mapping approach to conservation action could be used by a variety of resource managers to measure progress, including when trying to make NDFs for CITES. My simplified approach would be particularly useful for countries in the developing world, which are often daunted by the process of making NDFs because of the limited understanding of CITES, anxiety about capacity and resources, and lack of baseline data (Abensperg-Traun et al., 2011; De Angelis 2012). While spatial approaches have historically been neglected in work on NDFs (Rosser, 2008; Rosser and Haywood, 2002; Smith et al., 2011; Thorson & Wold, 2010), their applicability in making NDFs is now being recognised (Aylesworth et al., 2020). Spatial data may be derived from local knowledge (Thornton & Scheer, 2012), can be generated relatively quickly and cheaply (Aylesworth et al., 2017), and is central to many management measures.

My "good-enough" approach may be broadly useful for countries trading in seahorses that have decided to declare bans on export to conserve their seahorse populations, rather than creating the NDFs that depend on knowing the species and its status (Foster et al., 2019; Vincent & Foster, 2017). In particular, many key exporting countries took such decisions to ban exports as a means of avoiding a Review of Significant Trade (RST) but are now confronting significant illegal trade (Foster et al., 2019; Foster and Vincent, in review). Given that Parties often simply declare a ban without any enforcement and pay little attention to the ensuing black-market trade of the banned organism, perhaps CITES may do well to insist that Parties make NDFs even for species protected by bans. This means that Parties would still be held accountable and need to generate data on the state of the species, without simply being able to default to the claim of a ban. My pragmatic approach can be used to assess and navigate the challenges of poorly implemented bans and untrammeled destructive fishing that countries do not acknowledge or are unable to tackle. While there has sometimes been some resistance to using local knowledge because of the disorganized nature of information obtained in this way, I found that systematic local knowledge visualized in the form of maps, offers an effective approach to making NDFs and managing fisheries (as per Anuchiracheeva et al., 2003).

Should India need to make an NDF for its seahorses, it could follow the four-step process that I employ here, for the most critical region in the country. Although I covered only one district of

Tamil Nadu, and only for a single pressure (fishing), this region is undoubtedly the most important in terms of reported catches and trade (Perry et al., 2020; Salin et al., 2005; Vaidyanathan et al., 2021; Vinod et al., 2018), and incidental catch of seahorses the biggest threat to their populations (Perry et al., 2020; Vaidyanathan et al., 2021; Vinod et al., 2018;). Extending my approach to the whole country – or at least most of it – would allow India to make NDFs. In contrast, any current attempts by India to make NDFs – with the current ban on fishing and export in place - would probably falter considering the huge illegal capture and lack of other management measures in the key region of Tamil Nadu.

Any move by India towards making NDFs will have to be considered carefully. The first step might be accepting the capture of seahorses and legalize the catch. Removing a ban on catch would result in the decriminalization of fishers, which will allow them to co-operate in data collection and knowledge generation. Authorities can then access and use both stakeholder knowledge and conventional scientific sources to map distribution data for seahorses, distribution data for pressures and threats, and distribution data for conservation and management measures. It further means overlaying all three sets of spatial data to assess gaps and discrepancies that can guide both the NDF assessment and conservation action to develop legal and sustainable exports. Even while removing the fishing ban, the export ban should probably remain for a time, to discourage any acceleration of the catch, whether in Tamil Nadu or the rest of the country. Eventually, of course, the goal would be capacity for India to make positive NDFs and reopen exports in compliance with CITES. Such a scenario will certainly depend on heavy (implemented) constraints on bottom trawls, particularly given their overcapacity in the Palk Bay region (Scholtens, 2015), and drag nets. In the case of dragnets, the fishing villages are cohesive enough that community based MPAs may be a possible means of reconciling fisheries with conservation.

In proposing this qualitative mapping approach to reconciling conservation and resource management, I follow a practical path that has also been taken, although with some controversy, for establishment of MPAs and terrestrial reserves (e.g., Hansen et al., 2011; Grantham et al., 2009), one where ad hoc or pragmatic action is more imperative than systematic or ideal analyses. The latter generally require significant time, technical expertise, and resources without necessarily offering better outcomes. Opportunistic approaches to reserve selection have found to perform better than random chance (Hansen et al., 2011), while also providing a first conservation action, and a baseline on which a systematic approach may be built (Hansen at el., 2011). Similar findings have been made with regards to protecting critical habitats required for species recovery, where using the best available information even with uncertainty, was preferred over more data, which did not necessarily translate to more successful results (Martin et al., 2017). While many studies often call for more data (Hamann et al., 2010; Young & Van Aarde, 2011), delaying action in the eternal quest for perfect advice may be more damning (Johannes, 1998), particularly when the threat is ongoing (Grantham et al., 2009).

Given the need to accelerate conservation action for the ocean, even while still trying to develop a strong understanding of situations, a pragmatic stakeholder-oriented approach has real value for managing fisheries and other exploitation for long-term sustainability. Using spatial data generated from local fisher knowledge I was able to rapidly evaluate the distribution and key threats, and therefore infer the effectiveness of existing management measures, despite large uncertainties and imperfect data (Aylesworth et al., 2020; Smith et al, 2011). I find that in data-limited situations, rather than feeling stalled by inadequate information, countries would do well to make decisions based on existing and imperfect data (Johannes, 1998) while building on such knowledge for adaptive management (Aylesworth et al., 2020; Meffe & Viederman, 1995; Smith et al., 2011). In fact, adaptive management is increasingly recommended as the best way forward for reconciling conservation with resource management, in a whole host of scenarios (Smith et al., 2011).

Table 5.1 Peer reviewed literature used in my study to map seahorse presence in the Ramanathapuram District.

Location	Objectives	Study
Multiple locations in the Palk Bay region	First estimate of extent of seahorse fisheries in Palk Bay	Marichamy et al., 1993
Palk Bay region	First look at seahorse trade after the 2001 exploitation ban	Lipton and Thangaraj, 2002
Thondi, Palk Bay	Estimates of the volumes of seahorses exported until the imposition of an exploitation ban	Salin and Yohanan, 2005
Mullimunai, Palk Bay	First reported occurrence of *H. mohnikei* from Palk Bay from bycatch	Thangaraj and Lipton, 2007
Multiple locations in both the Palk Bay and Gulf of Mannar region	Identification of seahorses and pipefishes, and estimation of their catches in fishing gear	Murugan et al., 2008
Three locations in the Gulf of Mannar	Estimation of seahorse catches from the Gulf of Mannar	Murugan et al., 2011
Multiple locations from Coromandel coast to Kanyakumari (Both Palk Bay and Gulf of Mannar)	Primarily for genetics from seahorse samples obtained from fishing boats	Lipton and Thangaraj, 2013
Multiple locations in the Palk Bay and Gulf of Mannar region	Estimation of seahorse catches in the Palk Bay and Gulf of Mannar by non-selective fishing gear, and the impact of the seahorse fishing ban on fisher livelihoods	Vinod et al., 2018

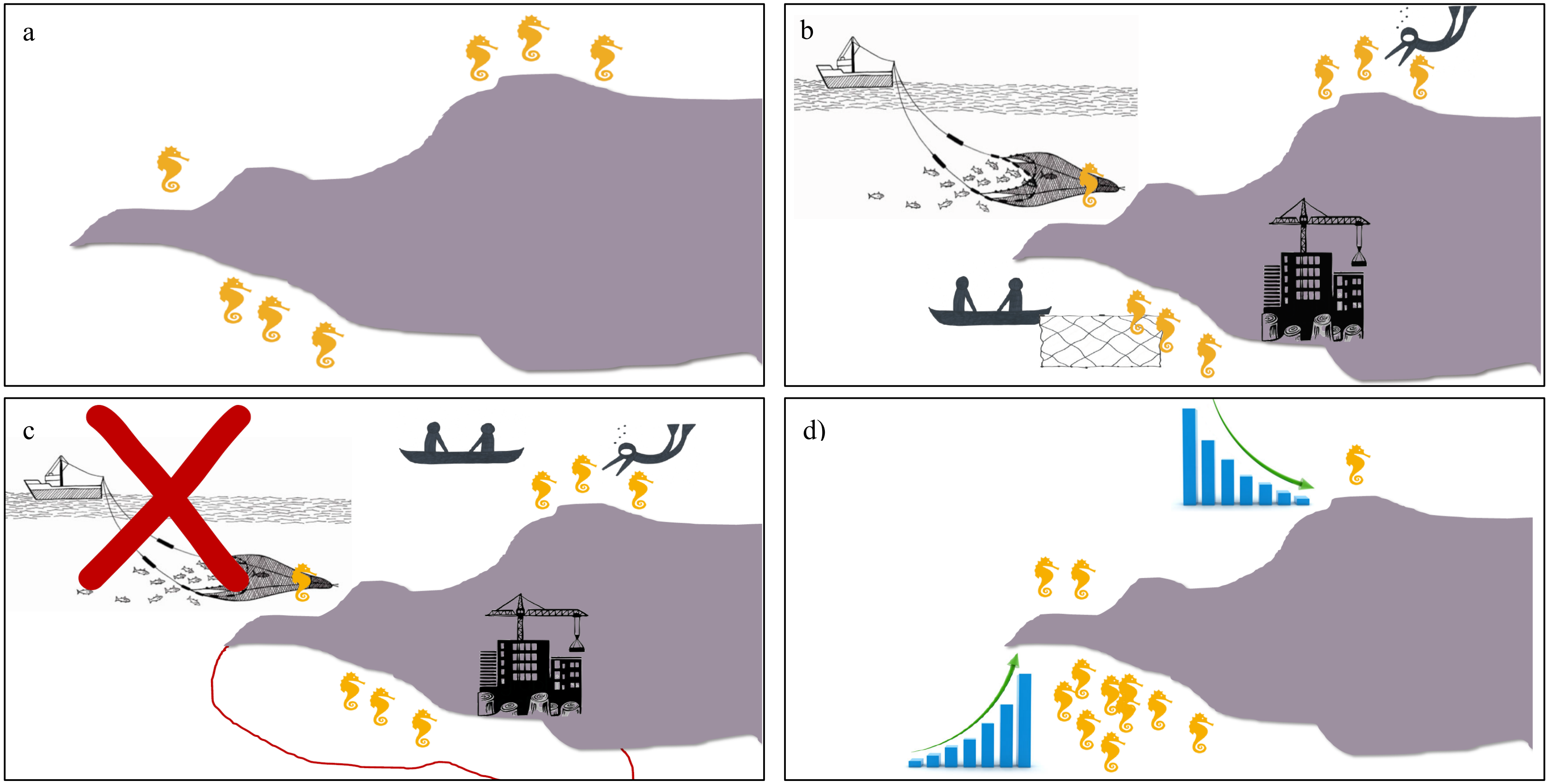

Figure 5.1 Pictorial depiction of the core questions of a simplified NDF. From left to right: a) where are the species found (distribution)?; b) what threats do the species face where they are (e.g. non selective fishing throughout the region)?; c) what are the management measures in place relevant to the threat (e.g. fisheries regulations and/or an MPA)?; and d) are the management measures working (e.g. is there evidence of increased or decreased abundance)? (Adapted from R. Bestbier/Project Seahorse).

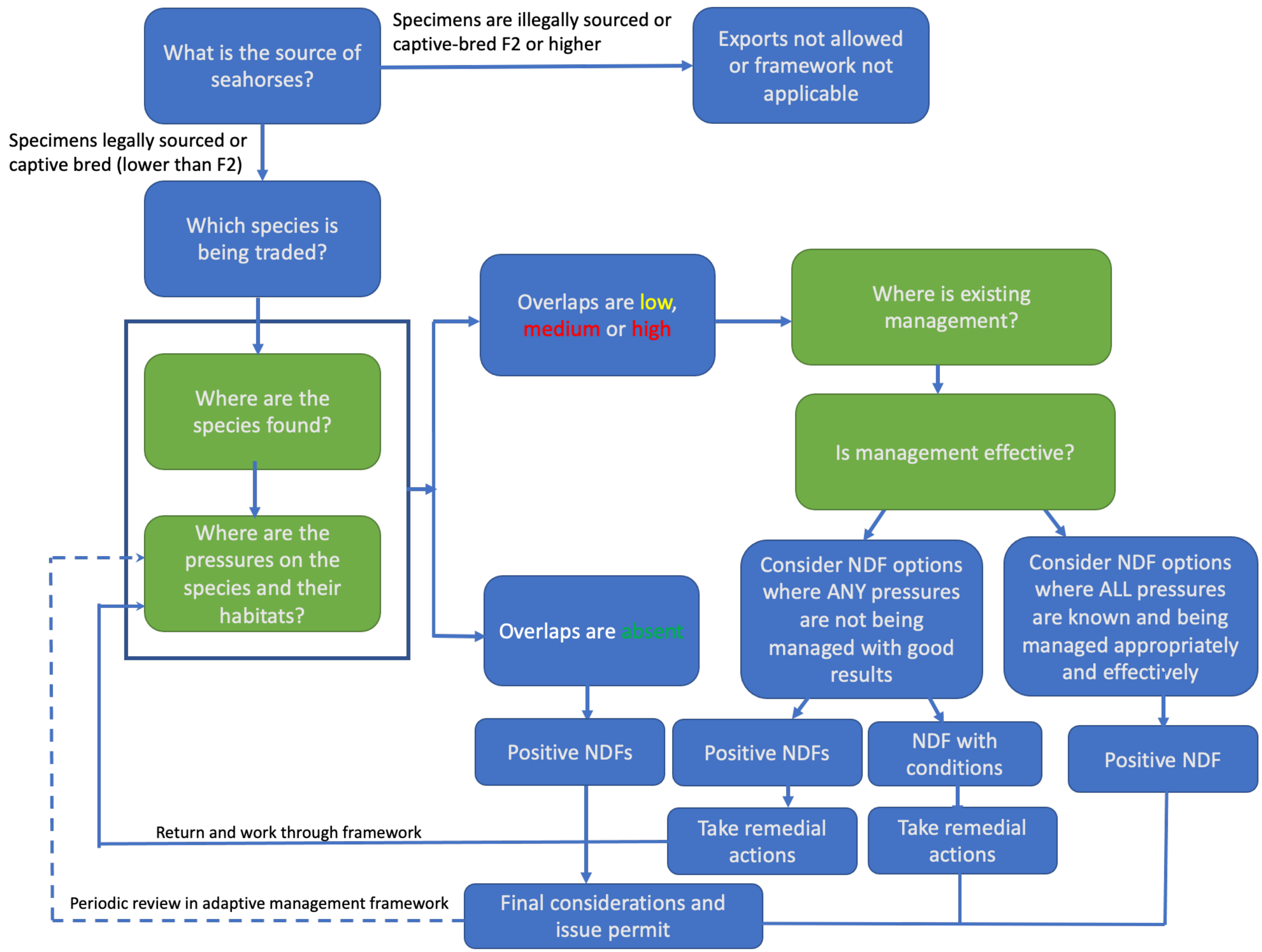

Figure 5.2 Flowchart describing the simplified Non-Detriment Finding framework.

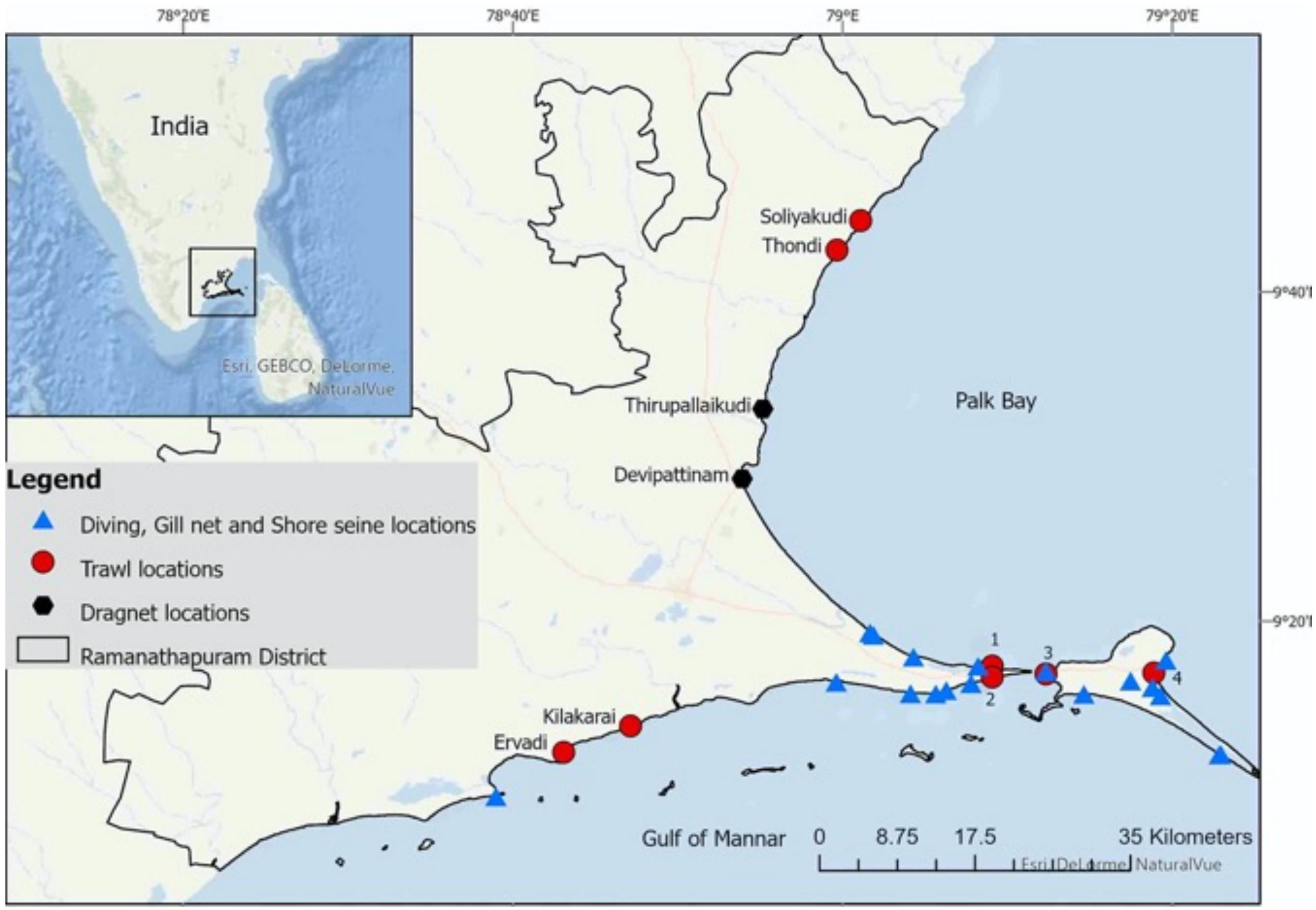

Figure 5.3 Location of seahorse interviews carried out between 2015-2017 at coastal villages and fish landing centres of the Ramanathapuram District. Major trawl landing centres and drag net landing sites are labeled. Trawl centres along the Rameswaram Peninsula have been numbered (from west to east): 1. Mandapam North; 2. Mandapam South; 3. Pamban; 4. Rameswaram Fishing Harbour. Note that although Thondi is a major drag net centre, the few drag-netters interviewed in the region did not provide information about locations in which they caught seahorses.

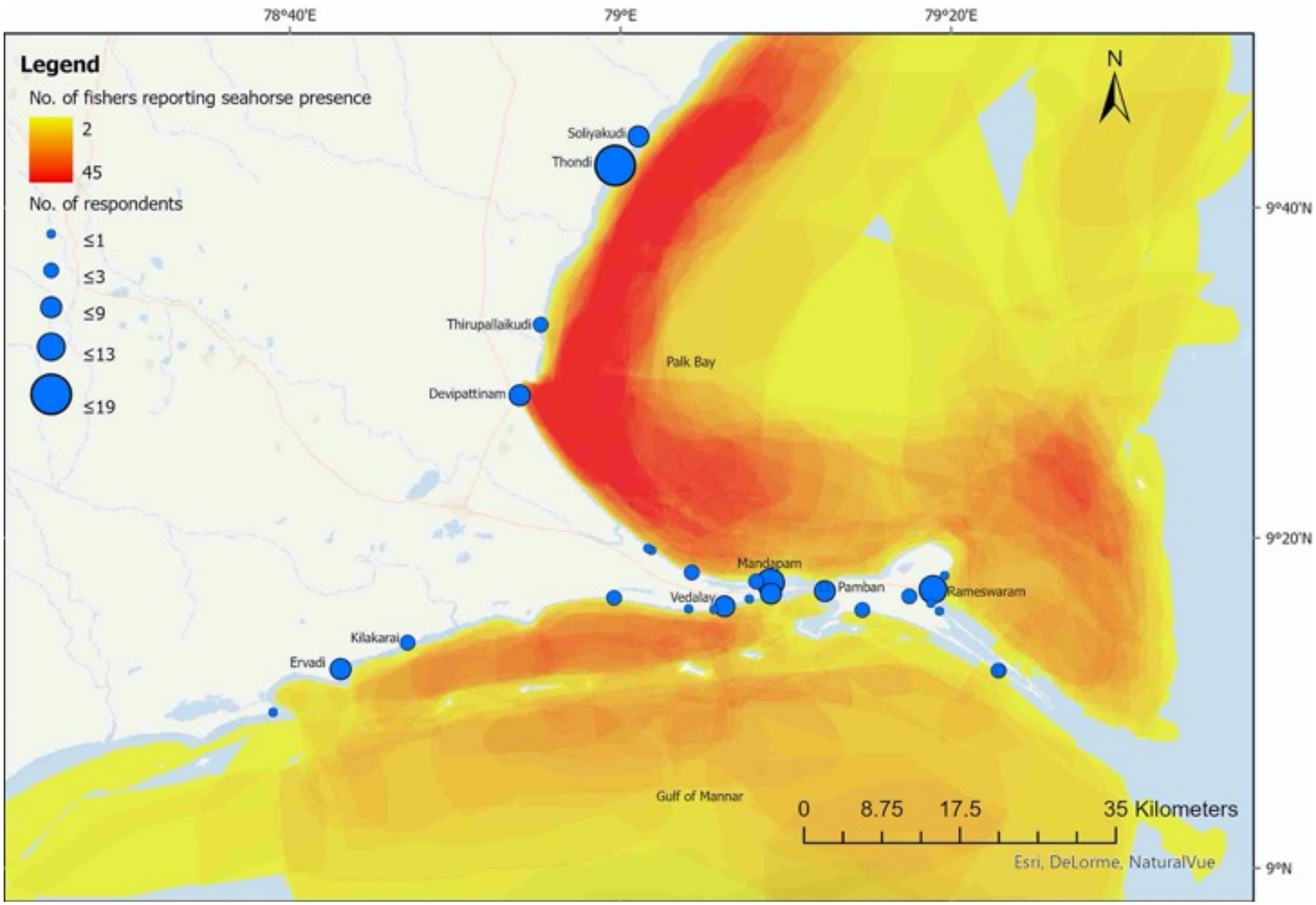

Figure 5.4 Number of fishers reporting catching seahorses across the region. The greatest number of fishers reported catching seahorses in the Palk Bay (n=45). In the Gulf of Mannar, fishers reported catching most seahorses along the coast and towards the seaward side of the islands of the Gulf of Mannar Marine National ParkThe blue dots represent the location of fisher interviews, with the size representing the number of fishers interviewed, varying from 1 to 19.

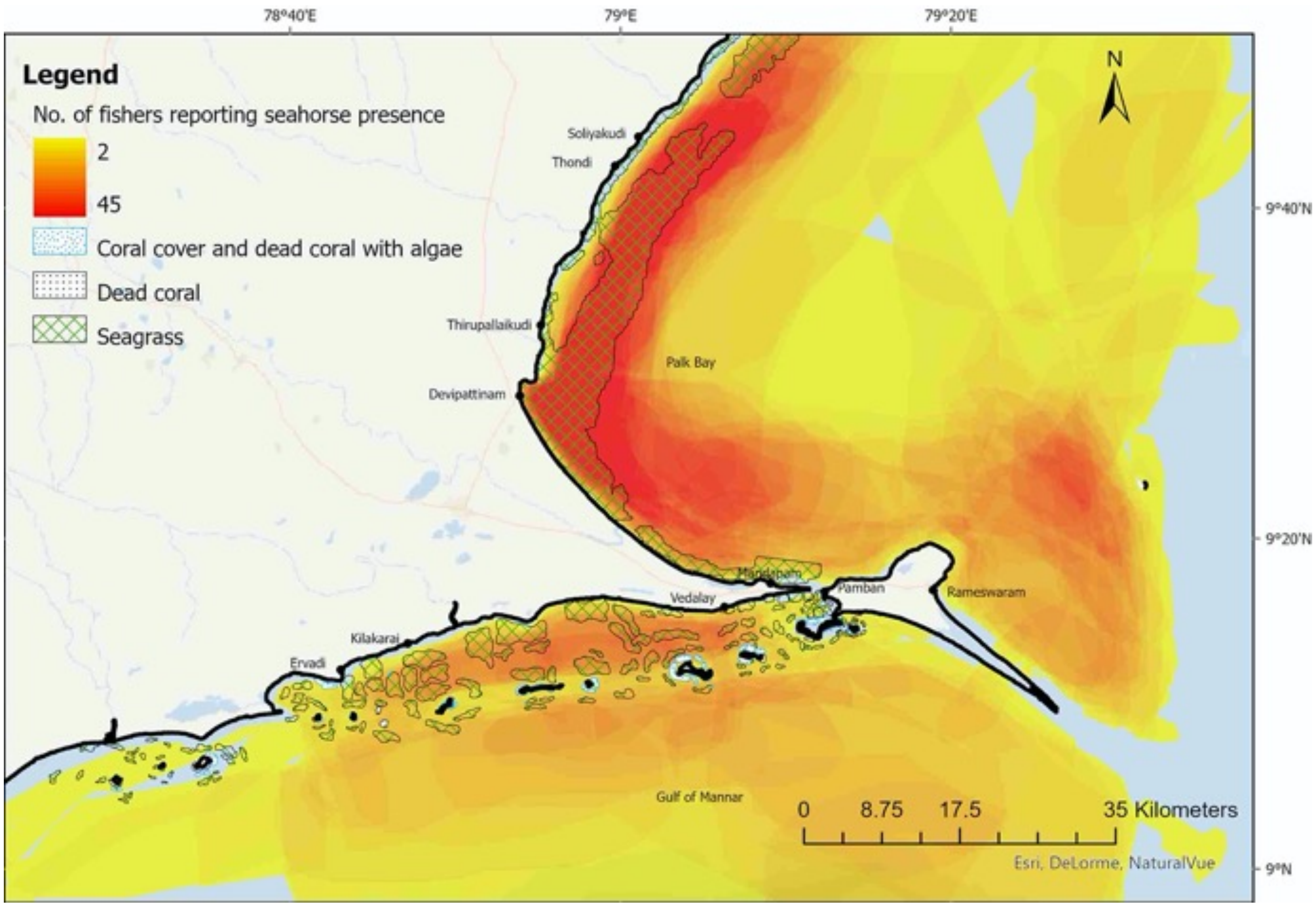

Figure 5.5 Map showing available habitat data along the Palk Bay and Gulf of Mannar regions overlaid with maps of seahorse presence. Seagrass data for the Palk Bay region was extracted from Geeverghese et al. (2017) and for the Gulf of Mannar region from Mathews et al. (2010).

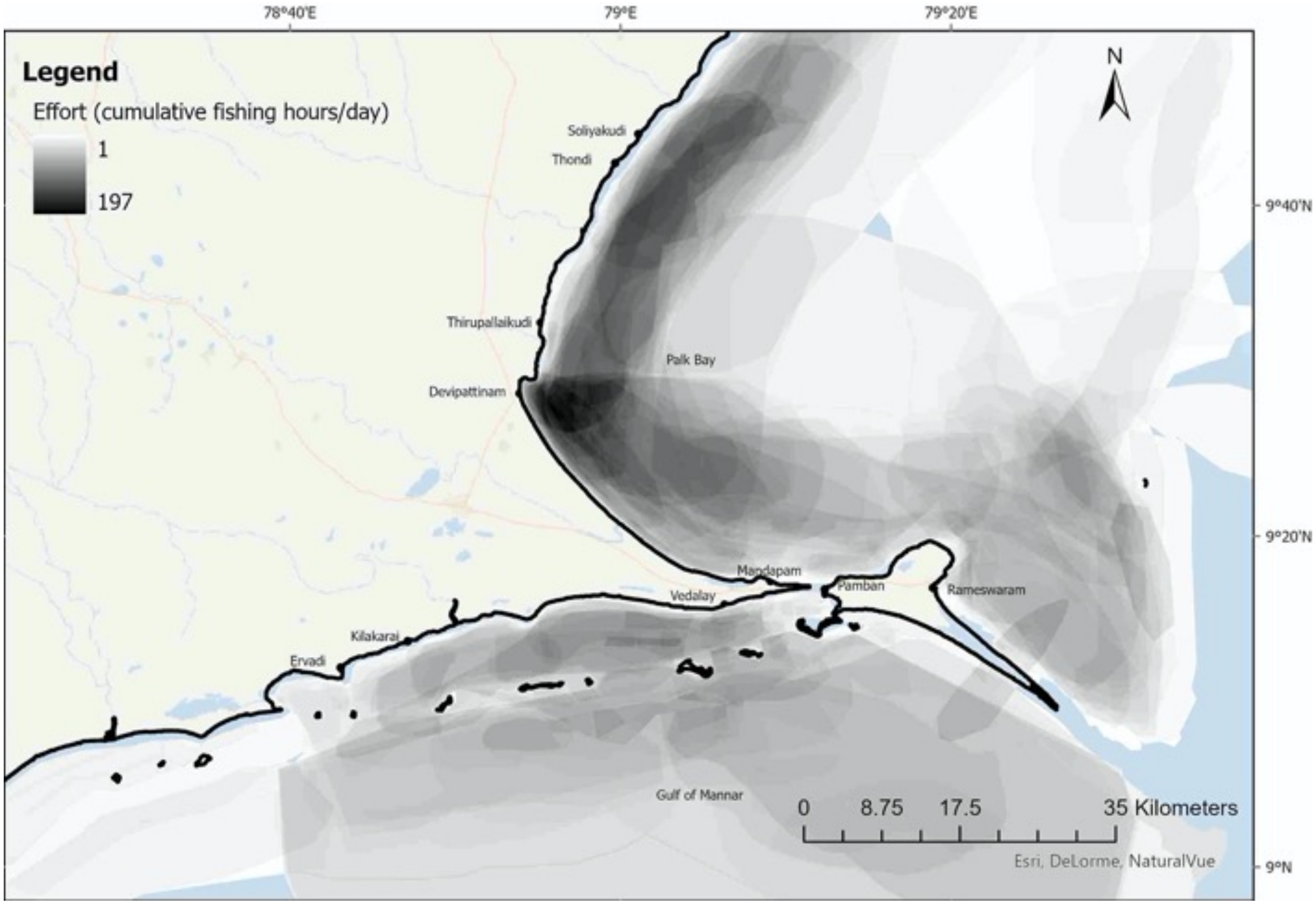

Figure 5.6 Pressures faced by seahorses from fishing in the the Palk Bay and Gulf of Mannar, as measured by the collective duration of time that fishers of all gear types actively deployed their nets (hours/day). Fishing pressure was greatest closest to the shore along the entire extent of the Palk Bay region.

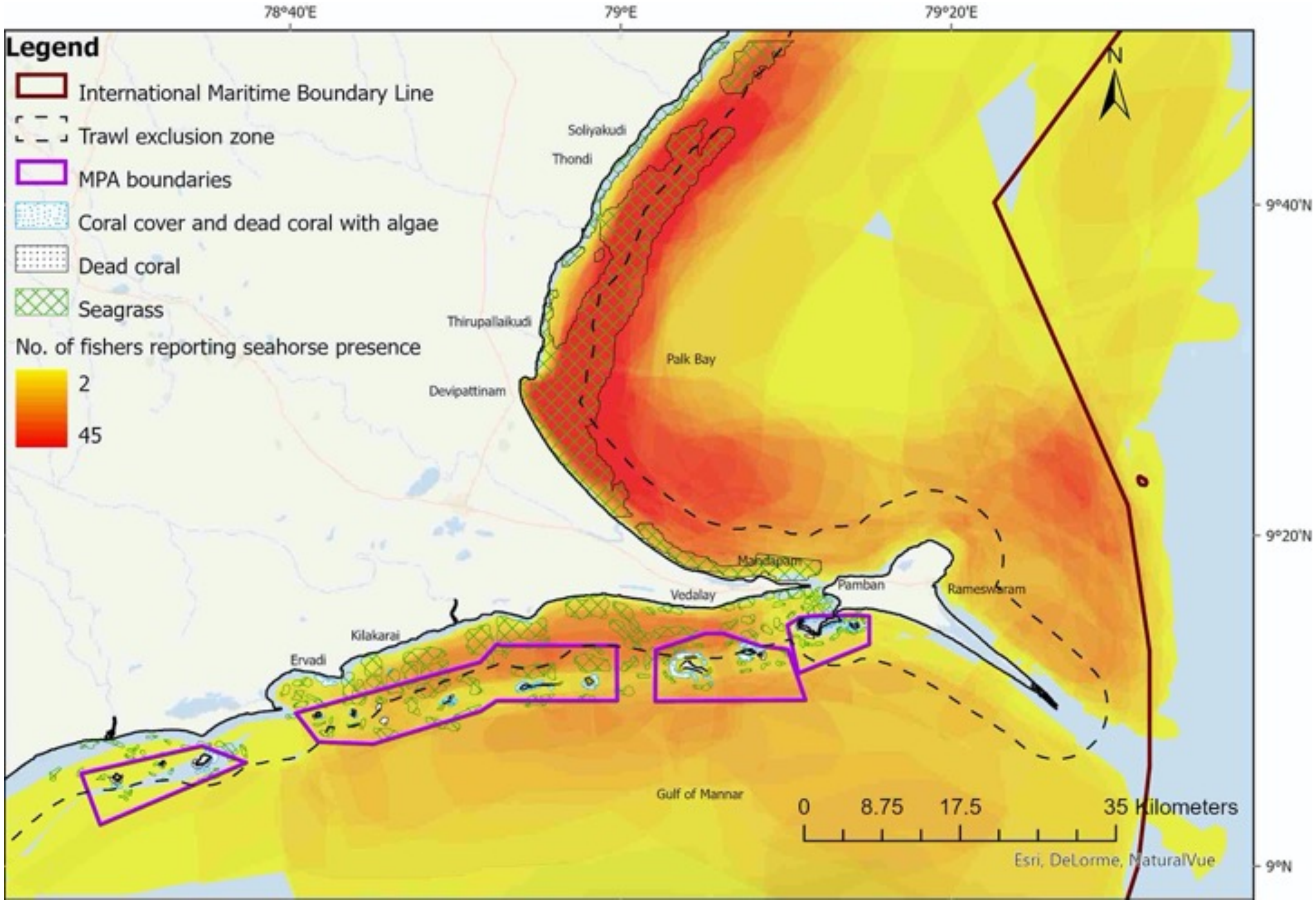

Figure 5.7 Overlay of management measures (trawl exclusion zone within 3nautical miles and MPA boundaries) with seahorse presence maps in the Palk Bay and Gulf of Mannar. For temporal closures, during the 60-day ban, both drag-netters and trawlers are prohibited from operating for an extent ranging from the coastline to the International Maritime Boundary Line.

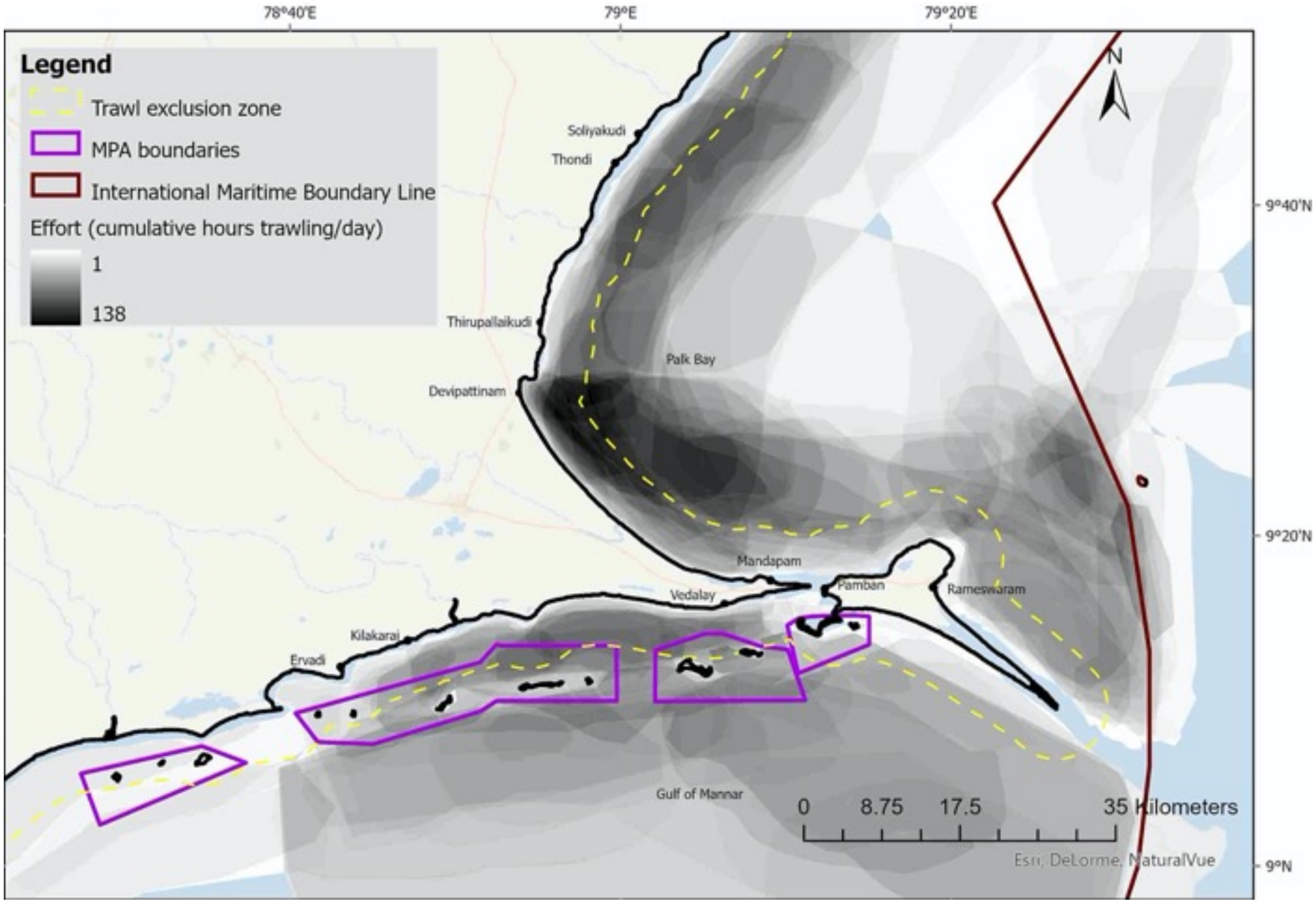

Figure 5.8 Pressures faced by seahorses only from trawlers, as measured by collective duration that fishers employed their nets while fishing (cumulative fishing hours/day). Fishing pressure was found to be greatest closest to the shore along the entire extent of the Palk Bay, and within regions that trawlers should not have been operating.

Chapter 6: Conclusion

My research suggests that a ban on capture and sale of wildlife without enforcement is futile for conservation. This is clearly the case for India, where capture and trade of seahorses continued apace despite a notional and national ban on both activities. The ban in India appears to have been ineffective yet informative, and point to the risks of using a rigid, one-dimensional approach to conservation. In meeting its declared commitment to seahorse conservation, India would do well to reconsider this approach. Rather than implementing a ban as a stand-alone measure for seahorse conservation, the country should develop a suite of complementary management measures for maximum effectiveness. The same would hold true for conservation of other species, in particular, for sea cucumbers and other taxa whose capture is theoretically banned but which are primarily obtained in non-selective gear.

6.1 Research Findings

I now turn to extracting my key findings for each of my research questions and their importance in answering the overarching research questions that guided my thesis. I then summarize my work and draw broad conclusions from my various research chapters. I subsequently offer some conservation insights from my work, and a few caveats, before offering ways forward with seahorse – and marine – conservation in India.

6.1.1 Research Question 1: Does a national ban on fishing seahorses actually affect catch of those species, nationally and locally? (Chapters 2 and 3)

In finding that seahorse extraction continues in large numbers, my first two chapters show that a ban has failed to control exploitation, both nationally and locally. While it appears that the ban has been successful in limiting the direct exploitation of seahorses through diving, any alleviation in such pressures appears to have been offset by the increased intensity of non-selective fishing. In executing surveys of seahorse fisheries and trade, my work covers a larger geographic area than ever examined before. Based on my large seahorse catch estimates in incidental gear, it appears that my current global estimate of 37 million individuals caught this way (Lawson et al., 2017) is clearly too low. My findings on the scale and impact of non-selective adds to growing and severe concerns about the impact of trawling on seahorse populations (Baum et al., 2003; Perry et al., 2010; Vincent et al., 2011; Aylesworth et al, 2017; Perry et al., 2020), even while also acknowledging the enormous impacts of traditional gear operations on seahorse populations (Lawson et al., 2017; Aylesworth et al, 2017). Parts of the country that traditionally traded seahorses had a high awareness of the ban. However, as for many other species, illegal trade continued (Rivalan et al., 2007), now pushed underground (e.g., Rosen and Smith 2010; Underwood et al., 2013), and was profitable for those willing to take risks (Wyatt, 2009; Zimmerman, 2003).

In Chapters 2 and 3, I argue that if the ban does not impede, hinder or slow exploitation of seahorses, it is clearly ineffectual for conservation. The situation becomes more difficult when bans are imposed on incidentally caught organisms, because extraction of fishes is rarely managed, thus making it difficult for fishers to identify incidental catch – indeed, the name says it all. My findings add to concerns about the use of bans, suggesting that extraction bans do little to aide in the conservation of incidentally caught species, either on land (e.g., babirusa in snares) (Clayton et al., 1997) or in the water (e.g., sharks in Sri Lanka) (Collins et al., 2020). The results of my study should motivate the large number of countries that have resorted to bans to protect their biodiversity, provoking them instead to manage the pressures

While much of the current research on the impact of bans, both on land and in water, has been on larger charismatic animals (e.g., Challender et al., 2015; Schiffman and Hammerschlag, 2016; Rivalan et al., 2007), my work expands on this knowledge to include their impacts on small incidentally caught organisms. This is important because gear modification measures are often recommended to avoid the incidental capture of organisms, particularly in the marine realm (e.g., Broadhurst 2000), but what happens when the protected species are the same size as the organisms being targeted? While it may be possible to develop effective turtle excluder devices (TEDs), no modification of gear technology will ever reduce bycatch of seahorses or the many hundreds of other species in the bottom of the net.

6.1.2 Research Question 2: Why do fishers keep catching seahorses when that catch is banned? (Chapter 4)

My work revealed that there was low compliance with the ban on catch and trade amongst fishers. It appears that a number of factors converge to motivate fishers to persist in illegal activities, starting with declining fish catches. This is often combined with few options to exit the fishery, which means that the income from seahorses benefits fishers. Since they are incidentally caught, catching seahorses requires no extra time, effort, or costs, during regular fishing trips. Fishers perceive no benefit in releasing seahorses when they were already caught in the fishing nets. This is especially true because the small size of the organisms, together with the large areas in which fishers operate, and the relatively low enforcement capacity persuade fishers of the negligible probability of punitive measures. Finally, in the absence of being involved in the decision-making process before the imposition of a ban, fishers found less legitimacy in the rule, particularly given their long history in exploiting the resource.

My work adds to the growing understanding of the role of compliance, and the factors determining compliance with rules and regulations, which is critical for successful conservation outcomes in both terrestrial and marine ecosystems (Arias, 2015). My study explores and provides support to the concept of "opportunistic exploitation", where less abundant but high-value species could potentially be exploited while targeting more abundant but less desirable species in the same habitat (Lobo et al., 2010; Branch et al., 2013). My work is one of the few studies to understand fisheries non-compliance in developing countries (e.g., Carr et al. 2013; Cepic and Nunan, 2017), and amongst very few papers on compliance that do not focus on sharks. Ultimately, for countries with limited enforcement, success of management measures will only come from involving all stakeholders in the decision-making process (Berkes, 2007), particularly those most affected by - and with the most to lose from - such measures.

6.1.3 Research Question 3: How might we come up with management measures for fisheries that would perform better than the ban? (Chapter 5)

The focus of this chapter was to understand how to simplify advice on management, here represented by NDFs to meet CITES obligations but really embracing all sustainable use and sound fisheries practice. In responding to the requirements of NDFs, I was also assessing whether current management measures would suffice to ease the pressures faced by seahorse populations, in the event the ban was revoked. Given the data-limited situation, I used local fisher knowledge which has been found to be a cheap and fast way to generate an initial snapshot for understanding species distribution (Thornton and Scheer, 2012, Aylesworth et al., 2020). My work is one of a handful studies that may be easily replicated for identifying seahorse priority areas (Zhang and Vincent, 2018) and for evaluating the effectiveness of existing management measures (Aylesworth et al., 2020). After years of being overlooked, integration of spatial data has only recently been employed for CITES Appendix II species (Aylesworth et al., 2020).

My research is particularly applicable for CITES Parties that have struggled to make NDFs for seahorses and for other Appendix II marine species such as sharks. Parties often perceive NDFs to be too complicated and detailed (Rosser and Haywood, 2002), particularly as the country often must work within the constraints of limited data and capacity. My findings suggest that while the simplified NDFs may be far from perfect, they provide a valuable snapshot that acts as a starting point on which management can build (Meffe and Viederman, 1995; Smith et al., 2011). My research shows that through addressing the core questions of simplified NDFs for any Appendix II species, Parties may be able to evaluate quickly how current management is performing, address gaps in existing measures, and work towards issuing positive NDFs, thereby moving away from ineffectual bans towards sustainable trade. The influence of trade on exploitation depends largely on whether trade drives the fishery, or the fishery drives the trade, as is the case with non-selective equipment that strips all species from the ocean without distinction or pause.

6.2 Overview of findings

On evaluating the impacts of a national-level ban on catch and trade on the conservation status of seahorses, nationally (Chapter 2) and locally (Chapter 3), I found that - despite the ban - seahorses continued to be caught in large numbers (predominantly by non-selective fishing gear) and illegally traded, primarily in the state of Tamil Nadu. My findings provide a critical and much overdue snapshot on the extent of fisheries and trade of seahorses in a country that was one of the first to use bans as tools for seahorse conservation. Unfortunately, my findings offer up a cautionary tale for other countries considering bans as management measures. For Chapter 4, I set out to understand why fishers continued to exploit a banned resource and found that the convergence of a number of factors - such as the value of supplemental income and the lack of extra effort required to catch the fish in nonselective gear – created a perfect storm in undermining the effectiveness of the ban. The findings of this chapter 4 highlight the importance of generating compliance with management measures for them to succeed, particularly because the vast extent of the oceans makes stringent enforcement difficult. In Chapter 5, I developed a relatively quick and cheap method that uses spatial data generated from fisher knowledge to evaluate the effectiveness of existing management and help guide sustainable exports. I find that in the region where greatest seahorse catches in the country were observed, spatial management measures such as a three nautical mile trawl exclusion zone and a no-take marine protected area only offered nominal protection, and fishers continued operating and catching seahorses in these areas. My integrated findings suggest that a ban alone may not be appropriate management for the conservation of marine fishes, particularly when a species is incidentally caught. Perhaps, only constraints on the gears themselves will combat pressures faced by seahorses and provide a starting point for effective management.

The approaches and techniques I employed for my work may be used for other data-poor species and situations. Throughout this thesis, my findings reveal the richness and importance of information that may be obtained from local knowledge as key contributions to conservation of species and spaces. In Chapter 2 and 3, from my interviews, I discovered a storehouse of information going far beyond what had conventionally been explored in trade surveys. Through models, I then substantiated my knowledge of factors determining the presence of seahorses in fishing catches. Further, I used analytical tools (bootstrapping) to overcome the limitation of sparse data for understanding the extent to which seahorses were caught in India's fisheries each year. In Chapter 4, the economic information, and qualitative data I obtained from fisher interviews made it possible to appreciate why fishers did not comply with the ban, providing lessons for managers when implementing future measures. For Chapter 5, I was able to generate spatial data relatively quickly from my fisher interviews to evaluate the effectiveness of current fisheries management measures for the conservation of seahorses. The methods used in this chapter are easily transferable and could be used as a guide to many other counties struggling to make NDFs, particularly in data-limited situations. Despite the uncertainty associated with using fisher knowledge, I find that distinct patterns emerged. Fisher information certainly provides the basis for management measures which can be refined as we collect more detailed data and targeted knowledge.

6.3 Conservation Insights

I now discuss why India's ban on exploitation and trade of seahorses has not stopped their catch and trade. In fact, I argue, the ban has had a number of unintended – and worryingly deleterious - consequences for both conservation of seahorses and livelihoods of associated people. Based on my findings, I suggest other conservation measures that are likely to be more successful than a species-ban.

Conservation measures have often been designed with the goal of conserving biodiversity, enhancing ecological conservation, and promoting social and economic well-being (Hirsch et al., 2011; McShane et al., 2011). However, such goals are seldom achieved, often because of the conflicting conservation and socio-economic objectives, which may result in only one objective being successful at the cost of the other (Fastre et al., 2020; Hirsch et al., 2010). However, with this ban, it appeared that none of these objectives (conservation, ecological, socio-economic) were being met. Such failure is of deep concern to me as a conservationist committed to the marine life of my country.

India imposed a ban on seahorse catch and trade, purportedly to combat the rapidly increasing trade in these fishes and to alleviate conservation concerns (Salin et al., 2005). However, my research indicates a few issues with India's stated commitment to seahorse conservation. One of the biggest issues is that India has taken no other remedial action to conserve seahorses, because at least on paper, stringent measures exist to manage India's seahorse populations. By instituting a notional ban before seahorses were listed on Appendix II of CITES, India gave an appearance of being ahead of other countries. In fact, however, this only resulted in India circumventing the CITES Review of Significant Trade (RST) process, which addressed failings by other CITES Parties. Instead of leading the CITES process, India escaped from it. Finally, despite the ban, India's participation in illegal trade of seahorses has been echoed in other countries, such that about 95% of dried seahorses in trade were found to be illegal by 2017 (Foster et al., 2019).

From an ecological point of view, the ban India could have been used to move towards a better understanding of their seahorse populations, generating knowledge that would ultimately help with their management. In reality, the ban resulted in a lack of progress in the understanding of issues that supposedly impede seahorse conservation from two decades ago – such as an understanding of seahorse abundance, distribution and taxonomy (Sreepada, 2002). The ban has also resulted in challenges with conducting research on seahorses for reasons including: i) getting permissions for ex-situ studies (e.g. aquaculture, genetics) on these supposedly protected species no longer being straightforward and ii) obtaining reliable and on-going data on seahorse exploitation was compromised because fishers saw no benefits in providing this information, but rather worried how it might be used against them (A.Murugan, *pers.comm*).

The success of conservation initiatives hugely depends on the socio-economic context within which they are framed (Muhumuza and Balkwill, 2013). If stakeholders feel that the conservation initiative furthers their cause, is legitimate, and support it, the initiative is more likely to achieve its objectives (e.g. Hard et al., 2012). My research suggests that seahorse conservation in India does not, in fact, follow these tenets in a number of ways. The biggest point of contention is that the ban criminalized an entire section of society: all those who land seahorses. Given that catching even one seahorse is a crime, over 90% of the fishers I interviewed would apparently be guilty of criminal behaviour. Another issue is that the the ban took away a significant portion of livelihood from the highly skilled divers in the Palk Bay region, who used to actively and selectively target seahorses (as well as sea-cucumbers, which are also banned). Many divers have now either moved out of the industry or moved on to larger boats (Vinod et al., 2018). While it could be argued that the lack of divers is one less pressure on the conservation of seahorses, unfortunately, seahorse catches appeared to have been redistributed towards larger, more destructive fishing gear. Finally, the women who form the backbone of many fishing communities (Anna, 2012), no longer earn any notable income from seahorses. Nowadays, the only seahorses women are able to obtain come from sorting miscellaneous fish, which are generally ones that the onboard fishing crew on trawlers overlooked, and therefore tend to be small and low value. Income that women might previously have used to support the household is now largely earned by male fishers and used to support their recreational activities (smoking and drinking).

From my research, I find four significant drawbacks of the ban. Identifying these flaws is an important step in identifying approaches that should be more functional and effective.

1. The ban did not address the biggest pressure faced by seahorses, viz. indiscriminate catches in non-selective fishing gear. Trawlers and drag-netters, which are the greatest threats to seahorses (Salin et al., 2005; Murugan et al., 2008; Vinod et al., 2018), continued to operate in large numbers, in poorly regulated fisheries.
2. The ban did not offer even notional protection for the habitats in which the species were found. In the Palk Bay region, where most of India's seahorses have been known to be caught and sold (Marichamy et al., 1993; Salin et al., 2005; Vinod et al., 2018), non-selective fishing gear operate on seagrass habitats to catch juvenile prawns and, incidentally, seahorses (Marichamy et al., 1993; Murugan et al., 2008, Vinod et al., 2018). Despite being considered as Ecologically Sensitive Areas under India's Coastal Regulation Zone notification (2011), seagrasses are afforded no exclusive protection. Without habitat protection, seahorse populations would be unlikely to thrive even if the ban had actually reduced seahorse catch.
3. The original law upon which the ban was based was developed with India's large terrestrial mammals in mind, as revealed by the penalties and punishments associated with violations. Applying terrestrial laws to marine fishes did not translate well, particularly given the extent of the marine realm and open-access nature. Under the WLPA, killing a tiger and catching a seahorse would technically evoke the same punishment, something many fishers would find difficult to equate, and to accept; it was

certainly unlikely that any enforcement process would apply these punitive measures equally.

4. Excluding stakeholders during the decision-making process has resulted in an alienation of those dependent on the resources and has resulted in a reduced compliance with the ban.

Ultimately, the appearance of good is not the same as doing good. India appears committed to conservation, if one were to judge by the number of multilateral environmental agreements the country has signed, and its supposedly stringent conservation laws. However, the reality is that such pledges have, in practice, amounted to little more than intentions.

I want to highlight a larger issue, affecting most marine life in inshore waters. Even if the exploitation ban on seahorses had been respected, seahorse populations would fare badly in the context of general threats to marine communities. In the hypothetical situation that fishers released all seahorses they caught back to the ocean (and the seahorse(s) survived), the seahorse population might have fared marginally better for a short time. However, the continued pressure of indiscriminate fishing by trawlers and draggers on both critical seahorse habitats, such as corals and seagrasses, and on hundreds of lesser-known species, indicates that thriving seahorse populations would have been unlikely, whatever the direct take. The pressure of bottom trawling in this region is so extreme that it is rapidly becoming 'annihilation fishing' (sensu Vincent, 2017), with no endpoint other than entire ecosystems laid waste (sensu Vincent, 2017).

6.4 Caveats

My research had its fair share of challenges- both while conducting field research, given the ambitious extent of my work, and in the subsequent data acquisition. I have already addressed the limitations relevant to each chapter above, but now discuss additional challenges. I first discuss challenges inherent to the methodology employed before turning to the lessons I learned from this endeavour that I would apply were this research to be replicated and expanded upon

Local knowledge was one of the strengths of my research, particularly in such data poor situations, but such sourcing of information also has drawbacks. Limitations include large uncertainties because of inherent biases including recall bias (Filion, 1980) and retrospective bias (Neis et al., 1999; Ainsworth et al., 2008). In general holders of local knowledge are inclined towards pessimistic scenarios (Ainsworth and Pitcher, 2005), but also a tendency to remember positive events that were rare (Bradburn et al., 1987; Tourangeau, 2000). Underreporting of the true extent of exploitation is also known to be a common problem, particularly in situations where the species in question is of conservation concern (Jones et al. 2008, Rist et al. 2010). Ultimately, my interviews were dictated by the willingness and comfort of the respondents to be a part of my interview. I found that a knowledge of the ban meant that fishers and traders were often reluctant to be a part of my interviews or divulge much information because of the perceived risk of recrimination.

During my fieldwork, gathering economic data was problematic, as some fishers were not comfortable providing this information, and I had to draw on diverse sources to fill in the blanks. I am, therefore, cautious about accepting any particular fact, even while being confident in the patterns themselves.

Also, some sources of data were problematic or limiting. As one example, I found notable discrepancies between the information from central research institutes and the state department. The central research institutes have a standardized approach to data collection across the country but have few researchers collecting data while state fisheries collect data in a less transparent way, but the department is better staffed. As a second example, for habitat data in my final chapter, conflicting maps existed from the same region, and local researchers suggest that delineating seagrasses and seaweed in the region has actually proved to be challenging (K. Sivakumar, *in litt*.).

While I had to depend on local knowledge and accept the constraints inherent in exploring a legal issue and in probing people's economic status, I do recognise that some aspects of my methods could also be improved next time. Firstly, I would change my approach to understanding fisher awareness of the ban. I started my fieldwork in Tamil Nadu, where during my first field season every fisher I interviewed spontaneously mentioned the ban. In a bid not to bias my interviews, in parts of the country outside Tamil Nadu, I did not explicitly ask the question about the awareness of bans, and very rarely did fishers bring up the topic. In a future study, I would include a prompted question about their awareness of a ban at the end of each interview. Next, I would focus more tightly on core questions. During my second field season, I explored a broad interest in the catch and socioeconomic issues of trawl fisheries. While this was fascinating work, it limited my capacity to explore seahorse-specific issues in bycatch across diverse fisheries, and thus constrained some investigations. For example, I would have liked more data on seahorse distributions as deduced from diverse gears, whereas most of my information came exclusively from trawl fisheries.

6.5 Future directions

My work suggests that the deceptively simple approach of implementing a ban does not work in reality. The question then becomes, what does?

A starting place would be for India to remove seahorses from the Wild Life Protection Act. Such a move would acknowledge that the ban has not worked, indeed, cannot work by itself in the current context, and use that information to set the stage for India to take a more nuanced approach to seahorse conservation, one that engages fishing communities in contributing to the solutions. Despite the ban supposedly being India-wide, fishing communities of Tamil Nadu feel that they are the only ones targeted by the ban, primarily because this state catches most seahorses. The ban has alienated fishing communities in the region where seahorse fisheries and trade have historically operated. Removing the ban would not leave India's seahorses exposed but would rather make them subject to normal CITES provisions, such that India would actually have to prove that its export trade is sustainable (and India has very little domestic trade). Restrictions directed at sustainable use (as is intended with CITES Appendix II listings) can often do more for a species than a blanket ban on capture and trade, if only because the country must account for the effect of its decisions on wild populations (Vincent, 2014). Restrictions on trade do not, of course, limit seahorse catches, but nor did a ban on capture.

With the removal of ineffective bans which punish stakeholders, what are the next steps for effective, realistic seahorse conservation? Spatial management must be considered, particularly in the form of no-take reserves where fisheries (and particularly non-selective gears) are banned (e.g., Halpern and Warner, 2002; Roberts et al., 2002). Current MPAs in the state of Tamil Nadu account for only 560 km^2, and are largely ineffectual, primarily because boundaries have not officially been delineated because of push-back from local fishers, despite it being over three decades since its designation (Rajagopalan, 2008). A no-take zone in Palk Bay, which has the largest areas of sensitive seagrass beds, would afford formal protection to the seahorses and to the habitats, the latter of which is also sorely needed. Marine protected areas generally work best where there is good community support, so will only be effective in some parts of the state of Tamil Nadu, and of India as a whole. Elsewhere, restrictions on bottom trawling may have to take the form of bans on the gear as a whole.

There is some potential for the small-scale (sail driven) dragnet fishers Bay to help advance seahorse and marine conservation. As a first step, we must generate their participation in securing long-term conservation – and especially of spatial protection – of ocean resources. Community-based co-management may be an effective option, because fishers feel a sense of ownership over the resources; this leads to a greater compliance because of peer pressure and better enforcement of rules by fishers themselves (Berkes, 2007; Pomeroy and Williams, 1994). If fishers perceive that they receive benefits or recognition for this work, they are more likely to engage with conservation initiatives in the future. It will be important to work with drag-netters, who exert the greatest pressure on seahorses, to establish no-take reserves with full protection (e.g., Hughes et al., 2002; Roberts et al., 2002). This may be relatively tractable because most fishers operating drag nets are concentrated in a few landing centres, and drag-netters operate relatively near-shore, unlike the diffused nature of typical traditional fisheries in India. Of course, caste and religious dynamics of fishers operating this equipment must be accommodated and drag-net communities would require additional government support to make sure that fishers from other communities (using other equipment, generally) also respect the no-take zones. Community based initiatives have had success in other parts of the world, and in the Danajon Bank, Philippines, where concerns about seahorse conservation prompted establishment of 35 community-managed reserves (https://www.projectseahorse.org/action-marine-protected-areas, accessed on 10 Oct 2020). Cross-visits from fishers involved in other effective spatial management ventures, who share their learnings and outcomes, could help overcome apprehensions that fishers may have.

It is hard to envision a scenario where fishers who operate the larger engine-powered trawl boats elsewhere on the coast will make a meaningful contribution to conservation. In the Ramanathapuram District, where the greatest number of seahorses were caught with fairly small trawl boats (under 15 m long, four- nine crew), community buy-in is likely to be near-impossible because of large social-heterogeneity with respect to caste and religion (Manuel and Sridhar, https://www.dakshin.org/governance-and-leadership-in-fishing-communities-in-ramanathapuram-district-tamil-nadu/, accessed on 16 Dec 2020). The District just doesn't have the capacity for local governance through caste panchayats (*Ur panchayat*) that have been successful in managing fisheries in the Nagapattinam-Karaikal region, through decrees prohibiting near-shore trawls and limiting ring-seine fishing in longlining areas (Bavinck and Vivekanandan, 2017). In the larger scale industrial trawl fisheries in Tamil Nadu, every legal restriction on trawling – by size, time at sea, or engine power – has resulted in a series of unintended consequences, usually in the form of breaking other rules, such as using banned pair-trawling (e.g., Ramanathapuram District). Where time out at sea was constrained, fishers dropped their nets indiscriminately, and landed all they fished in such an unsorted pile that it was often sold for chicken feed at pennies per kg (e.g., Tuticorin fishing harbour). In regions where engine power was constrained, fishers simply did not register their boats (e.g., Chinnamutom fishing harbour). Moreover, many, if not most of the fishers working on trawl boats in this area had no affinity to the ocean or to fishing. Rather they had come from other regions, rural or urban, to work as labour on the boats, with no particular commitment to the persistence of the industry or its resources. Simply legislating change does not – and will not – make it happen. Trawl fisheries are simply not amenable to management directed at sustainable use of marine resources, including seahorses.

Ending bottom trawling would be the ideal. This can be done, as evidenced by Indonesia where trawling was banned while it was at its height both in terms of catches and value (Bailey 1997). An end to trawling would provide the most complete protection of seabed habitats while also potentially increasing catches by other fishing gear (McConnaughey et al., 2020). In places where trawling has been banned (e.g. Qatar and Venezuela) the artisanal fishers have benefitted (Al-Abdulrazzak, 2013; McConaughey et al., 2020) from a shift to passive, more-selective gears, such as stationary nets and longlines (Pham et al., 2014; Suuronen et al., 2012) that do not impact the bottom-habitats. The use of passive gear to extract marine resources has been beneficial in other parts of India, as observed when gillnets in Karnataka caught heavier king seers, with more total value, than those obtained in trawlers and purse seiners (Dineshbabu et al., 2012). As a start, phasing out trawlers should start with large offshore trawl vessels, followed by reducing commercial/large-scale trawl vessels, and then owner operated small-scale trawlers. Decisions on the future of drag-netters would depend on how well their resources responded to spatial management, thus prompting careful engagement with the establishment of MPAs. By winding down bottom trawl operations, India would also be able to work towards reducing conflicts with Sri Lanka, where a number of trawlers from the state of Tamil Nadu are known to operate (Scholtens, 2015) and address overextraction of other species in bottom trawls. India would be also be working towards meeting its obligations to CITES by ensuring that no exports would have come from (often illegal) trawl fisheries; these are so destructive as to preclude making positive NDFs.

In seeking to ensure long term sustainability of ocean resources, we need to reconcile fisheries and conservation mandates, a challenge commonly faced by resource managers and policy makers in Tamil Nadu, in India and globally (Margalida, et al., 2011; Preisler et al., 2006; Young et al., 2005). State or national fisheries departments (charged with marine production) are often at loggerheads with state or national forest departments (charged with conservation) yet must work together to ensure conservation success. What is needed in the region, as in so many other parts of the world, is a specific department working for the betterment of the oceans, focused on conservation objectives to balance the production imperative of fisheries agencies. Such a unit would help address the problems of having personnel with forestry and terrestrial expertise charged with conservation of ocean resources. Indeed, a new Resolution by the IUCN Union of more than 1400 conservation agencies and organizations has agreed to the need for governments to create just such ministries or departments in countries around the world (WCC-2020-Res-107).

6.6 Conclusion

India's ban on removing seahorses appears to be ineffective and misplaced, particularly when the equipment which takes these animals incidentally, and in very large numbers, and destroys marine habitats and communities remains legal and in wide use. Bans have been considered as straight-forward measures (Moyle, 2003) finding increasing usage in many cases (e.g., sharks) because of their perceived simplicity particularly in capacity constrained situations (Shiffman and Hammerschlag, 2016). However, from my research, I argue that bans are anything but straightforward, and that countries often use bans only on the notional grounds of doing something for species conservation, and not with any real intent and/or understanding of multi-dimensional conservation needs. Bans are inherently complex, and in the case of the ban on India's seahorses there were many additional layers of complexity: i) the species were incidentally caught in fishing gear; ii) the species were data-poor; iii) the species were economically important; iv) the pressures threatening the species were not managed; v) the patchy distribution of species that meant a national law was largely applicable to one region; and vi) the government had limited capacity (manpower and enforcement). Even worse, this ban appears to have been poorly conceived, criminalizing an entire sector while achieving little to control the problem, akin to the effects of punitive measures to control drug use (Pew Charitable Trusts, https://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2018/03/more-imprisonment-does-not-reduce-state-drug-problems, accessed on 15 Dec, 2020) or sex work (Vanwesenbeeck, 2017).

My findings from India should be a cautionary tale for other countries considering bans as management measures, both on land and on water, particularly when the means of extraction continues unchecked, and the species are incidentally caught. Instead, my work points to the need to constrain pressures on wild populations in extent and time. Just as releases of captive bred animals are largely pointless while the pressures that led to the decline of their wild populations remain persistent (IUCN/SSC,2013), so a ban on capturing wild animals is pointless unless it reduces pressures on their wild populations. The findings of my study highlight the need to address the substantial challenge of reducing trawl pressures for thousands of small species caught in these nets, for the many marine habitats vulnerable to trawl damage, and for the selective fisheries that provide more durable food security and economic resources. Ultimately, if we can protect marine resources such as seahorses and their habitats in shallow-waters, where a great diversity exists but is matched by undue anthropogenic pressures, we might have greater success in extending the scope of our conservation aspirations (Vincent, 2011).

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Appendices

Appendix A Supporting material for Chapter 2

This appendix contains the following supporting material from my methods i) questions asked during interviews.

Appendix A.1 Questions asked during interviews

Fishers	**Name (if possible):**

Interview Number: Date: Start Time: End Time:

Place Interview was conducted:

General

1. How old are you?
2. How many years have you been fishing for?
3. What kind of boat do you fish with? What is the length of the boat? Is it motorized or mechanized? What is the horsepower?
4. How many people work on your boat?
5. What kind of net do you use? What is the mesh size of the net? How long is the net?
6. Do you use the same type of gear year-round?
7. If there are any particular months you do not fish, which are those? What do you do during those months?
8. Do you use other fishing boats or gear if you fish during those months?
9. 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?
10. How many trips do you make per week? Per month? Per year?
11. How many days do you fish in a month? Per month? In a year?
12. How long is each haul? How many hauls do you make in a day?
13. Where do you fish? What is the distance you travel? What depth? What habitat?
14. How long does it take to travel to and from your fishing grounds?

Seahorses

15. Seahorses often catch on to objects with their tail. Have they ever caught on to your nets with their tail? If yes;
    a) What depth do you find them in?
    b) What habitat?
    c) Is there any season when you find more seahorses?
    d) For an average *unit of time* (e.g., haul/day/week/month/year) in *high season*, how many seahorses do you find?

e) For an average *second unit of time*(e.g., haul/day/week/month/year) in *high season*, how many seahorses do you find in your nets?
f) For an average *unit of time* (e.g., haul/day/week/month/year) in *low season*, how many seahorses do you find in your nets?
g) For an average *second unit of time* (e.g., haul/day/week/month/year) in *low season*, how many seahorses do you find in your nets?
h) On an average how many seahorses do you catch during a *unit of time* (e.g., haul/day/week/month/year)?
i) On an average how many seahorses do you catch during a second *unit of time* (e.g., haul/day/week/month/year)?
j) Which fishing gear catch more seahorses?
k) Has there been a change in the catch of seahorses? Over what time period? If so why?
l) Are you aware of others who catch seahorses?
m) How many types of seahorses do you catch?
n) Are they smooth or spiny?
o) What size range of seahorses do you catch? What size are most of the seahorses you catch? [= average size]
p) What do you do with the seahorses you catch?
q) When you throw them back, are they alive or dead?
r) How long do you drag/set the nets for at a time?
s) Does everyone just throw them back, or do you know of anyone who does anything different with them?
t) Is there anything you can use seahorses for?

If the topic of a ban was brought up (not necessarily for seahorses)

1. Are you aware of the ban on seahorses?
2. If yes, how were you made aware of the ban?

If they have been fishing before the ban;

3. Compared to before the ban, is there any difference in the number of seahorses that you catch (for high and/or low season)?
4. Compared to before the ban, is there any difference in the types of seahorses you catch?
5. Compared to before the ban, is there any difference in the average size of seahorses you catch?
6. Compared to before the ban, is there any difference in the price of seahorses?
7. Compared to before the ban, is there any difference in the number of buyers?
8. Why you think the change has occurred?

If sold

16. If you sell seahorses;

i) Who do you sell them to?
ii) Do you sell them dead or alive?

iii) Do you sell them wet or dried?
iv) Do you think they all buy about the same amount, or are some buyers bigger than others?
v) How much do the buyers pay for seahorses? Does the price vary depending on colour, or size, smooth/spiny, etc?
vi) Are there any seahorses that the buyers won't take?
vii) Do you know what the buyers do with the seahorses?
viii) What else does the buyer purchase along with seahorses?

Buyers:

1. How old are you?
2. How many years have you been in business for?
3. What products do you deal in?
4. Are seahorses a small part, or an important part of your business?
5. How did you start selling seahorses?
6. How many other buyers are there in this area (or city) at the same level? [and at other levels?]
7. How do you think the scale of your business in seahorses compares to other buyers at the same level? Do you think you get more, fewer, or about the same quantity?
8. How many types of seahorses do you sell? What do they look like (colour, smooth/spiny, size range, average size)?
9. Who do you buy seahorses from - directly from fishers, or from middlemen? (If they buy from fishers, what types of fishers/gear catch seahorses?) Where are they located?
10. How many people (of each type) do you buy from?
11. Do the people who sell you seahorses sell only seahorses, or do they deal in other products?
12. What region do the seahorses come from?
13. Do you know of any other areas where seahorses are caught/sold?
14. Is there a season when seahorses are easier to get, or more plentiful?
15. How often do you usually buy seahorses/do people sell seahorses to you?
16. For an average *unit of time* in *high season*, how many seahorses do you buy?
17. For an average *second unit of time* in *high season*, how many seahorses do you buy?
18. For an average *unit of time* in *low season*, how many seahorses do you buy?
19. For an average *second unit of time* in *low season*, how many seahorses do you buy?
20. How many seahorses does one person usually sell at one time during *high season*?
21. How many seahorses does one person usually sell at one time during *low season*?
22. Approximately how many seahorses are there in a kg? [or other unit. Be sure to ask, if the buyer has mentioned different size categories, how many seahorses there are per kilogram for each of the different size classes.]

23. How much do you usually buy them for? [Expect some hesitation with this - businesspeople aren't always willing to talk about the financial details of their business.]
24. How many people do you usually sell to? Who do you usually sell to (where are they from, and names if possible)?
25. How many buyers do you know of at the next level up?
26. How much do you usually sell to them at a time (for high and low season)?
27. How often do you usually sell to them?
28. How much do you usually sell them for? Do the prices differ depending on size, or type?
29. Are there any seahorses that your buyer won't take (e.g. with holes or broken)?
30. Does the buyer come in person, or do they send them to them? If they send them, how do they send them? Where are they located? Do you know where they in turn send the seahorses? What route does it take?
31. Do you know what your buyer does with them? Do you know what they are usually for, eventually?

If they bring up the topic of the ban:

1. How were you made aware of the ban?
2. Compared to before the ban, has there been any change in your supply of seahorses/the number of seahorses you get?
3. Are they any easier or more difficult to get than they were?
4. Compared to before the ban, has there been any change in the number of people who sell seahorses to you?
5. Compared to before the ban, has there been any change in the types of seahorses that you get?
6. Compared to before the ban, has there been any change in the size range, or average size of seahorses that you get?
7. Compared to before the ban, has there been any change in the number of seahorses per kg (or other unit of measure)?
8. Compared to before the ban, has there been any change in the demand for seahorses from your buyers?
9. Compared to before the ban, has there been any change in the price of seahorses (buying and selling)?

MAPPING:

1. What habitat(s) do you find seahorses in?
2. What depth(s) do you find seahorses at?
3. Distance from shore that you find seahorses?
4. Can you map where you find seahorses on this map?
5. Can you map where you do not find seahorses on this map?
6. Are you aware of what species of seahorses you catch?

Appendix B Supporting material for Chapter 3

This appendix contains the following supporting material from the methods and results, and includes i) a table with the seven predictors used in my models ii) variables considered for the correlative models iii) a table with the model scenarios created iv) methods for identifying predictors for seahorse presence/absence in catch and CPUE v) results from the four correlative models in identifying important predictors for seahorse presence/absence in catch and CPUE (with figures and tables) vi) mean purchasing price and selling price per individual across various trade levels.

Appendix B.1 Response and predictor variables related to seahorse catches based on interviews conducted between 2015 and 2017 along the coast of Tamil Nadu.

Type	Variable	Description (Range for continuous variables / Levels for categorical factors)	Number of observations
Response	seahorse presence/absence	0/1	636
	seahorse CPUE	0 – 11,300 individuals / year	491
Predictor	Latitude	N 8.172 - 13.127	636
	Gear type	Three types: Gill net, Trawl, Other	636
	Gear operation style	Two types: Active vs. Passive	636
	Water layer	Two layers: Bottom vs. Water column	636
	Habitat	Three levels: Biogenic vs. Flat vs. Rocky/stony	358
	Depth	0 - 256 m	263
	Selectivity	Selective or not	636

Appendix B.2 Variables considered for the correlative models

For habitat type, corals, seagrass, seaweeds, soft coral, and sponges were categorized as biogenic habitats, and muddy, sandy and bare bottoms as flat habitats. Distance from shore could not be used as a predictor variable as fishers often just reported distance travelled per trip, and not necessarily outward from shore. Additionally, landscape scale variables were considered, and divided the study area into five: 1. Northern region 2. Central region 3. Rameswaram Peninsula 4. Southern region and 5, West coast of Tamil Nadu. But this region variable is highly correlated with latitude, and thus was not included in the final dataset.

Appendix B.3 Model scenarios created to deal with the large number of NAs in the variables of my dataset

Scenarios	Number of observations	Number of predictors	Response variable	Model
1	241	7	Presence / absence	RF + GLM
2	636	5	Presence / absence	RF + GLM
3	199	7	CPUE	GAM
4	458	5	CPUE	GAM

Appendix B.4 Methods for identifying important predictors for seahorse presence/absence in catch and CPUE

For the 1st and 2nd scenarios, random forests (RFs) and generalized linear models (GLMs) were used to detect important factors and their relationships with seahorse presence/absence in fisheries. Important predictors were selected from the original predictors based on the 'Boruta algorithm' (R package Boruta). This algorithm identifies important predictors by iteratively comparing predictors' importance with that achieved at random (using permuted copies of all predictors, Kursa and Rudnicki 2010). 1000 classification trees were used to model the relationships between seahorse presence/absence with only the significantly important predictors based on the RF model in Scenario 1 and in Scenario 2, respectively (R package randomForest, Liaw and Wiener 2002, Cutler et al. 2007). The accuracy of the RF model was evaluated based on three measures: presence accuracy, absence accuracy, and the Matthews correlation coefficient (MCC, Matthews 1975). The MCC considered true and false positives and negatives, and thus it was considered a balanced measure of model quality. The value of MCC ranges from -1 (worst) to 1 (best). It has been widely used in machine learning such as random forest algorithm, even for the classes of different sample sizes as with the data from this study (more presences than absences) (Boughorbel, 2017). The effect of different predictors was then analyzed and plotted their relationships with the response variable based on GLMs (R packages 'stats' and 'MASS', Venables & Ripley 2002, R Core Team 2019). The best model was identified based on two criteria: Akaike information criterion (AIC) and Bayesian information criterion (BIC), whichever derived the least number of predictors. The lower value of AIC or BIC, the better the model fit for the given dataset.

For the 3rd and 4th scenarios, generalized additive models (GAM) with a negative binomial distribution were used to fit the CPUE data. This type of model allows non-linear relationships between the CPUE and predictors (Guisan et al. 2002) and has been suggested to be suitable for predicting zero-inflated CPUE data (Drexler & Anisworth 2013), which was the case in this study. The 3rd scenario contained two continuous variables (i.e., latitude and depth) to which regression spline fits were applied. Simple GAMs were first constructed based on each of the two continuous variables (with spine functions) in the 3rd scenario, and a GAM contained both variables. The model complexity was then increased by adding one of the other predictors (categorical variables) each time to the above three GAMs. Only one categorical predictor was added each time, given that these categorical predictors were highly correlated (e.g., trawl nets are active gears) and initial trials found that this could make the model's parameter estimates difficult to interpret. All these models were then compared based on their scores of AIC and the proportions of explained deviances (PED). The lower AIC and higher PED, the higher goodness of model fit. Plots of model fitted values vs. residuals were made for the best model. The same process was followed to construct the 4th scenario. The only difference was that this scenario excluded depth and habitat data as there were NAs in these two variables as described above.

Appendix B.5 Results from the four correlative models in identifying important predictors for seahorse presence/absence in catch and CPUE

When seahorse presence/absence in the catch was used in Scenario 1 (presence / absence: 226/15), depth, latitude, gear type, gear selectivity and gear operation style were significantly important predictors in the RF model (Fig. B.1a). In Scenario 2, four of the same predictors were important (presence/absence: 577/59) while depth was not considered because of lower sample sizes (Fig. B.1b). Water layer and habitat type were not important in the 1st scenario, and the former was also not important in the 2nd one (in which habitat type was not considered). However, these results should be interpreted with caution as they were based on poor random forest (RF) models. Although both RF achieved high accuracy in predicting presences (99.6%, 99.3%), they had very low accuracy in predicting absences (0%, 5%) (Table B.1). Their MCC were also quite low (-0.02, 0.12), suggesting that both RF models performed no better than random classification.

When presence/absence data was used as the response variables in GLMs (1st and 2nd scenarios), it was found that depth was the only predictor that had a significant effect (in the best GLM of the 1st scenario, Table B.2). The individual GLMs in the 1st (sample size = 241) and 2nd scenarios (sample size = 636) suggested that none of the predictors had a significant effect on seahorse presence in the fishing catch (all $p > 0.007$, t test with Bonferroni correction on p-value; Table B.2). In the 1st scenario, the best GLM (explained 20% deviance, AIC = 98, BIC = 111) contained a fixed effect of depth (here, log-transformed) and gear type. The effect of depth is significant and negative ($p < 0.007$, coefficient = -5.384); the effect of gear type was not significant, although trawl nets tended to more likely catch seahorses compared with gillnets ($p = 0.009$). The best GLM in the 2nd scenario contained latitude and the water layer of gear operation, which was not statistically significant ($p = 0.03$ and 0.04 respectively > 0.01, t test with Bonferroni correction on p-value) (Table B.2).

When the CPUE was used as the response variable in GAMs (3rd and 4th scenarios), more significant effects of the predictors were found compared with the first two scenarios (Table B.2 vs. Table B.3). First, latitude and depth while used alone (i.e., individual GAMs) explained more than half of the deviance and their spline fits (both $k > 4$) were significant ($p < 0.007$, t tests with

Bonferroni correction). When both latitude and depth was used in the GAM in the 3rd Scenario, it was found that higher CPUEs were more likely to be found in the latitudes between N 9.0 – 10.5 Central Region and Rameswaram Peninsula) and secondarily between N 12.5– 13 (northern part of the Northern region, Fig. B.2). This was consistent with the result from a simple GAM based on latitude alone in the 4th Scenario when all available data for latitude was used (Fig. B.3).

There tended to be higher CPUE at deeper waters as suggested by the best GAM in the 3rd scenario (Fig. B.2). But when only depth was used in the GAM (in the 3rd Scenario), CPUE tended to be higher in shallower waters, this effect also tended to be non-linear ($s > 7$, $p < 0.007$; Fig.B.4). Among the gear types, trawl net and other gears (including divers, drag nets and shore seines) caught significant more seahorses than gill nets. Active gears caught significantly more seahorses than passive gears. Gears operated in the water column caught fewer seahorses than gears operated at the bottom. Flat and rocky/stony habitats also tended to catch slightly fewer seahorses than biogenic habitats. Selective gears tended to catch slightly more seahorses than non-selective gears in the 3rd scenario, while they caught significantly less seahorse in the 4th scenario. Overall, the best CPUE predictive models explained over 72% of the deviance in the 3rd scenario, but only 47% in the 4th scenario. The best fitted model was achieved when only gear type was used as the fixed-effect variable in both scenarios, suggesting that my gear-type variable (trawl vs. gill net vs. others) could be the best categorical predictor (compared with other variables used in the study) in representing the impact of gears upon CPUE of seahorses.

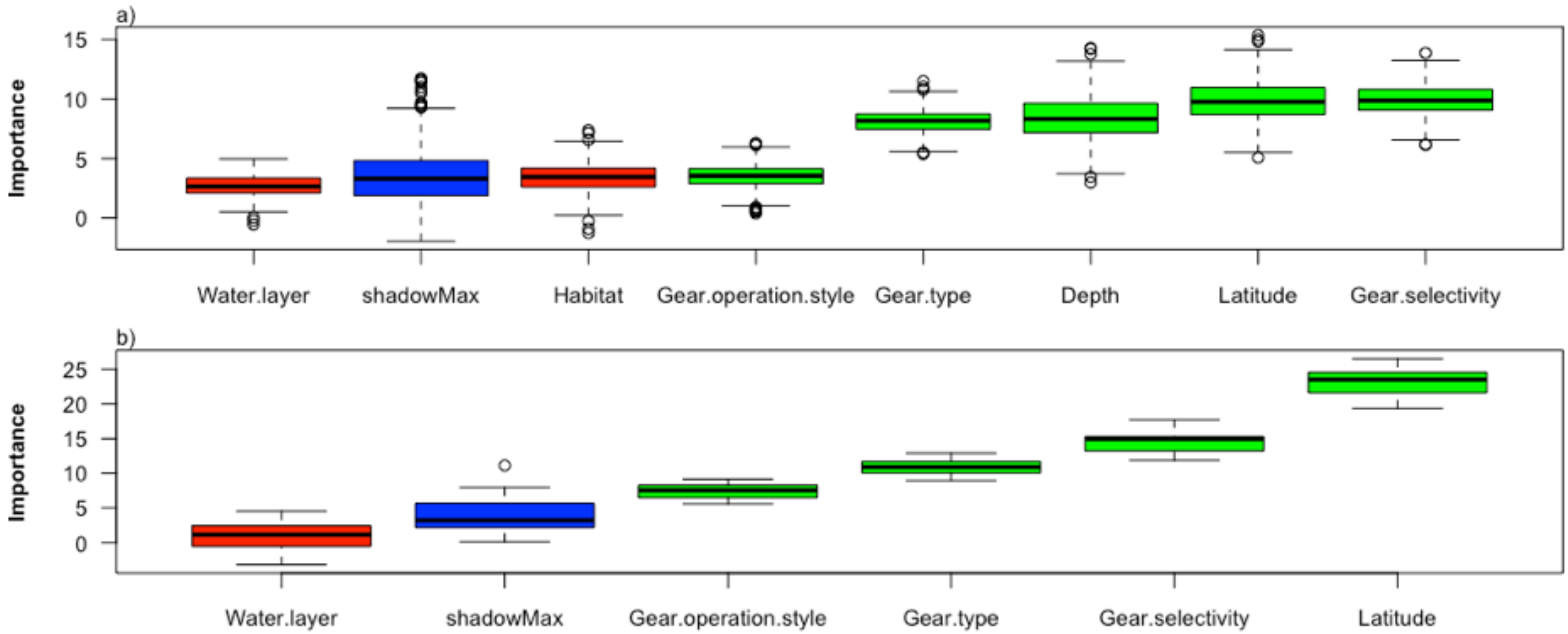


Figure B.1 Importance of seven predictors in the random forest model in a) Scenario 1 and b) Scenario 2. The importance was measured by the normalized mean decrease in model accuracy after permutating data of the predictor. shadowMax, the maximum importance of 'shadow' variables in each permutation. The shadow variables' values are derived by shuffling values of the original attribute across objects. Each time, the minimum, mean, and maximum importance value of all shadow variables were calculated. This shuffling was performed multiple times to obtain statistically valid results. The maximum importance of the shadow variables was used as a reference for detecting important attributes. Attributes with green boxes were important.

Table B.1 Rank of importance of the different variables in predicting seahorse presence/absence in catches for scenario 1 and 2 based on RF models.

Variable	1st Scenario	2nd Scenario
	Rank of importance in RF	Rank of importance in RF
Latitude	2	1
Gear type	4	3
Gear operation style	5	4
Water layer	Not important	Not important
Habitat	Not important	-
Depth	3	-
Selectivity	1	2
Presence: Absence	226:15	577:59
Model accuracy	0.93	0.91
Presence accuracy	99.6%	99.3%
Absence accuracy	0%	5%
Matthews correlation coefficient	-0.02	0.12

Table B.2 GLMs in the 1st and 2nd scenarios using seahorse presence/absence in the catch. In Scenario 2 it was found that only depth had a significant effect on seahorse presence/absence in the catch. The effect of gear type was not found to be significant, though seahorses were more likely to be present in trawl nets than gill nets. The best GLM in scenario one contained a fixed effect of depth and gear selectivity, and in Scenario 2 contained latitude and water layer of gear operation.

Variable	Category	1st Scenario		2nd Scenario	
		individual GLM	Best GLM	individual GLM	Best GLM
Intercept			10.9*		4.73*
Latitude	-	-0.336 (p = 0.066)	-	-0.267 (p = 0.0124)	-0.228 (p = 0.03)
Gear type	Trawl	-0.435 (p = 0.645)	3.280 (p = 0.01)	0.231 (p = 0.446)	
	Gill net	2.833 (control)	(control)	2.124 (control)	-
	Others	-0.067 (p = 0.933)	-3.45 (p = 0.03)	0.164 (p = 0.725)	-
Gear operation style	Active	2.693 (control)	-	2.344 (control)	-
	Passive	0.14 (p = 0.875)	-	-0.220 (p = 0.455)	-
Water layer	Bottom	2.713 (control)	-	2.460 (control)	-
	Water column	-0.005 (p = 0.995)	-	-0.722 (p = 0.016)	-0.629 (p = 0.04)

Table B.2 (Con't) GLMs in the 1st and 2nd scenarios using seahorse presence/absence in the catch

Habitat	Biogenic	3.738 (control)	-	-	-
	Flat	-1.718 (p = 0.027)	-	-	-
	Rocky/Stony	15.828 (p = 0.992)	-	-	-
Log (1+Depth)	-	-1.475 (p = 0.021)	-4.85*	-	-
Selectivity	no	2.812 (control)		2.418 (control)	-
	yes	-0.585 (p = 0.343)		-0.406 (p = 0.15)	-
Null deviance		112.35	112.35	392.72	392.72
Residual Deviance			89.51		382.85
AIC	-	-	97.51	-	388.85
BIC	-	-	111.45	-	399.7
% deviance	-	-	0.203	-	0.025
		*p-value < 0.0071 namely 0.05/7 (Bonferroni correction)			*p-value < 0.01 namely 0.05/5 (Bonferroni correction)

Table B.3 Scenario 3 and 4 using CPUE as a response variable in GAMs. It was found that individual GAMs of latitude and depth explained more than 50% of the deviance. Overall the best model in Scenario 3 explained ~72% of the deviance, but only ~47% of the deviance in Scenario 4.

Variable	Category	3rd Scenario		4th Scenario	
		individual GAM	Best GAM	individual GAM	Best GAM
Latitude	-	s = 6.212*	s = 7.847*	s = 7.466*	s = 7.317*
Gear type	Trawl	0.417	2.344*	0.792*	1.238*
	Gill net	5.086* (control)	2.413*	5.195* (control)	4.056* (control)
	Others	2.173*	2.828*	2.361*	2.474*
Gear operation style	Active	6.147* (control)	-	6.445*	-
	Passive	-1.061 (p = 0.007)	-	-1.249*	-
Water layer	Bottom	6.135* (control)	-	6.399* (control)	-
	Water column	-0.975 (p = 0.018)	-	-1.256*	-
Habitat	Biogenic	6.903* (control)	-		-
	Flat	-1.319*	-		-
	Rocky/Stony	-2.793*	-		-

Table B.3 (Con't) Scenario 3 and 4 using CPUE as a response variable in GAMs.

Log (1+Depth)	-	s = 7.33*** (56.6%)	s = 4.764*		-
Selectivity	no	6.045* (control)	-	6.406* (control)	-
	yes	0.110 (p = 0.7)	-	-0.676*	-
deviance	-	-	72.1%	-	46.80%
AIC			2253		5518
		*p-value < 0.0071		*p-value < 0.01	
		namely 0.05/7 (Bonferroni correction)		namely 0.05/5 (Bonferroni correction)	

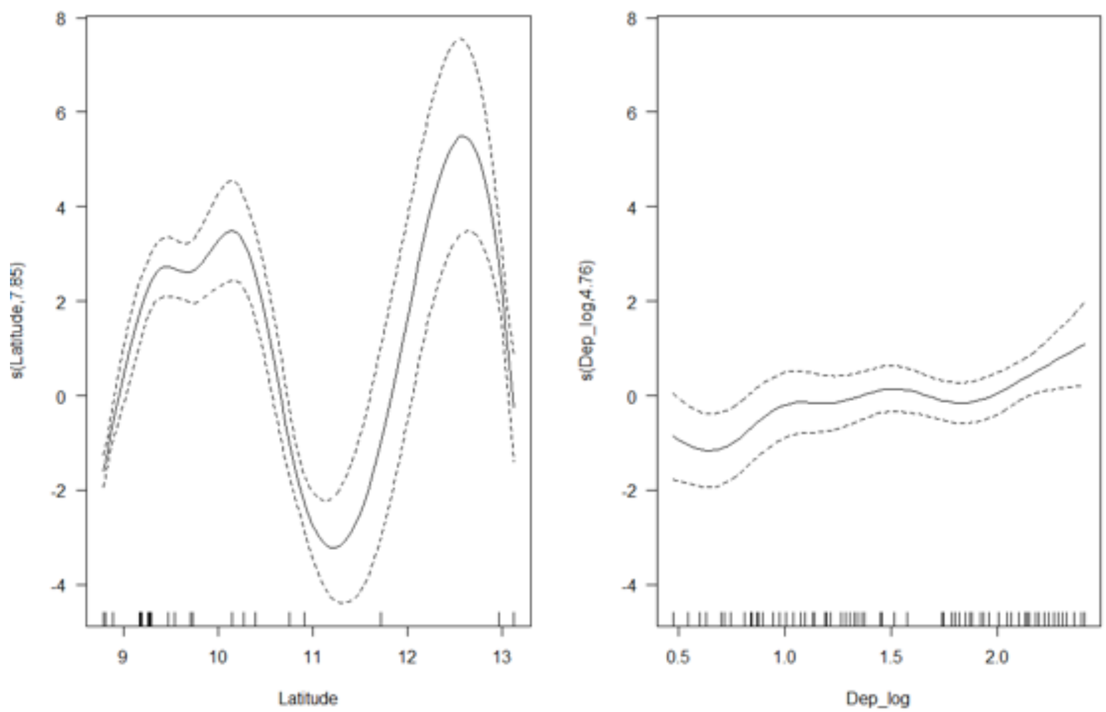


Figure B.2 Smoothed curve of the additive effect to the estimated catch per unit effort (CPUE) of seahorses for the log-transformed depth (left) and latitude (right) in the GAM (best GAM model using depth, latitude, and gear type as predictors in Scenario 3). Value on the y-axis represent the effect size. A negative value means a negative effect upon CUPE. Dotted lines represent 95% confidence intervals, and the mark along the x-axis represent a single observation. When latitude and depth were used in the GAM. The effects of log-transformed depth and latitude on CPUE was non-linear ($s = 7.33$ and 6.21, both p values < 0.001). CPUE was likely to be greater in the latitudes between N 9.0 – 10.5 (Central Region and Rameswaram Peninsula) and secondarily between N 12.5 – 13.0 (northern part of the Northern region, but this might reflect the error associated with the interpolation of latitude data given there were only a few observations in this range).

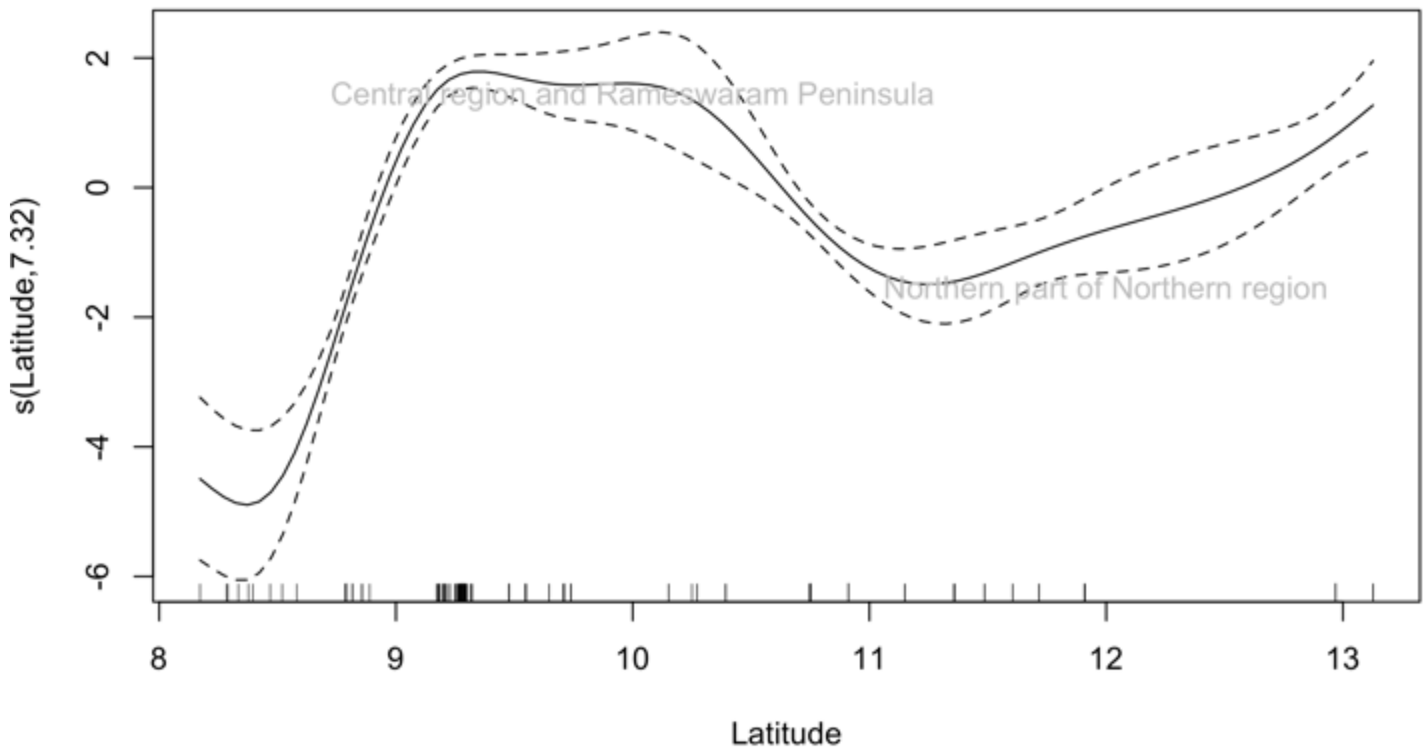


Figure B.3 Smoothed curve of the effect of latitude to the estimated catch per unit effort (CPUE) of seahorses in the GAM (best GAM model using latitude and gear type as predictors in Scenario 4). A negative value means a negative effect upon CUPE. Dotted lines represent 95% confidence intervals, and the mark along the x-axis represent a single observation. The effect of latitude to CPUE is non-linear (s = 7.47, p < 0.001). CPUE was likely to be the highest in the latitudes between N 9.0 – 10.5 (Rameswaram Peninsula and Central Region).

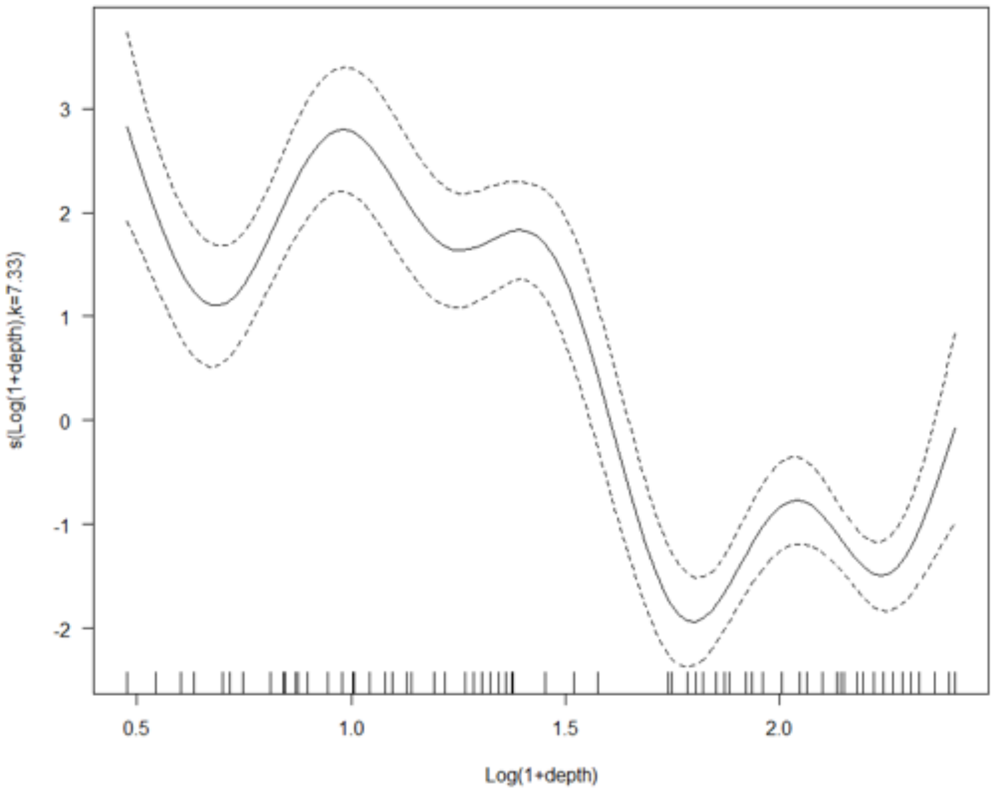


Figure B.4 Smoothed curve of the effect of log-transformed depth to the estimated catch per unit effort (CPUE) of seahorses in the GAM (GAM model using log-transformed depth alone in Scenario 3). A negative value means a negative effect upon CUPE. Dotted lines represent 95% confidence intervals, and the mark along the x-axis represent a single observation. The effect of log-transformed depth to CPUE is nonlinear (s = 7.33, p < 0.001). CPUE is higher in shallower water (log(1+depth) < 3.8 or depth < 44 m).

Appendix B.6a Mean purchasing and selling price per individual seahorse (plus or minus SD) across various trade levels along the Northern region. According to traders in this region, SS represents Super small seahorses (400 seahorses/kg), S for Small (300seahorses/kg), M for Medium (100 seahorses/kg), L for Large (60 seahorses/kg).

Level	Purchasing price in USD per individual							Selling price in USD per individual				
	Mean ± SD (n)	Mean price by size (n)					Mean ± SD (n)		Mean price by size (n)			
		S	M	L	Dry	Wet		SS	S	M	L	Alive
Secondary Buyer (Level3)		Negligible						0.62(1)		5.51(1)	16.64(1)	
Primary Buyer (Level 2)		0.21±0.1 (2)		11.19±5.38(2)				0.41(1)	0.74±0.69 (3)	6.88(1)	13.66±6.66 (2)	
Fishers (level1)							3.82±3.38(41)		0.26±0.15(39)		7.86±4.94(48)	1.72(2)

Appendix B.6b Mean purchasing and selling price per individual seahorse (plus or minus SD) across various trade levels along the Central Region. The only estimates available were from fishers, and classification of seahorses in to small, medium, and large was based on the length of the seahorses. SS stands for super small seahorses, S for small seahorses (<6 cm in length), M for medium seahorses (6-15 cm in length) and L for large seahorses (> 15 cm) based on reports from fishers interviewed.

Level		Purchasing price in USD per individual						Selling price in USD per individual					
	Mean ± SD (n)		Mean price by size (n)					Mean ± SD (n)	Mean price by size (n)				
		SS	S	M	L	Dry	Wet		S	M	L	Dry	Wet
Fishers (level1)								0.43±0.07(40)	0.32±0.24(5)		0.99±0.34(5)	0.28±0.11(2)	0.28±0.15(3)

Appendix B.6c Mean purchasing and selling price per individual seahorse (plus or minus SD) across various trade levels along the Rameswaram Peninsula. According to traders in this region, SS represents Super small seahorses (1100 seahorses/kg), S for Small (638 seahorses/kg), M for Medium (494 seahorses/kg), L for Large (295 seahorses/kg) based on reporting size by fishers and traders.

Level		Purchasing price in USD per individual						Selling price in USD per individual						
	Mean ± SD (n)		Mean price by size (n)					Mean ± SD (n)		Mean price by size (n)				
		SS	S	M	L	Dry	Wet		SS	S	M	L	Dry	Wet
Consolidator (Level4)	0.21(1)	0.05 (1)			0.69(1)			0.27(1)	0.08±0.02(2)	0.33±0.2(2)	0.64±0.22(3)	1.48±0.87(4)		
Secondary Buyer (Level 3)			0.14(1)	0.48(1)	0.69(1)					0.28(1)	0.69(1)	0.97(1)		
Primary Buyer (Level 2)	0.4±0.2(5)							0.78±0.1(4)				1.41(1)		
Fishers (level1)								0.20±0.1(51)		0.31±0.05(3)		0.26±0.04(3)	0.27(1)	0.15±0.04(4)

Appendix B.6d Mean purchasing and selling price per individual seahorse (plus or minus SD) across various trade levels along the Southern region. According to traders in this region, S represents Small seahorses (600 seahorses/kg), M for Medium (475 seahorses/kg), L for Large (225 seahorses/kg) based on reporting size by traders.

Level	Purchasing price in USD per individual						Selling price in USD per individual					
	Mean ± SD (n)	Mean price by size (n)					Mean ± SD (n)	Mean price by size (n)				
		S	M	L	Dry	Wet		S	M	L	Dry	Wet
Consolidator (Level4)								0.23 (1)	0.45(1)	1.59(1)		
Fishers (level1)							0.09±0.11(33)		0.76(1)	1.378(1)	0.27(1)	0.27(1)

Appendix C Supporting material for Chapter 4

This appendix contains the following supporting material from the methods and results, and includes i) questions asked during my interviews ii) a table with a description of the sites in which I conducted interviews iii) sources of data on operating costs of boats and labour wage structures iv) wage structures from published literature and my interviews v) methods for determining the effect of different predictors on boat income and crew income vi) results from post-hoc comparisons for CPUE and prices vii) supplemental percentage income from seahorses across different boat scenarios and wage structures viii) results about the factors determining the income from seahorses relative to boat and crew income.

Appendix C.1 Questions asked during interviews

Fishers	**Name (if possible):**

Interview Number: Date: Start Time: End Time:

Place Interview was conducted:

General

1. What is your role on the fishing vessel (owner/driver/crew)?
2. What type of boat do you work on?
3. What is the length of the boat?
4. What type of net do you use?
5. What is the horsepower of the boat?
6. What is the mesh size of the fishing net?
7. What is the duration of each fishing haul (hours)?
8. How many hauls do you set per day?
9. What is the number of days per trip?
10. How many days do you fish per week?
11. How many days do you fish per month?
12. How many months do you fish in a year?
13. How many people work on this boat?
14. Which months are the peak season for fish?
15. Which months are the off season for fish?
16. What is the diesel consumption per trip?
17. If diesel, consumption is less than subsidized volume, what do you do with the rest?

Following questions are repeated for peak season and then off season:

18. What is the average weight of the haul?
19. What is the average value of the haul?
20. From your catch, what is the proportion of total catch going as fresh fish to the market? What is its value? What are the dominant species in this catch?
21. What is the proportion of total catch going as dried fish for human consumption? What is its value? What are the dominant species in this catch?
22. What is the proportion of total catch going for chicken feed? What is its value? What are the dominant species in this catch?
23. What is the proportion of total catch going as dried fish for fish meal and fish oil? What is its value? What are the dominant species in this catch?
24. What is the proportion of total catch being exported? What is its value? What are the dominant species in this catch?
25. What is the proportion of total catch being discarded? What is its value? What are the dominant species in this catch?
26. What is the proportion of total catch taken home personally by fishers? What are the dominant species in this catch?

27. What is the proportion of total catch given away to relatives? What are the dominant species in this catch?
28. What is the proportion of total catch used for other purposes (decorations etc)? What is its value? What are the dominant species in this catch?
29. What is the proportion that seahorses form (how many per trip/month/year)? What is its value?
30. Do you obtain sea cucumbers and other chanks? How many (different units of time)? What is it worth?

Operating Costs

1. What are your daily operating costs?
2. What are your monthly operating costs?
3. What are your yearly operating costs?
4. How much is the daily income of the boat?
5. How much is the monthly income of the boat?
6. How much is the yearly income of the boat?
7. What are the major costs? How is it divided?
8. How are the profits divided?
9. How are the labour paid? If it is a share system, what is the labour share?

Fish Buyers (first for peak and then repeat for off)

1. What is the average volume bought in peak season? For what value?
2. How many boats do you buy fish from?
3. What do you do with the fish bought?
4. What are the main types of fish bought?
5. What is your income from this fish?
6. Do you see seahorses?
7. How many per day/week/month/year?
8. What do you do with them?
9. How much income do you earn from them?
10. What do you do with this income from seahorses?

Fish sorters

1. How many boats do you sort for?
2. How many hours per day?
3. How many days per week?
4. How many days per month?
5. How many months per year?
6. How much do you earn in a day?
7. While sorting do you keep any fish aside?
8. How do you utilize this fish?
9. Do you see seahorses?
10. How many per day/week/month/year?
11. What do you do with them?

12. How much income do you earn from them?
13. What do you do with this income from seahorses?

Appendix C.2: Site description of the various landing centres in which interviews were conducted from 2015-2017, ordered from North to South.

Location	Description
Nagapattinam Fishing Harbour	A bustling harbour, with large multi-day trawl fishing boats. Harbour filled with mounds of miscellaneous fish, and occurrences of open auctioning of seahorses.
Palk Bay drag-netters	Many wind-sail boats tied by the water's edge. Boats operate on shallow, seagrass beds.
Palk Bay trawlers	Small landing centres, with similar smaller sized trawl boats that operate along the shore in the shallow, seagrass rich Palk Bay region
Mandapam	Two landing centres- one located on the North and South. North side trawlers operate from a busy beach and anchor amongst rocks. Fish brought to shore by smaller boats. South side boats operate in the highly biodiverse Gulf of Mannar region. Boats switch according to season.
Pamban	A small jetty with relatively fewer trawl boats operating on the south side of the Rameswaram Peninsula, in the Gulf of Mannar
Rameswaram Fishing Harbour	Many boats operating off a small jetty with the shore filled with discarded marine life. Boats often caught fishing in Sri Lankan waters, with the International Maritime Boundary Line (IMBL) a mere 8nm from shore. Trawl boats often on strike.
Ervadi and Kilakarai	Small number of trawl boats operated off a well-constructed and large jetty in Kilakarai and off the beach in Ervadi.
Tuticorin Fishing Harbour	A large harbour with large trawl boats. Single-day fishing, and all boats arrive at a similar time every night. Harbour comes alive every night, except Sunday which is a rest day

Appendix C.3: Sources of data for operating cost of fishing boats and crew wage structures.

Location	Income Data	Sources
Nagapattinam fishing harbour	Operating costs	• Primary interview data
	Crew wage structures	• Primary interview data • Local fisheries officials
Soliyakudi and Thondi	Operating costs	• Extrapolation from vessel data from other landing centres in the district
	Crew wage structures	• Stephens et al., 2013
Palk Bay drag nets	Operating costs	• Primary interview data
	Crew wage structures	• Primary interview data
Mandapam	Operating costs	• Primary interview data
	Crew wage structures	• Primary interview data • Stephens et al., 2013
	Operating costs	• Primary interview data
	Crew wage structures	• Based on pay structures from other landing centres in the district
Pamban	Operating costs	• Primary data
	Crew wage structures	• Primary data • Local fisheries researchers
Rameswaram	Operating costs	• Primary data • Johnson and Narayanakumar, 2015
	Crew wage structures	• Primary data • Stephens et al., 2013
Ervadi and Kilakarai	Operating costs	• Primary interview data

Ervadi and Kilakarai	Crew wage structures	• Primary interview data • Local fisheries officials
Sorters	Sorter wages	• Primary interview data
Tuticorin Fishing Harbour	Operating costs	• Primary interview data
	Crew wage structures	• Primary interview data

Appendix C.4 Classification of wage structures from different landing centres.

S.No	Wage structure	Risk	Locations observed
1	20% of total catch, with 2-3% for the driver	Medium	Soliyakudi, Thondi, Mandapam North and South, Pamban, Ervadi and Kilakarai
2	Daily allowance + 20% of the profit	Medium	Mandapam North
3	Daily allowance+20% of total catch sales (7.5-8% for drivers, 4-5% for crew, 6-7% for second drivers) *	Medium	Mandapam North, Rameswaram Fishing Harbour
4	Daily allowance+15-30% of the profit	Medium	Pamban
5	Fixed salary	Low	Ervadi and Kilakarai
6	1 share for the boat, 1 share for the owner, 1 share for the crew	Medium	Devipattinam and Thirupallaikudi
7	Fixed salary	Low	Nagapattinam Fishing Harbour
8	Fixed salary+30% of profits	Low	Nagapattinam Fishing Harbour
9	22 to 30% of catch sales	Medium	Nagapattinam Fishing Harbour
10	Fixed salary + profits at discretion of owner if profits greater than ~ USD 750	Low	Tuticorin Fishing Harbour

Appendix C.5 Methods to determine the effect of predictors on boat and crew income

Vessel income

I collated a total of 753 observations (72 for drag nets vs 681 for trawl nets) for three predictor variables and one response variable. These predictors were either directly provided by fishers or obtained from my field notes. The three predictors included one location variable (i.e., landing centre), one categorical variable for fishing gears (drag net vs trawl net), and one for vessel income scenarios (50% loss, at operating costs, 50% profit). I used fishers as the random variable, and my response variable was the proportion that seahorses contributed to overall vessel income in a day.

Crew income

I followed a similar methodology as above for crew income. The main difference from my analysis of vessel income was that I collated a total of 2484 observations (72 for drag nets vs 2372 for trawl nets) for four (rather than three) predictor variables and one response variable. The fourth predictor variable came from crew income scenario; (1) Low-risk scenario where the crew were paid a base salary and could earn incentives on top and (2) Medium-risk scenario where salaries depended on the catch/profit and crew received about 20-30% shares.

Appendix C.6a Post-hoc analysis of CPUE using the conover test with bh adjustment, after significant differences were observed between groups using the Kruskal-Wallis Test.

Col Mean- Row Mean	Mn	NFH	PBD	RMM	PBT	Sorters
NFH	12.67630 0.0000*					
PBD	0.440272 0.3851	-13.09196 0.0000*				
RMM	0.448443 0.4041	-11.72824 0.0000*	0.035712 0.4858			
PBT	0.723946 0.3084	-12.39745 0.0000*	0.303177 0.44211	0.248842 0.4220		
Sorters	8.535219 0.0000*	-7.280136 0.0000*	5.348371 0.0000*	4.927698 0.0000*	4.941678 0.0000*	
TFH	15.42328 0.0000*	6.034697 0.0000*	15.88614 0.0000*	14.51949 0.0000*	15.23510 0.0000*	10.87451 0.0000*

Appendix C.6b Post-hoc analysis of price per seahorse using the conover test with bh adjustment, after significant differences were observed between groups using the Kruskal-Wallis Test.

Col Mean-Row Mean	Mn	NFH	PB	RMM	PBT	Sorters
NFH	-15.92518 0.0000*					
PB	-5.91934 0.0000*	8.701817 0.0000*				
RMM	0.227871 0.41	14.76731 0.0000*	5.760685 0.0000*			
PBT	-3.880233 0.0001*	11.1011 0.0000*	2.015802 0.0251	-3.853927 0.0001*		
Sorters	6.057683 0.0000*	23.36505 0.0000*	11.96848 0.0000*	5.417954 0.0000*	9.907381 0.0000*	
TFH	6.43231 0.0000*	23.80985 0.0000*	12.33863 0.0000*	5.767246 0.0000*	10.27753 0.0000*	0.378859 0.3703

Appendix C.6c Post-hoc analysis of prices obtained from seahorses per boat per day using the conover test with bh adjustment, after significant differences were observed between groups using the Kruskal-Wallis Test

Col Mean-Row Mean	Mn	NFH	PBD	RMM	PBT
NFH	-0.605386 0.3412				
PBD	-2.599185 0.0111*	-2.717400 0.0093*			
RMM	-0.098835 0.4607	0.495873 0.3326	2.544468 0.0113*		
PBT	-2.098631 0.0314	-2.081926 0.0294	0.556388 0.3340	-2.034397 0.0299	
TFH	4.754760 0.0000*	7.238388 0.0000*	7.872903 0.0000*	4.967122 0.0000*	7.407210 0.0000*

Appendix C.6d Post-hoc analysis of price received from seahorses per crew member per day using the conover test with bh adjustment, after significant differences were observed between groups using the Kruskal-Wallis Test

Col Mean-Row Mean	Mn	NFH	PB	RMM	PBT	Sorters
NFH	1.035469 0.1669					
PBD	-4.484796 0.0000*	-7.031982 0.0000*				
RMM	-0.005519 0.4978	-0.973461 0.1742	4.269702 0.0000*			
PBT	-2.252795 0.0159*	-4.148596 0.0000*	2.424758 0.0108*	-2.13916 0.0198*		
Sorters	3.881876 0.0001*	4.1516 0.0000*	9.281613 0.0000*	3.680498 0.0002*	6.80634 0.0000*	
TFH	7.564771 0.0000*	9.311595 0.0000*	13.20712 0.0000*	7.166485 0.0000*	10.80176 0.0000*	4.33365 0.0000*

Appendix C.7 Supplemental percentage income from seahorses to crew across all different boat scenarios and wage structures.

Location	Pay Structure		50% loss	Operating Costs	50%profit
PBD	1 share for boat, 1 for owner and 1 for crew	Mean	111.29	76.48	50.98
		SD	111	148.15	98.76
		Count	24	24	24
NFH	25% catch divided by labour and driver	Mean	6.1	3.05	2.03
		SD	7.65	3.83	2.55
		Count	90	90	90
	30% share catch divided by labour and driver	Mean	5.12	2.56	1.71
		SD	6.37	3.19	2.12
		Count	90	90	90
	Flat rate (but only % of catch if boat makes no money)	Mean	6.4	6.4	2.36
		SD	7.97	7.97	3.13
		Count	90	90	90
	Fixed salary+30% of profits	Mean	6.4	3.2	1.59
		SD	7.97	3.98	2.06
		Count	90	90	90
PBT	20% catch divided by labour and driver	Mean	10.73	5.37	3.58
		SD	11.11	5.55	3.7
		Count	21	21	21
	20% divided only by labour. Driver paid a separate wage	Mean	8.73	4.36	2.91
		SD	8.56	4.28	2.85
		Count	21	21	21
	20% with 2-3% for driver	Mean	9.97	4.99	3.32
		SD	9.79	4.89	3.26
		Count	21	21	21

Mn	20% catch divided by labour and driver	Mean	7.98	3.99	2.66
		SD	7.4	3.7	2.47
		Count	32	32	32
	Basic allowance+20% profit	Mean	16.77	16.77	5.39
		SD	15.77	15.77	5.03
		Count	32	32	32
	Basic allowance+20% of total catch (7.5-8% for drivers, 4-5% for crew, 6-7% for second drivers)	Mean	12.86	8.93	6.85
		SD	12.31	8.55	6.55
		Count	32	32	32
	20% catch divided only by labour	Mean	7.63	3.82	2.54
		SD	5.45	2.73	1.82
		Count	32	32	32
	20% catch divided with 2-3% for driver	Mean	8.72	4.36	2.91
		SD	6.23	3.12	2.08
		Count	32	32	32
PnS	20% catch divided by labour and driver	Mean	9.33	4.66	3.11
		SD	5.44	2.72	1.81
		Count	11	11	11
	20% catch divided only by labour	Mean	8.18	4.09	2.73
		SD	4.81	2.4	1.6
		Count	11	11	11
	20% catch divided with 2-3% for driver	Mean	9.35	4.67	3.12
		SD	5.49	2.75	1.83
		Count	11	11	11
	Basic allowance+22.5% profit	Mean	18.92	18.92	5.68
		SD	11.01	11.01	3.27
		Count	11	11	11

RMM	20% catch divided by labour and driver	Mean	9.86	4.93	3.29
		SD	8.79	4.39	2.93
		Count	21	21	21
	Basic allowance+20% of total catch (7.5-8% for drivers, 4-5% for crew, 6-7% for second drivers)	Mean	14.89	10.57	7.37
		SD	12.69	9.11	6.41
		Count	21	21	21
	20% divided only by labour. Driver paid a separate wage	Mean	8.23	4.11	2.74
		SD	7.31	3.66	2.44
		Count	21	21	21
	20% with 2-3% for driver	Mean	9.4	4.7	3.13
		SD	8.36	4.18	2.79
		Count	21	21	21
EandK	20% catch divided by labour and driver	Mean	3.35	1.67	1.12
		SD	1.88	0.94	0.63
		Count	10	10	10
	20% catch divided only by labour	Mean	2.87	1.43	0.96
		SD	1.61	0.81	0.54
		Count	10	10	10
	20% catch divided with 2-3% for driver	Mean	3.27	1.64	1.09
		SD	1.85	0.92	0.62
		Count	10	10	10
	Flat rate	Mean	1.61	1.61	1.61
		SD	0.85	0.85	0.85
		Count	10	10	10
TFH	Flat rate	Mean	0.01	0.01	0.01
		SD	0.02	0.02	0.02
		Count	37	37	37

Appendix C.8 Results regarding the factors determining the income from seahorses relative to boat and crew income.

a) Relative to boat income

Among the simple GLMMs, models with gear type (AIC=350.4) and location (AIC=262.5) were an improvement to model fit compared with the null model (AIC = 454) (Table C.1). In the case of boat scenarios (AIC=-831.9), I found the seahorse contribution to boat income had a significant negative correlation with the 50% boat profit scenario (coefficient = -0.31, p<2e-16) and a significant positive correlation with the 50% loss scenario (coefficient=0.59, p<2e-16). For gear type, supplemental seahorse contribution to boat income had a significant negative correlation with trawl boats (coefficient = -4.99, p < 2e-16), and for location I found a significant positive correlation with the Palk Bay region (coefficient =2.75, p =6.27 e-07) and significant negative correlations with the Tuticorin Harbour having a negative location (coefficient = -3.4, p =2.20 e-09).

For the best GLMM, value of seahorses relative to boat income had a significant negative correlation with trawl nets, but a significant positive correlation with all locations other than the Tuticorin Fishing Harbour location for which I observed a significant negative correlation (Table C.1).

b) Relative to fishers' income

Among the simple GLMMs, all models were an improvement on model fit compared with the null model (AIC = 9375.1). I find that supplemental seahorse contribution to labour income had a significant negative correlation with the 50% boat profit scenario (coefficient = -0.52, p < 2e-16), but a significant positive correlation with the 50% loss scenario (coefficient = 0.44, p < 2e-16). I also found a significant negative correlation between supplemental income from seahorses to labour income and trawl boats (coefficient = -3.5, p < 2e-16). For locations, I found that supplemental seahorse contribution to labour income had a significant positive correlation with the Mandapam, the Palk Bay region and Pamban South region and a significant negative correlation with the Tuticorin location (Table C.2). I found that supplemental seahorse contribution to labour income had a significant negative correlation with the medium risk scenario (coefficient=-0.17, p=4.93e-08).

I found that in the best GLMM (AIC=7268.76) a significant correlation (negative) was observed between supplemental seahorse contribution to labour income in the 50% profit scenarios, in trawlers, at the Tuticorin location, and in medium risk locations (Table C Appendix.2).

Table C.1 Generalized Linear Mixed Models (GLMMs) using a gamma distribution to understand the effect of various predictor variables on the supplemental percentage contribution of seahorses to boat income.

Variable	Category	Individual GLMM	AIC	Best GLMM
Fisher		random effect	454	random effect
Boat scenario	Operating costs	Control***	-831.9	-
	50% loss	0.59 (p < 2e-16) ***		-
	50% profit	- -0.31* (p < 2e-16) ***		-
Gear type	Drag	Control***	350.4	-
	Trawl	-4.99 (p < 2e-16) ***		-3.86 (p < 2e-16) ***
Location	EandK	Control*	262.5	-
	NFH	0.217 (p = 0.68)		0.22 (p < 2e-16) ***
	Mn	0.64 (p = 0.26)		0.68(p < 2e-16) ***
	PB	2.75 (p = 6.27 e -07) ***		0.97(p < 2e-16) ***
	PnS	0.96 (p = 0.16)		1.011(p < 0.0008) **
	RMM	0.74 (p = 0.22)		0.78(p < 2e-16) ***
	TFH	-3.40 (p = 2.20e-09) ***		-3.36(p < 2e-16) ***
Best Model			176.8	

*denotes a significant difference

Table C.2 Generalized Linear Mixed Models (GLMMs) using a gamma distribution to understand the correlation of various predictor variables on the supplemental percentage contribution of seahorses to crew income.

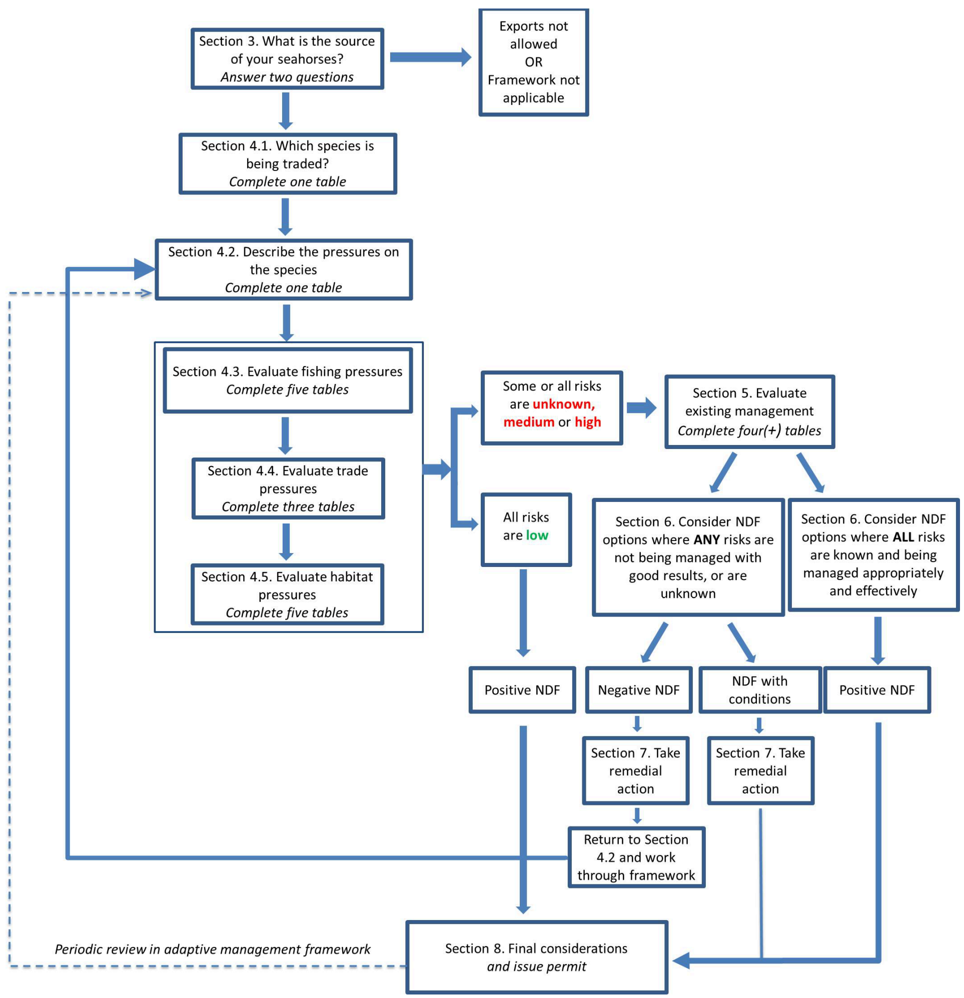
Variable	Category	Individual GLMM	AIC	Best GLMM
Fisher		random effect	9375.1	random effect
Boat scenario	Operating costs	Control	7635.9	-
	50% loss	0.44 ($p < 2e-16$) ***		0.45 ($p < 2e-16$) ***
	50% profit	-0.52($p < 2e-16$) ***		-0.51 ($p < 2e-16$) ***
Gear type	Drag	Control	9331.7	-
	Trawl	-3.50($p < 2e-16$) ***		-2.18($p = 6.40$ e -09) ***
Location	EandK	control	9108.8	-
	NFH	0.04 (p=0.94)		-0.06($p = 0.90$)
	Mn	1.35 (p= 0.01) *		1.40($p < 0.007$) **
	PB	2.12 ($p = 2.39e-05$) ***		1.01($p < 0.06$)
	PnS	1.46 (p<0.02) *		1.46($p < 0.02$) *
	RMM	1.04 (p=0.062)		1.07 ($p < 0.05$) *
	TFH	-4.39 ($p < 2e-16$) ***		-4.42 ($p < 2e-16$) ***
Risk level	Low	Control	9347.6	-
	Medium	-0.17 ($p = 4.93e-08$) ***		-0.21 ($p < 2e-16$) ***
Best GLMM			7268.6	

*denotes a significant difference

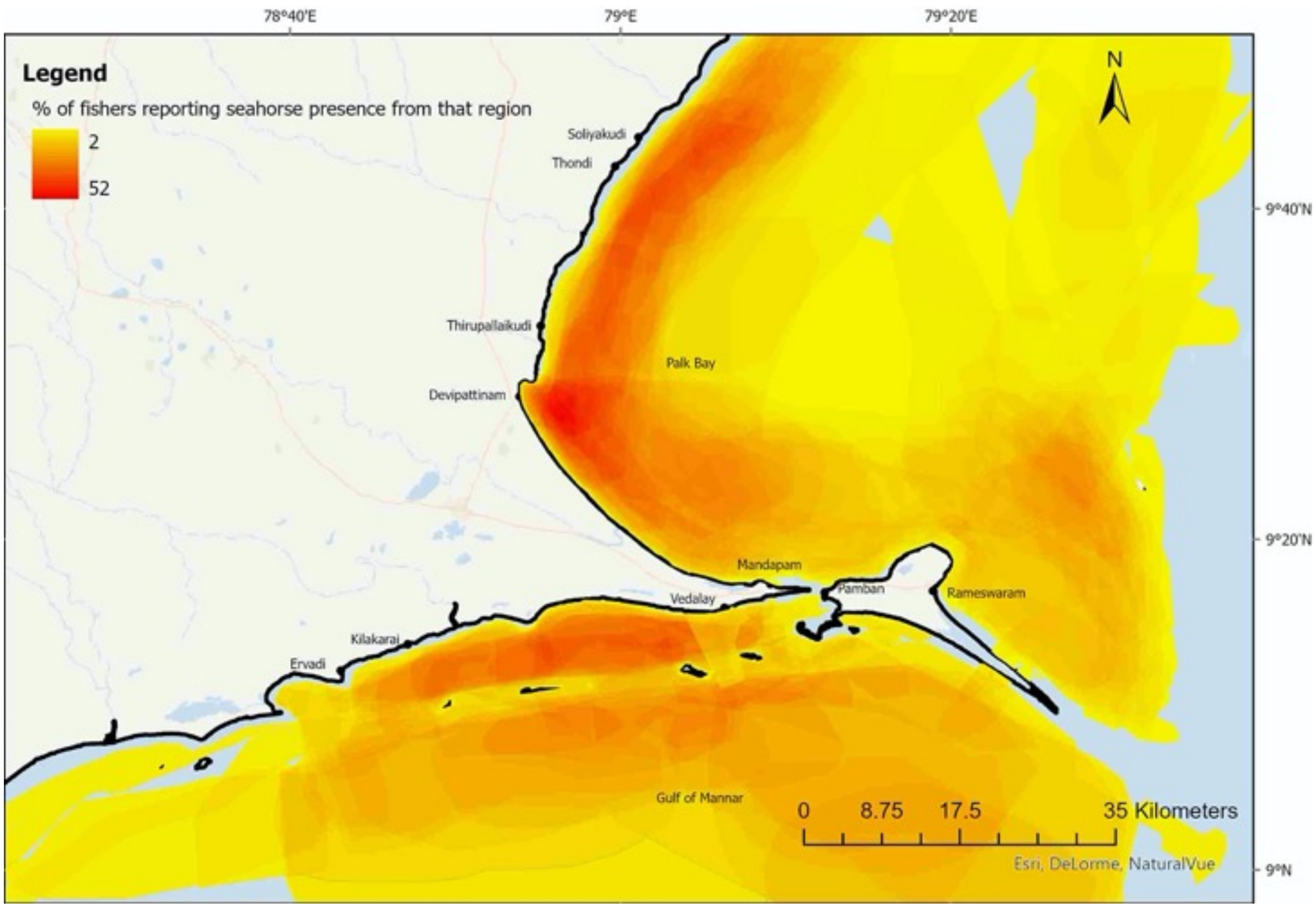
Appendix D Supporting material for Chapter 5

Material for this chapter includes i) the information that goes in to making NDFs and ii) maps on a) percentage of fishers who reported catching seahorses in the study region b) locations at which fishers reported an absence of seahorses in their catches c) percentage of all trawl fishers in the Ramanathapuram District reporting presence of seahorses d) percentage of traditional fishers from the Ramanathapuram District who reported the presence of seahorses e) pressures faced by seahorses from drag-netters and trawlers.

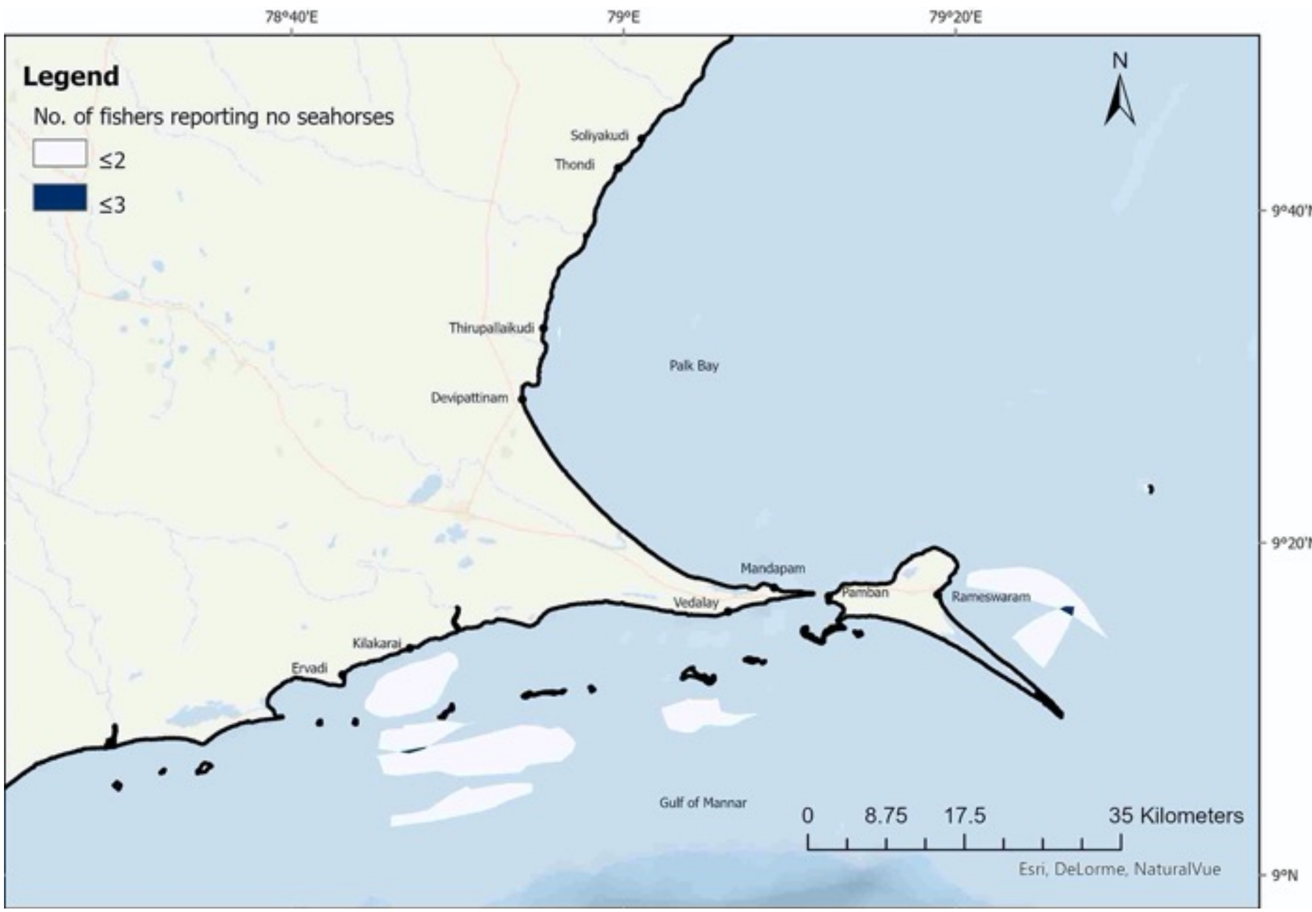
Appendix D.1 Flowchart showing the process and data requirements for making Non-Detriment Findings for seahorses. Detailed information required for the tables may be found in Foster, 2016.



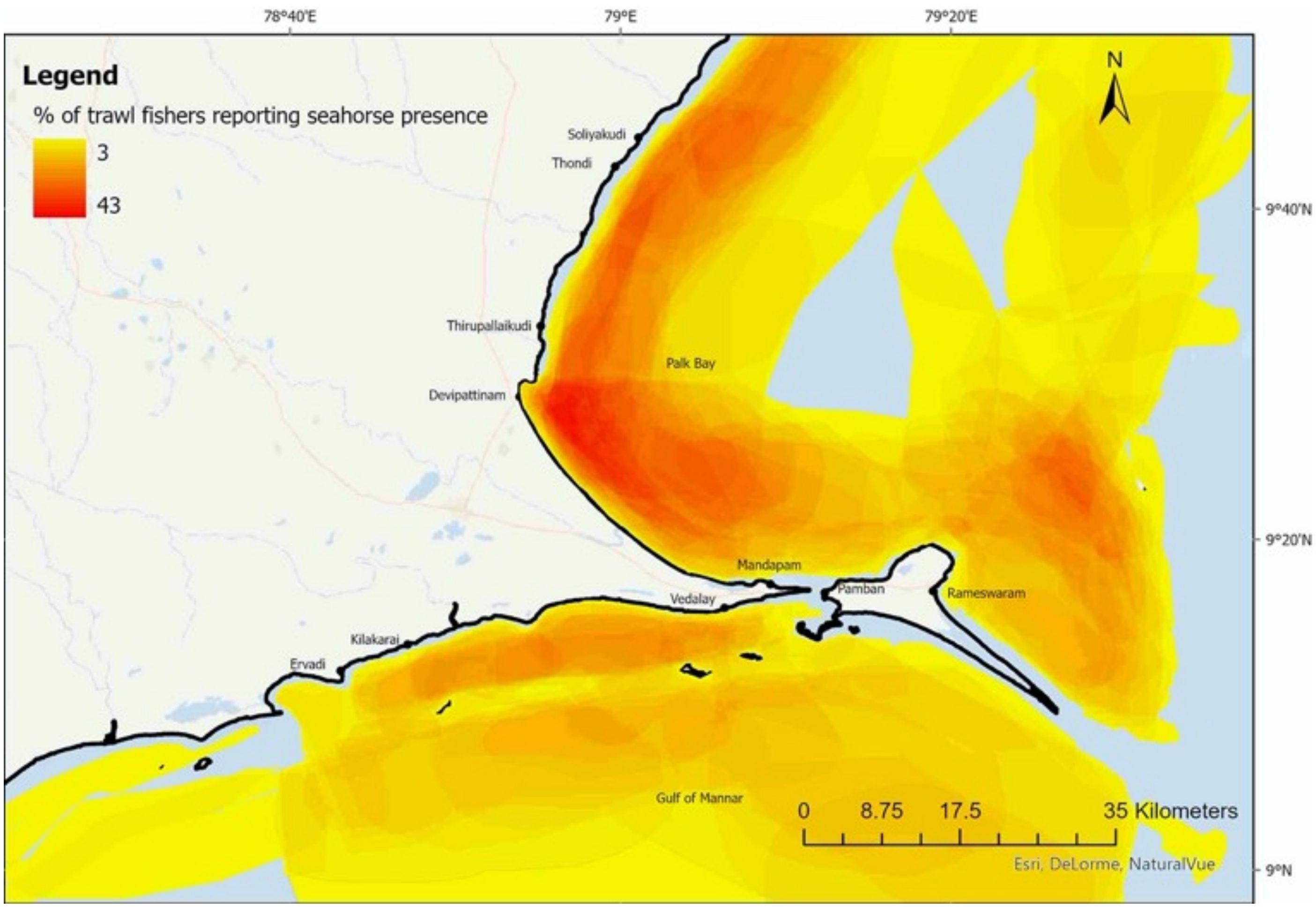
Appendix D.2 Percentage of fishers who reported catching seahorses in the study region, represented by the number of fishers reporting seahorse catches as a percentage of the number of fishers that reported fishing in each of Palk Bay (n=86) or the Gulf of Mannar (n=49). Fishers operating from the Rameswaram peninsula tended to fish in both the Gulf of Mannar and Palk Bay.



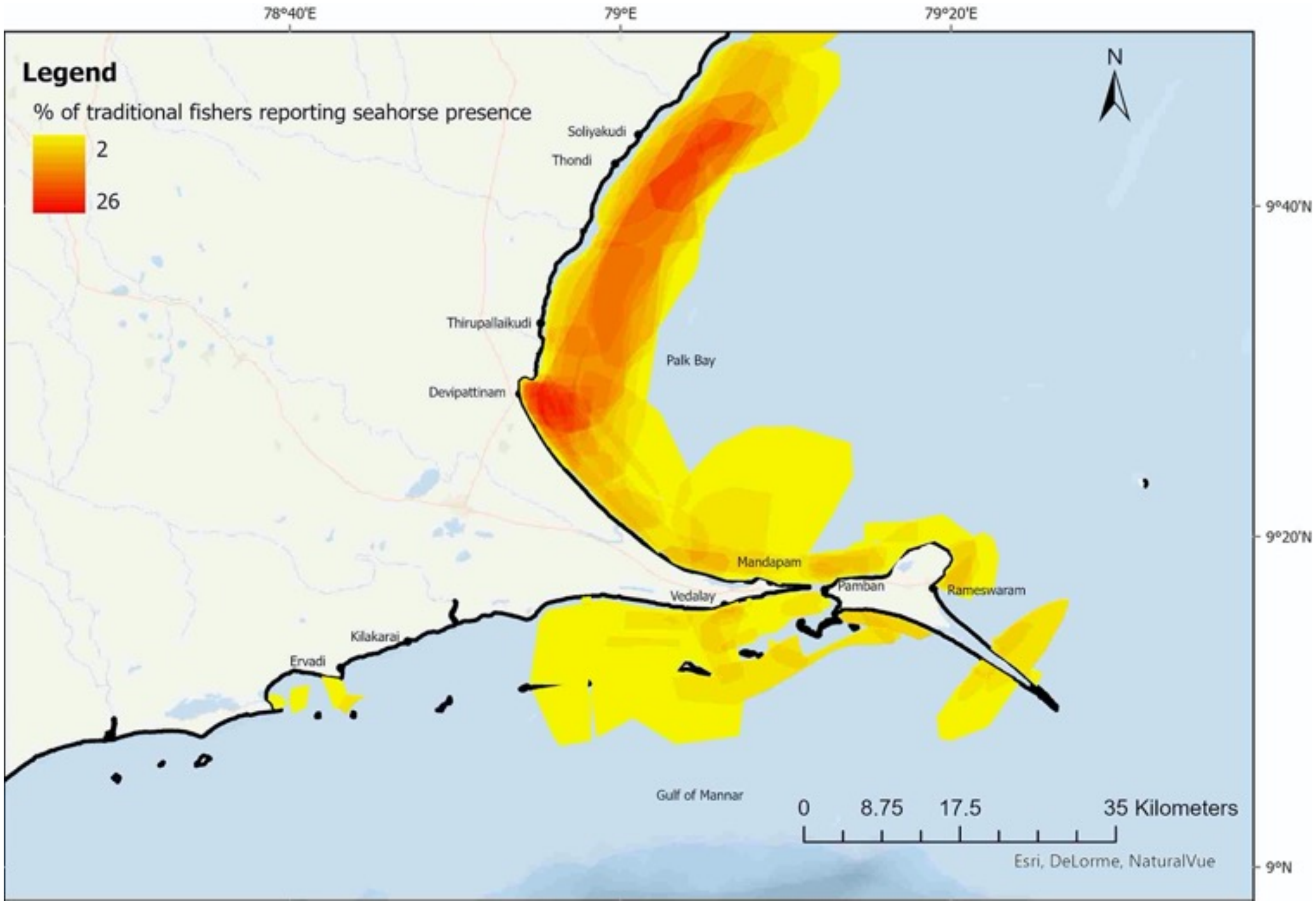
Appendix D.3 Locations at which fishers reported an absence of seahorses in their catches. A maximum of three fishers reported not catching seahorses in any given region- on the seaward side of the islands of the Gulf of Mannar and along the eastern part of the Rameswaram Peninsula.



Appendix D.4 Percentage of all trawl fishers in the Ramanathapuram district from my interviews and PL (n=72) reporting presence of seahorses. Most fishers reported seahorses in the Palk Bay region extending from Mandapam to the North of Soliyakudi.



Appendix D.5 Percentage of traditional fishers from the Ramanathapuram district from my interviews and PL (n=62) who reported the presence of seahorses. Most fishers reported seahorses in the Palk Bay region off the coast of Devipattinam, and further north off the coast of Soliyakudi.



Appendix D.6 Pressures faced by seahorses from drag-netters and trawlers, as measured by the collective active time that fishers employed their nets while fishing (hours/day). Fishing pressure was found to be greatest closest to the shore along the entire extent of the Palk Bay region.