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Assessment of demersal fishery resources in Brunei Darussalam

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BSc., MSc.

Thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy in Biological Sciences

School of Life Sciences
(Environmental Resource Management)
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March 2013

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Acknowledgements

Alhamdulillah.

My research would not have been possible without generous funding. For essential and much appreciated personal financial support, I am grateful to the Brunei Government for awarding me a Ministry of Education Scholarship. Thank you as well to the Scholarship Unit, Ministry of Education (Brunei) and University of Warwick (UK) for funding my research.

No thesis is accomplished alone. My most sincere thanks go to my 'official' supervisors, Dr. James Bull and Prof. Charles Sheppard for taking me under their wings after a year into my PhD, following the retirement of my original supervisor, Prof. Andrew Price. I am especially thankful to Jim for challenging me and helping me to broaden my horizons. His guidance, questioning, advice and contributions to this research have been plentiful that I could count on.

My original supervisor deserves special thanks, as he gave me the opportunity to study for PhD and has encouraged me from the conception of my research plan through to the submission of my thesis, even when it is beyond his call of duty.

Components of my research benefitted from intellectual input from my PhD supervisory committee, Prof. Laura Green and Dr. Paul Neve, whom I gratefully acknowledge. Also thanks to Mr Andrew Mead for his advice on the modelling in Chapter 5.

I am tremendously indebted to the Department of Fisheries (Brunei) for their kind permission in letting me carry out this research project. They allowed me to access their fishery databases and reports in which they have invested a lot of resources. My thanks extend to the DOF officers and staffs: Awang Hj. Abdul Halidi Mohd. Salleh (Director, DOF), Awang Matzaini Hj Juna (MFDM), Awang Elviro A Cinco (MFDM), Awang Abdul Hamid Hj Zainin (MFDM) and Awang Ishak Jarudin (MAS) for their help and useful ideas and suggestions in our discussion sessions; Awang Bidin Suru, Awang Mahmud Abdullah, Awang Hj Amzah Hj Edin, and Awang Hj Aji Hj Sapar for their experienced assistance in the field. I am especially grateful to Dayang Ranimah Hj Abdul Wahab, who was then Head of MFDM when I first started my PhD, but now the Deputy Director of DOF. She not only helped me navigate the bureaucracy at DOF, but has also been considerably supportive throughout my PhD. She has been a true inspiration both as an exceptional leader and as someone who is always approachable and ever patient with my queries.

I owe much thanks to all the fishers in Brunei who participated in the interview survey. I must also express my gratitude to all contacts I made in my pursuit of maps and data; Dayang Hjh Roseidah Hj Kamis (Survey Department, Brunei), Mr. Warwick Newall (Integrated Environmental Consultants Sdn. Bhd.), and personnel from Brunei Darussalam Meteorological Service and Department of Economic Planning and Development (JPKE).

Appreciation is also due to my research assistants, Sarif Mahmud and Aizuddin Roslan, who were with me through every step of data collection in Chapter 5. Also thanks to Hilni Harunsani and Ewana Yusop for proof reading the thesis.

Above all, I am grateful to my family and friends for their constant prayers and unwavering support.

Declaration

I hereby declare that the work presented in this thesis is the result of original research carried out by myself, under the supervision of Dr. James Bull and Prof. Charles Sheppard, unless stated otherwise. All sources of information presented in this thesis have been acknowledged by a reference. No part of this thesis has been submitted for a degree at another university.

Other than my supervisors, Prof. Andrew Price was part of the development of the proposals of the chapters of the thesis, and specifically provided edits and suggestions for improvement of the drafts of Chapter 5.

A manuscript related to Chapter 3, titled "Changes in community structure of finfish catches in Brunei Darussalam between 2000 and 2009", co-authored with CRC Sheppard, R Wahab, ARG Price and JC Bull, has been published in the peer-reviewed journal, *Ocean & Coastal Management,* **76**, 45-51. I conducted data analysis and wrote the manuscript, under the supervision of JC Bull. R Wahab provided the data, while CRC Sheppard and ARG Price reviewed and edited the manuscript.

Summary

A problem commonly encountered in stock assessments of tropical marine resources in developing countries is data paucity, which invariably results from the lack of both human and economic capacity within the government to implement and maintain programmes for data collection and analysis. With special reference to the demersal fishery of Brunei Darussalam, this thesis examines approaches for extracting useful information from data-poor fisheries to assess the state of resources and inform fishery management actions. By using official fishery statistics, augmented by local ecological knowledge (LEK) obtained from fishers engaged in either the large-scale (LS) or small-scale (SS) fisheries in Brunei, changes in demersal fishery resources over the years were assessed. The sustainability of Brunei's demersal capture fishery was evaluated in the face of its ongoing development and climate change.

Using trophodynamic indicators such as mean trophic level (MTL), Fishing-in-Balance (FiB), trophic spectra (TS) and community structure analyses, LS fishery catches of Brunei between 2000 and 2009 revealed a deteriorating state of the coastal demersal ecosystem. Closer examination of the abundance of overall demersal finfish stocks, using the Catch-Per-Unit-Effort (CPUE) index – standardised for other factors not related to abundance – indicated a declining trend, even when total catches remained stationary, although trends in abundance of the different demersal fish families varied. This rapid significant change in recent years is further supported by fishers' LEK on relative abundance of Brunei marine resources. The study on LEK has also revealed the 'shifting baseline syndrome' (SBS) among currently active fishers and their exploited populations, a phenomenon not previously reported for Brunei fisheries.

Findings from the study are synthesised with other information, where a number of key issues and policy options are discussed, and recommendations for the management of the fishery are made. This thesis demonstrates that researchers in data-poor fisheries can utilise different assessment tools, given the resources at their disposal, to assist in the management of marine resources.

List of Abbreviations

C	Catch
CCF	Cross-Correlation Function
chl-a	chlorophyll-a concentration level
CPUE	Catch Per Unit Effort
DOF	Department of Fisheries, Brunei
EAFM	Ecosystem Approach to Fisheries Management
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organisation of the United Nations
FDFW	Fishing Down the marine Food Web
FiB	Fishing-in-Balance
FiSAT	FAO-ICLARM Stock Assessment Tools
FLC	Fish Landing Complex
GIS	Geographic Information System
GLM	General Linear Model
IUU	Illegal, Unreported and Unregulated
LEK	Local Ecological Knowledge
LS	Large-Scale
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
MT	Metric Tons
MTL	Mean Trophic Level
nm	nautical mile
SBS	Shifting Baselines Syndrome
SOI	Southern Oscillation Index
SS	Small-Scale
SST	Sea Surface Temperature
TL	Trophic Level
TS	Trophic Spectra
VMS	Vessel Monitoring System

To Mama and Babah,
and Brunei Darussalam…

Chapter 1
General Introduction

"Give a man a fish and you feed him for a day.
Teach a man to fish and you feed him for a lifetime."
– Chinese Proverb

1.1 Background

For centuries, because of the vastness of oceans and seas, it was widely believed that their resources were inexhaustible and that fishing could go on indefinitely (Costanza, 1999). Time and research have proven that this idea of infinite marine resources is far from right, as the world witnessed the collapse or decline of several fishery resources, the classical example being the Peruvian anchoveta and the North Atlantic cod (Hilborn and Walters, 1992; Myers *et al*., 1997). Human population growth throughout the world has resulted in immense and growing pressure on most natural resources, and it is generally agreed that conventional approaches to control fishing have failed to sustain fish populations or fisheries (Pauly *et al.*, 2002).

The demersal fishery resources of tropical coastal areas such as Brunei Darussalam consist of highly diverse, multi-species complexes, which are predominantly *K*-strategy species (Pauly, 1979), with a general trend for long-term site attachment (Jones *et al.*, 2002) and a relatively small home range (Jones *et al.*, 2008). Unlike their pelagic counterpart, influence of climate variability on this ecological group has not been clearly identified (e.g. Klyashtorin, 2001), and this is further exacerbated by the relatively short time-series of many of the fishery datasets from the tropical regions (e.g. Venkatachalam *et al.*, 2010).

In this study, particular emphasis has been placed on Brunei waters. Despite its relatively small landings and fishing area covered, Brunei marine ecosystem is considered a valuable reference point – a lightly harvested system within a region chronically overexploited (Silvestre and Garces, 2004). Brunei’s stable economy which is largely based on oil and gas, small population, and low reliance on coastal resources place Brunei in a unique position in terms of fishery development and management challenges. Yet, fisheries research progress in Brunei is relatively slow compared to the neighbouring countries, and the impact of fisheries and climate variability in Brunei waters remains poorly understood. Although fisheries data became available from 1980s onwards, Brunei's fishery was rendered "data-poor"[1], not because of lack of data, but mostly due to lack of reliable data with adequate and appropriate analyses. Previous studies of the demersal stocks in Brunei have not examined the impacts from fishing and climate in great detail, and existing management strategies do not consider natural climate variability of climate change on the dynamics of demersal stocks abundance.

Globally, the estimated fish consumption per person per year reached an all-time high of 18.8 kg in 2011 (FAO, 2012b). In Brunei and other coastal Southeast Asian countries, fish is the traditional and preferred source of animal protein, and will remain so in the foreseeable future. Despite a decrease in fish contribution to supplies of total protein from 16% in 1961 to 10% in 2007, the per capita consumption of fish for Brunei remained one of the highest in the world at 33 kg per year for 2010 (FAO, 2012a). However, FAO's *The State of World Fisheries and Aquaculture 2012* reported that about 87% of monitored marine stocks worldwide are now fully exploited, overexploited or depleted with no further potential for increasing marine catches. A sustainable fishing industry, therefore, is of considerable importance in Brunei, in line with the country's efforts to diversify from the dominant petroleum industry, and reduce the heavy dependence on imported

[1] "Data-poor" – a condition to describe a fishery that lacks sufficient information to conduct a conventional stock assessment; this includes fisheries with few available data, as well as fisheries with copious amounts of data but limited understanding of stock status due to poor data quality or lack of data analysis (Honey *et al.*, 2010)

fresh fish supply and attempts at self-sufficiency (Silvestre and Matdanan, 1992; DOF-MIPR, 1992). To understand the fishery and enable sustainable exploitation of fishery resources, it is essential, not only to recognise the dynamics of the resources, but also to understand the marine environment and their effects on fishery production, hence this study.

1.2 Brunei Darussalam, coastal features, and climate and environmental status

Brunei Darussalam is a coastal state with a land area of 5 765 km^2, located in the north-western part of Borneo Island and bordered by the east Malaysian state of Sarawak (Figure 1.1). The country has a 161 km long coastline fronting the South China Sea, dominated with sandy beaches, mud flats and estuaries with mangroves and peat swamps. The total marine territory covers an area of 38 600 km^2, within the 200 nautical mile (nm) limit of Exclusive Economic Zone (EEZ). This area is bounded by the Malaysian state of Sabah on the eastern side and Sarawak on the western side. Brunei waters is also included in the Palawan/North Borneo Marine Ecoregion, which borders the north western part of the Coral Triangle – the most diverse and productive marine system in the world (The Nature Conservancy, 2004; Allen, 2008).

Coastal features

The territorial waters of Brunei are characterised by a narrow continental shelf (within the 200 m isobaths) of about 8 600 km^2, and an offshore area of about 30 000 km^2 within which depths reach ≥ 2 000 m depth. The bottom substrate is sandy between the shoreline to around 30 m depth and around Ampa Patches. Depth gradients between 10 m and 40 m are irregular due to sand deposition by longshore drift and raised areas covered by coral/hard grounds (e.g. Ampa and Champion areas; Silvestre and Matdanan, 1992).

Brunei has three large estuaries (Brunei, Tutong and Belait) covering 400 km^2, which serve as important nursery/feeding grounds for fishery resources and are sites of significant fisheries and traditional human settlements (i.e. water villages) (DOF-MIPR, 1992). The mangrove forests of Brunei make up 3.2% (184 km^2) of the country's total land area and provide coastal protection and harbour unusual wildlife (DOF-MIPR, 1992). The highly diverse coral reefs of Brunei cover 50 km^2 as claimed by the government of Brunei (DOF-MIPR, 1992; Turak and DeVantier, 2011), although authors from the Reef at Risk in Southeast Asia (RRSEA) project estimated the coral reef and coralline areas to cover roughly 200 km^2, including fringing reefs, patch reefs, and one atoll (Burke *et al.*, 2002)[1]. An estimated 185 species of stony corals belonging to 71 genera and over 150 fish species from more than 30 families have been reported (DOF-MIPR, 1992). These numbers were found to increase in the recent Rapid Marine Survey of Brunei's Coral, Fish and Sea Shell Biodiversity in 2009 – over 650 species of fish, 404 species of reef building coral and 330 species of bivalves and gastropods were identified (Scubazoo, 2009). The major reefs include Ampa patches, Brunei patches and Champion shoals (Figure 1.1b). There are also several artificial reefs made up of tyres, galvanised pipes, concrete piles and redundant oil platforms which have been placed at several sites parallel to the coastline, mainly for fisheries purposes (DOF, 1999; DOF-pers.comm.).

[1] Meanwhile, the GIS analysis carried out in this study revealed the coral grounds of Brunei to cover an area of c.154 km^2.

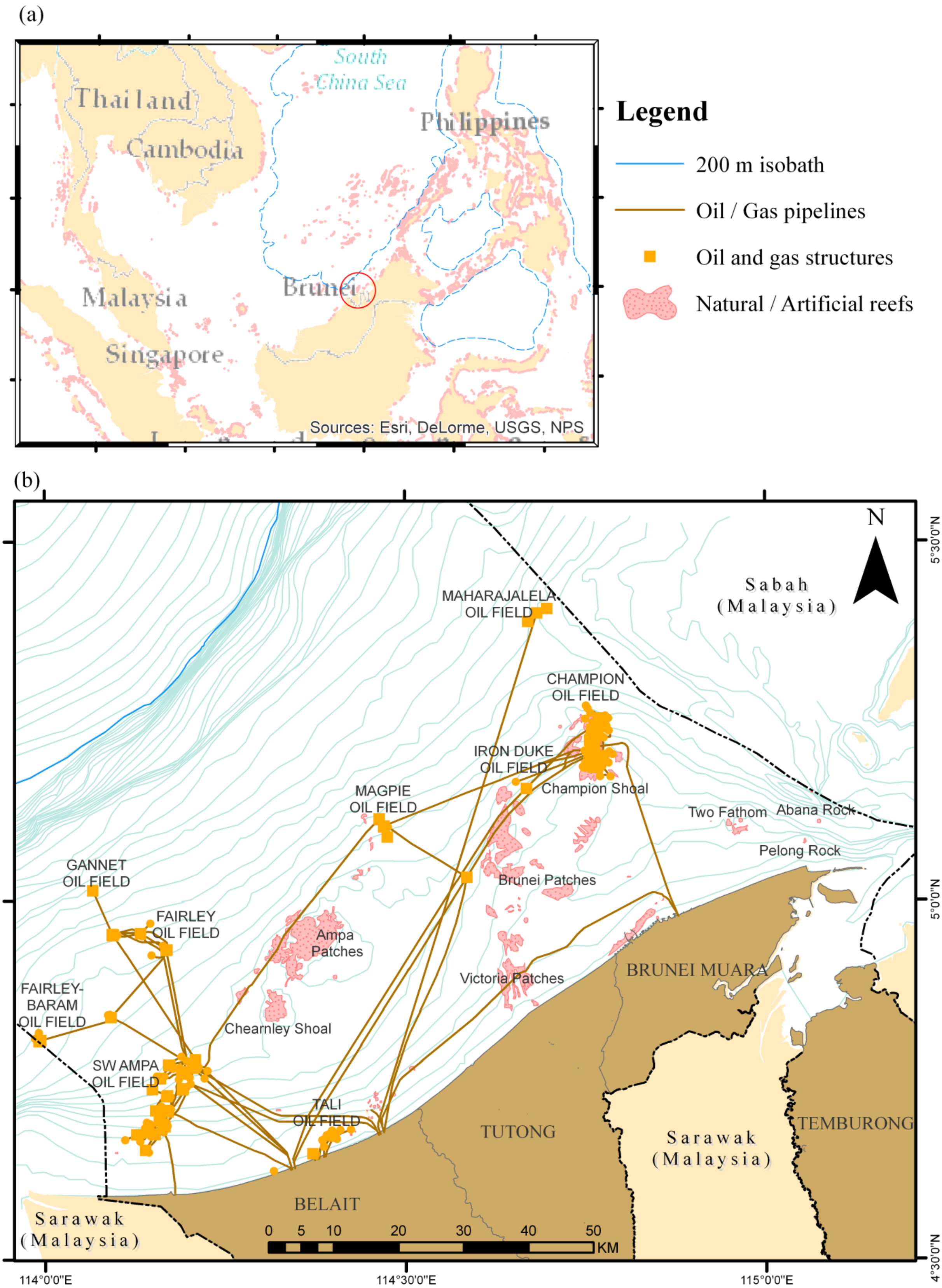

FIGURE 1.1: Map of Brunei Darussalam and the surrounding area (a) Geographic location of Brunei in relation to other Southeast Asian countries; (b) Depth distribution, as well as the distribution of oil industry structures and coral grounds in the coastal waters of Brunei. The four districts of Brunei are also shown.

At present, there are nine offshore oil/gas fields in operation, with connecting pipelines between the platforms (Figure 1.1b). Over 60% of Brunei's gross domestic product (GDP) is contributed by the oil and gas industry, so any fisheries and environmental development program must ensure safety and unhampered operation of the sector's offshore installations. Since 2000, a 500 m no fishing "buffer zone" surrounding the oil platforms has been prescribed by the petroleum companies, while the Government implements a "no take" zone of 1 nm from both sides of the oil/gas pipelines and structures.

Environmental status

Much of the natural environment in Brunei is claimed to be in good, pristine or near pristine conditions (Khartini, 2004). However, the coastal region, where more than 85% of Brunei's population is living (Ranjith and De Silva, 1998 - figure might actually be higher now), is under increasing anthropogenic pressures as the population continues to increase. Brunei's population growth rate is reported to be one of the highest in Asia, at around 2% per annum (WHO, 2012), and in the light of industrialization and urbanisation, almost all of the major economic activities are confined to the coastal zone. Since almost the whole of the northern coastal belt between Kuala Belait and Muara consists of soils not suitable for any large-scale agriculture use, the coastal land has been used for urban, residential and industrial development (dela Cruz *et al.*, 1987; DOF-MIPR, 1992). Consequently, the considerable land developments that took place resulted in some undesirable coastal environmental impacts, including siltation from land due to erosion, as a result of unplanned land clearance, untreated waste discharges as well as indiscriminate cutting of mangroves for residential and industrial development, aquaculture, fuel wood and timber.

Climate

The climate of Brunei is governed by its location within the equatorial tropics, and the wind systems of Southeast Asia – in a form of two monsoon seasons – which result from the atmospheric pressure distribution over the region as a whole (Sirabaha, 2008). During the northern hemisphere winter months from December to March, the northeast monsoon winds affect the South China Sea and Borneo, while the broad flow of southwest monsoon winds move across Brunei from June to September. The first transitional period occurs in April and May while the second one in October and November. The mean monthly rainfall indicates certain seasonality which reflects the two monsoon seasons in conjunction with the related movements of the "Inter Tropical Convergence Zone" (ITCZ) and the influence of the localized land-sea circulations. On an inter-annual timescale of three to seven years, the climate of Brunei is also influenced by El Niño Southern Oscillation (ENSO). The warm (or cold) episode of El Niño (or La Niña) is normally associated with prolonged dry conditions (or wetter than normal) in Brunei (Sirabaha, 2008).

1.3 State of marine capture fisheries in Brunei Darussalam

Brunei has a long fishing tradition and early European accounts as far back as the sixteenth century attest to the significance of fisheries as a way of life. The fishing industry, comprising capture, aquaculture, and seafood processing sectors, is one of the most important non-petroleum industries in Brunei, and under the current National Development Plan (2007 – 2012), BND $115M (around GBP £65M) was allocated for the continued development of the country's fishing industry (BEDB, 2012).

In Brunei, the marine capture fisheries contributed about 70% of the total supply of fish products and can be characterised as multi-species and multi-gear (Matzaini *et al.*, 2007; JPKE, 2010). Total annual production from the capture fisheries increased markedly at the turn of the 21st century, from 6 705 metric tons (MT) in 1997 to 15 329 MT in 2010 (JPKE, 2010). The bulk of fisheries activities are concentrated in Brunei's estuarine system and in the coastal waters off Brunei-Muara district which has the highest concentration of human population.

1.3.1 Fisheries management and research

The Department of Fisheries (DOF), under the Ministry of Industry and Primary Resources, is the authoritative body in charge a wide array of functions, including fisheries research, extension, enforcement, marketing, conservation, development and management of Brunei fisheries (Silvestre and Matdanan, 1992). In particular, the Marine Fisheries Development and Management division, under this department, is responsible for the research, assessment, monitoring and management of marine fisheries resources in Brunei waters (DOF, 2009). Like many other Asian countries, the fishing area in Brunei is divided into "fishing zones" established in 1990, which act as a spatial management tool to restrict fishing in particular areas, based on the distance from the coastline (Garces *et al.*, 2006 ; Figure 1.2). Other existing management mechanisms are reviewed in Chapter 6 (Section 6.2).

Fundamentally, the Government of Brunei started to manage the fisheries in Brunei waters since the late 1960s after the establishment of the DOF in 1966. However, technical capacity and scientific knowledge in the country are quite limited, so Brunei is seeking help from regional and international organisations in executing comprehensive assessments and monitoring programs (Burke *et al.*, 2002; DOF-pers.comm.). Earlier studies on fishery and stock assessments of Brunei are reviewed in Chapter 2 (Section 2.5).

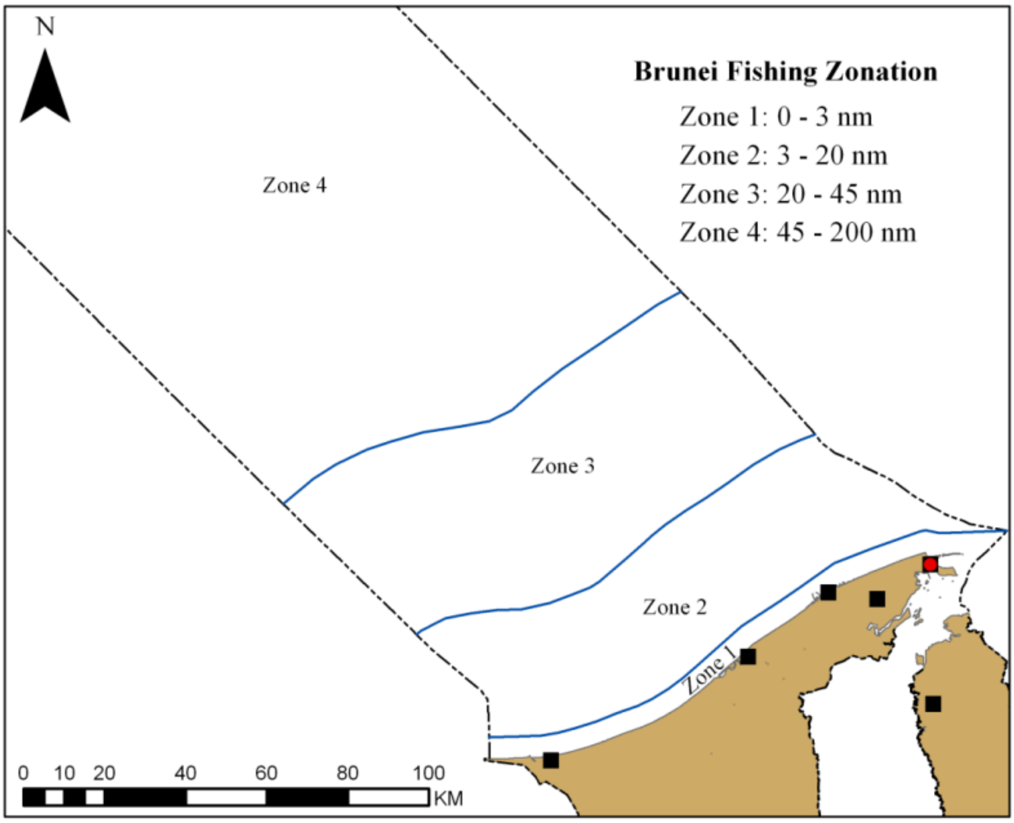

FIGURE 1.2: The fishing zones in Brunei waters, used for management purposes. Red circle shows the location of Muara Fish Landing Complex (FLC), which is the main FLC in Brunei. Map adapted from Matzaini *et al*, 2007.

1.3.2 The fishing fleets

The marine capture fisheries of Brunei, well described – albeit outdated – in a review by Silvestre and Matdanan (1992), are divided into large-scale (LS) and small-scale (SS) sectors based on the level of capital inputs and associated characteristics (Table 1.1).

TABLE 1.1: Differences between the large-scale and small-scale fisheries sectors in Brunei.

	Large-scale sector	**Small-scale sector**
Permitted fishing area	Zone 2, 3 and 4	Zone 1, 2, 3 and 4 – Individuals Zone 2, 3 and 4 – Companies
Common types of gears[(a)]	Purse-seines Bottom trawls Horizontal bottom long lines and large fish traps	Surrounding nets Seine nets Lift net Falling gear Gill nets Scoop nets Traps Hook and Line Others (i.e. gleaning)
Vessels characteristics	Inboard engines Equipped with navigational instruments No refrigeration system	0 or 1 or 2 outboard engines Some equipped with navigational instruments No refrigeration system
Fish marketing	1) Fishmongers →Retailers →Consumers 2) Retailers →Consumers	1) Fishmongers →Retailers →Consumers 2) Retailers →Consumers 3) Consumers 4) Own consumption
Working time[(b)]	Full-time	Full-time Part-time
Landing sites	1) Muara Fish Landing Complex (FLC)	Any place suitable for landing, but common sites include 1) Jerudong Beach 2) Pengkalan Sibabau 3) Danau 5) Seria Beach 6) Lumut Beach 7) Kuala Belait FLC

(a) Only main categories of fishing gears used by small-scale fishers are shown, following the classification and definition of FAO.
(b) Full-time fishers refer to those solely dependent on fishing for their livelihood (time spent fishing ≥ 80%), while part-time fishers are those whose chief income sources are from other occupations but who fish during weekends, holidays or times of peak fish abundance (time spent fishing ≤ 10%) (Silvestre and Matdanan, 1992, Ranimah 2008).

1.3.2.1 The large-scale sector

Silvestre and Matdanan (1992) classified the large-scale sector as “modern”, “commercial”, “industrial” and “offshore”. LS vessels operate only from Muara where a fish landing complex (FLC) is available. There is also another FLC facility offered in Kuala Belait, although there are no LS companies currently based there.

The LS vessels can be subdivided into three types based on the gears used, namely trawlers (*kapal pukat tunda*), purse seiners (*kapal pukat lingkung*) and long liners (*kapal rawai*) (Figure 1.3). Although identified as long liners, the latter group of vessels are also known to utilise large fish traps (*bubu*) in most of their operations.

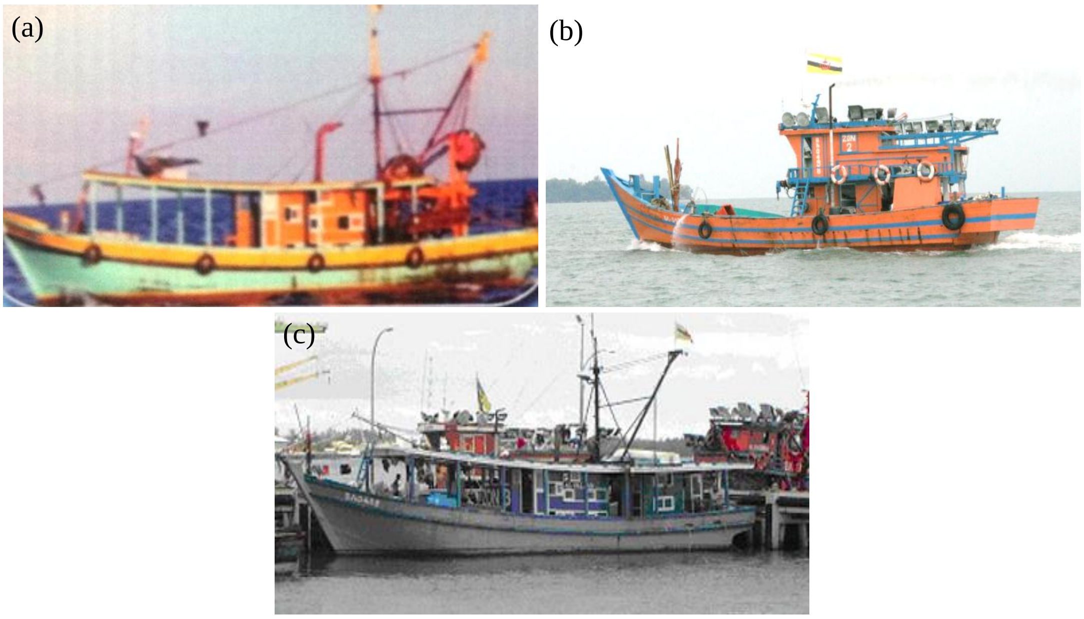

FIGURE 1.3: Three types of vessels used in Brunei’s large-scale fishery; (a) bottom trawlers (*kapal pukat tunda*), (b) purse-seiners (*kapal pukat lingkung*), and (c) long liners (*kapal rawai*).

The LS sector was launched in the 1980s, and all vessels were locally owned (Khoo *et al.*, 1987). In 2011, there are a total of 43 LS vessels (21 trawlers, 12 purse seiners and 10 long liners) registered with DOF. LS vessels’ skippers are required to be certified in Fishing Technology and Navigation course conducted by DOF, and are also mandated to complete a monthly fishing logbook. All of the vessels are fitted with radars, echo-sounders and VHF radios. The LS vessels are restricted from operating in Zone 1 but this separation does not always work in practice.

1.3.2.2 The small-scale sector

The SS sector, which is also indicated as “traditional”, “artisanal” and “near shore” by Silvestre and Matdanan (1992), is quite old but its nature has changed with time. The sector’s fishing techniques had improved over the years as modern electronic devices such as global positioning system (GPS) equipment, echo-sounders and fish-finders become cheaper and easily available. The boats are also well-constructed, easy to manoeuvre and commonly fitted with the latest models of outboard motors.

FIGURE 1.4: The small-scale sector of Brunei fishery can be divided into two groups; (a-b) single boat operated small-scale fishery, and (c-d) fleet operated small-scale fishery.

At present, this sector can be further classified into two groups based on their mode of operation (Figure 1.4): single boat operated ("small-scale individual" or SSi) and fleet operated ("small-scale company" or SSc) (Ranimah, 2008). The SSi group use only a single boat operated by the owner himself, and can either be full-time or part-time fishers. The SSc group is differentiated by having more than one fishing boat managed by one owner. A company usually owns the fleet, with foreign labour commonly employed to operate the boats and fishing gears. All SSc fishers are full-time fishers.

On average, 70% of the total marine capture production is contributed by SS fisheries. However, this trend has only been observed in the recent years, which seems to coincide with the drastic increase in the number of fishers. Indeed, the total number of full-time fishers in Brunei nearly tripled, while the number of part-time fishers almost quadrupled between 2000 and 2005 (Figure 1.5; Matzaini *et al.*, 2007; Ranimah, 2008).

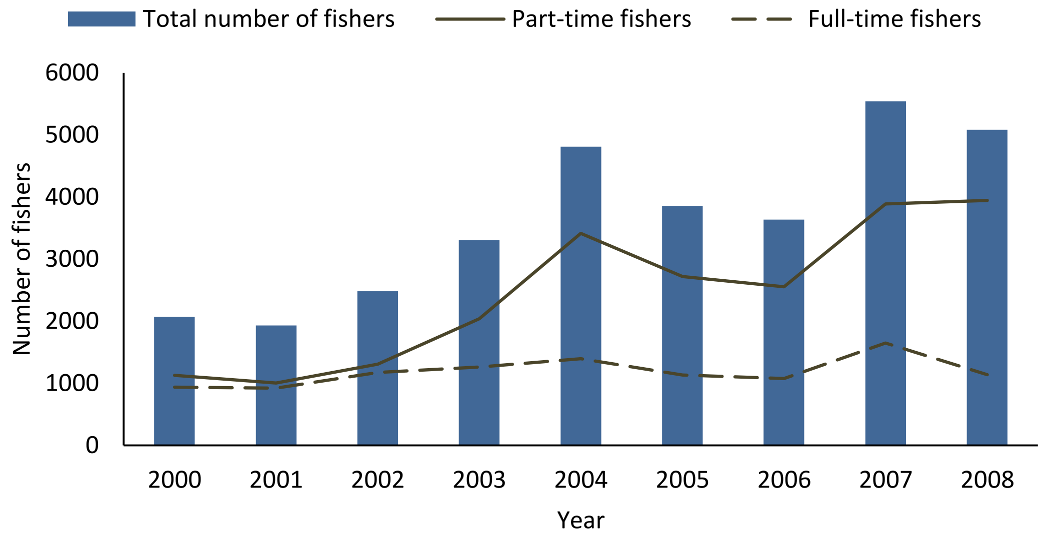

FIGURE 1.5: Annual change in number of small-scale fishers in Brunei from 2000 to 2008, taken from Ranimah (2008).

1.3.3 Marine fishery resources of Brunei

The marine resources of Brunei waters, typical of fish communities in dominant soft-bottom areas of the central Indo-West Pacific, are characterised by high species diversity. About 500 species of fish and invertebrates have been reported from the catch of various fishing gears used in Brunei waters – 80% are demersal species while the rest are pelagics. Overall, the fisheries resources of Brunei are estimated at about 21 300 MT in terms of potential yields, which comprised of 12 500 MT for demersal resources (500 MT contributed by the shrimp fishery) and 8 800 MT for pelagic resources (Matzaini *et al*., 2007).

Assessments of the pelagic resources using hydro-acoustic technique revealed that the pelagic resources were dominated by sardines (Dussumieriidae, *Dussumieria*), horse mackerels (Carangidae, *Carangoides*), scads (Carangidae, *Decapterus*) and driftfishes (Ariommatidae, *Ariomma*), which account for over 80% of standing stock (Silvestre and Matdanan, 1992).

Catches from trawl surveys conducted in the 1970s and 1980s showed that the demersal resources of Brunei have been consistently dominated by low-value families/groups such as ponyfish (Leiognathidae), goatfish (Mullidae), threadfin breams (Nemipteridae) and sharks/rays, as these groups collectively account for c. 47-68% of demersal biomass between 1970 and 1990 (Silvestre and Matdanan, 1992). In their most recent demersal trawl survey in 2008, the DOF noted that the top three most dominant families for each hauls were Leiognathidae, Mullidae and Priacanthidae, representing up to 27%, 9% and 6% respectively (DOF-pers.comm.).

Overall, fish abundance exhibits spatial and temporal fluctuations, which are strongly related to depth, seasonal life cycles and productivity phasing, and time of the day (Silvestre and Matdanan, 1992).

The demersal resources of Brunei contribute up to 75% of the annual capture fishery production value for the LS sector, which was worth BND $7.4M (GBP £4.5M) in 2008. While assessments of fisheries have been undertaken in Brunei, they are often published in "grey literature" and so not widely available. This ecological group of fish has been classified as over-exploited in the region over past few decades (Pauly, 1988), but its status in Brunei waters remains unclear from the existing literature.

When DOF carried out trawl survey stock assessments in 2000 and again in 2008, an alarming declining trend was detected. In 2008, only a fifth of the overall demersal stock abundance in 2000 was left, based on the mean catch rate during the trawl survey (DOF-pers.comm.). Their finding was rather surprising considering the 'lightly exploited' status of demersal stocks in Brunei up till the late 1990s (Silvestre and Matdanan, 1992; Silvestre and Garces, 2004) and the prudent development of the marine capture industry practised by the authority.

1.4 Research aims and objectives

In the light of the above gaps in knowledge, the overall aim of this study is to assess changes in demersal fishery resources and harvesting pressure imposed by the fisheries in Brunei Darussalam, while simultaneously evaluating the sustainability of its demersal capture fishery in the face of its on-going development and climate change.

This thesis has four specific objectives:

1) Examine the current state of Brunei marine ecosystem (Chapter 3).
2) Distinguish the effect of fishing, environmental and other drivers of abundance and/or productivity of selected demersal stocks, pertaining to the large-scale fishery sector (Chapter 4).
3) Analyse population changes of selected demersal stocks, based on standardised Government catch statistics and information from an interview survey administered to fishers. (Chapter 4 & 5).
4) Critically review the policy and management framework governing Brunei's fisheries, and make recommendations to improve management of Brunei demersal fishery and its future research needs (Chapter 6).

The four objectives are addressed over four chapters. The chapters are conceptually connected, with the collective aim to examine the possibilities of extracting useful information from, and to contribute to the improvement in management of, data-poor fisheries in tropical countries such as Brunei Darussalam.

1.5 Thesis organisation: Summary outline of chapters

This chapter (**Chapter 1**) provides a general introduction to the thesis. In addition to defining overall aims and specific objectives of the study, the chapter also describes the current available information and key literature review pertaining to the study area, its fish resources and the fisheries. **Chapter 2** is an overview of fish stock assessments as commonly carried out in the tropics, with particular emphasis on 'data-poor' fisheries. It includes a comprehensive literature review for subsequent chapters and underpins the conceptual hypotheses and methodology developed in undertaking this study. In **Chapter 3**, a 'holistic' picture of Brunei marine ecosystem during the study period is described via trophodynamic indicators and community structure analyses. **Chapter 4** is a detailed analysis on recent abundance trends of overall demersal resources, as well as several commercially-important demersal stocks in the study area, by investigating the joint responses of fish productivity to fishing and climate variability. Through an interview survey of fishers in Brunei, **Chapter 5** then explores the utilisation of local ecological knowledge in assessing long-term abundance trends of selected finfish stocks. **Chapter 6** provides a synthesis of the study, through which the implication on current management of the fishery resources in Brunei is examined and recommendations on possible improvements to management of the demersal fishery are made. Finally, **Chapter 7** presents conclusions and suggestions for future research on demersal fish resources of Brunei.

Chapter 2
Review on Assessment of Tropical Fishery Resources

"All models are wrong, but some are useful."
– George Box, 1978

Chapter Summary

Using published research and opinion pieces, this review illustrates the issues commonly associated with tropical fish stock assessments in developing countries. Taking the limitations of fishery-dependent data into account, development of simple indicators based on such data can provide useful insights into the state of fish stocks and fisheries. In addition, fisheries scientists and managers are gradually engaging with fishers' local ecological knowledge (LEK) to provide novel and useful information with regards to fish stock status. It has also been increasingly recognised that a likely reason for the causes and mechanisms responsible for variability in fish stock abundance to remain poorly identified may be due to interactions between fishing and the environment. In Brunei Darussalam, earlier studies on fishery and stock assessment revealed that further research on the demersal fishery resources, to complement the fishery authorities' monitoring programme, is in order.

2.1 Overview of tropical fish stock assessment

The basic purpose of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources (Sparre and Venema, 1998), and this generally involves performing robust stock assessment techniques on appropriate data for comparison to reference points, and eventually the identification of actions required to achieve the aims of fisheries management. Hilborn and Walters (1992) defined stock assessment as being “the use of statistical and mathematical techniques to make quantitative predictions about the reactions of fish populations to alternative management choices”. Therefore, assessment approaches cannot be developed in isolation from the aims of management, nor the management actions that are to be applied to achieve them (Pilling *et al.*, 2009). Fishery managers increasingly realise that the benefits of fisheries management are not always measured in terms of increases in yields and that the fundamental purpose of fisheries management is to ensure sustainable production over time from fish stocks, in the face of environmental variability (Hilborn and Walters, 1992; Gallucci *et al.*, 1996; Hart and Reynolds, 2002a). Hilborn and Walters (1992) organise the objectives of fisheries management into four categories, namely (1) biological, (2) economic, (3) recreational and (4) social. In most cases the objectives for a particular management regime will be a mixture of the four. In general, however, management often strive to achieve the delicate balance between potentially conflicting aims of ensuring a profitable but sustainable fishery, without specifically assigning priorities to individual aims.

Through stock assessments, fisheries scientists attempt to estimate the amount of fish in a stock and its rate of growth and mortality, and compare those estimates to a stock's biological reference points. Numerous definitions of stock concept have been canvassed throughout the fisheries literature (Sparre and Venema, 1998), and a diversity of techniques has been used to identify and classify fish stocks (review by Begg and Waldman, 1999). In its current simplified form, a stock refers to a managed unit of a semi-discrete group of fish, typically based on their geographical location (Begg *et al.*, 1999), while a cohort is a group of fish born in the same year within a population of stock (Hart and Reynolds, 2002b).

The early works in stock assessments took place between the 1890s and 1950s (review by Munro, 2011), where means to estimate growth rates (i.e. via rings in otoliths and scales) and mortality rates (i.e. based on relative abundances of successive year classes) were developed, and foundations of the modern theory of fishing were established. The development of stock assessment concepts was greatly facilitated by the compilation of a set of 16 "key papers on fish populations" published between 1931 and 1981 by Cushing (1983). Eventually, the availability of personal computers started to facilitate enormously the application of stock assessments into feasible undertakings by small government and university fisheries laboratories with limited funding (Munro, 2011).

Stock assessment of a tropical fishery is usually adapted from traditional stock assessment techniques of temperate regions, as mostly described by Beverton and Holt (1957), Ricker (1975) and Gulland (1969, 1983), whose works form the backbone of fisheries science. The development of tropical fisheries science began in the 1980s, where Daniel Pauly became the dominant figure in this field, by introducing and developing suitable methodologies for use by scientists in developing countries (Pauly *et al.*, 1987). This was motivated by the fact that ageing tropical fishes was, until recently, assumed to be virtually impossible (Morales-Nin, 1992; Choat and Robertson, 2002). For instance, the lack of strong seasonality makes the distinction of seasonal rings, and hence, of year-rings, problematic for many tropical species. In addition, most tropical species would have less distinct spawning periods, with some spawning at least twice per year and often over long periods (Sparre and Venema, 1998). Hence, to apply conventional stock assessment methods of temperate waters on tropical fish, the required parameters must be estimated from length-frequency data, as opposed to data collected for the age-based assessment (Pauly *et al.*, 1987), since growth of fish is revealed to be well approximated by a von Bertalanffy curve (Jobling, 2008; Pitcher, 2008). In a length-frequency analysis, peaks of numbers in the length-classes are used to estimate the mean length of successive cohorts at integer intervals of age, and the relative numbers in these cohorts to estimate total mortality rates. Therefore, when properly sampled and analysed, length-frequency data can provide estimates of key parameters used in conventional stock assessments (Pauly *et al.*, 1987).

With the establishment of the Network of Tropical Fishery Scientists (NTFS) in 1982, a lot of effort was devoted to the development of tropical stock assessment techniques, as well as the development of specialized courses for fisheries scientists from developing countries. This led to close collaboration between groups working at the Food and Agriculture Organisation (FAO) and the then International Centre for Living Aquatic Resources Management (ICLARM) (Venema *et al.*, 1988), which then, among others, led the development of FiSAT (FAO-ICLARM Stock Assessment Tools) software (Gayanilo, 1997). FiSAT made use of applications based on length-frequency distributions, including length-based Virtual Population Analysis (VPA) and yield assessments for tropical stocks assessments. FiSAT II software is now available in a Microsoft Windows operating environment, with several additions of improved models and packages (Gayanilo *et al.*, 2005). Consequently, a host of new stock assessment programs have emerged in recent years, with some being well established and others in various stages of development (Munro, 2011).

The breakthrough in multispecies management of multi-gears fisheries in the tropics, however, arose with the development of Ecopath, a steady-state ecosystem model, which was further developed to the degree that it has become the *de facto* world standard for ecosystem modelling of marine resources (Christensen and Pauly, 1992; Christensen and Walters, 2011). The Ecopath with Ecosim (EwE) software suite, which is composed of three main components, namely Ecopath (a static, mass-balanced snapshot of the system; Christensen and Pauly, 1992), Ecosim (a time dynamic simulation module for policy exploration; Walters *et al*., 1997) and Ecospace (a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas; Walters *et al*., 1999), was recently recognised as one of NOAA's (National Oceanic and Atmospheric Administration, USA) top ten scientific breakthroughs in the last 200 years (Ecopath, 2011).

Nonetheless, the greatest problem commonly encountered in stock assessments of tropical species in developing countries is the lack of funds as governments are reluctant to spend large sums of money on fisheries research and management, especially on the small-scale sector that is not perceived to be of great value (Munro, 2011). Of course, this view is inaccurate, as shown by Sary *et al.* (2003) who demonstrated that the cumulative cost of non-management of Jamaica's trap fisheries amounted to US$1.3 billion over the previous 25 years. In fact, employment in the fisheries and aquaculture primary sector has continued to grow faster than employment in agriculture, whereby 54.8 million people worldwide were estimated to be engaged in the primary sector of fish production in 2010, of which Asia accounts for more than 87% of the world total (FAO, 2012b). The reality, however, is that against the priority central governments place on spending on health, education and military, fisheries will remain the poor relations (Prince, 2010).

Subsequently, obtaining a satisfactory sample size for assessment can be expensive, time consuming and labour intensive, particularly for the larger, rarer and more valuable species (Pauly, 1988; Munro, 2011). Where catch data are collected, they are mostly aggregated by families or into even broader groups, and hence, are of little value for stock assessment. With the few exceptions that gather fairly detailed catch data on regular basis, majority of the countries in the tropics would not have detailed catch statistics apart from periodic sample surveys (Munro, 2011). Furthermore, especially for the SS sector in the tropics, the numerous and scattered landings sites, as well as complex and variable market chains often limit the collection of robust data from these fisheries (Stobutzki *et al.*, 2006). In addition to the multispecies and multi-gear nature of the fisheries, the species caught often overlap between gears and sectors, and in some cases the same species may even be targeted at multiple life history stages by different sectors.

Data paucity invariably results from the lack of both human and economic capacity within government to implement and maintain programs for data collection and analysis. Where the "best scientific information available is simply inadequate for determining meaningful reference points and/or current stock status with respect to such reference points" (Richards and Maguire, 1998), fisheries may be considered as "data-poor" (Pilling *et al.*, 2009; Honey *et al.*, 2010). While the term "data-poor" is sometimes confounded with SS fisheries, mostly due to reasons identified earlier, these terms are not synonymous. Large-scale, but recently developed fisheries where fisheries research and management have lagged behind exploitation, or LS fisheries where the quality of data is poor or variable and difficult to assure, may also be deemed data-poor.

However, the Precautionary Approach, proposed by FAO in the International Code of Conduct for Responsible Fisheries (FAO, 1995), declares that the limitations, uncertainties or lack of data for the assessment of stocks or estimation of parameters, cannot be justification for not applying regulation measures. Therefore, managers of data-poor fisheries often face additional pressure to perform their responsibilities to achieve success within data and resource constraints. Realisation is growing across the field of fisheries science that the use of classic stock assessment models to derive relevant science-based reference points such as biomass (B) or effort (F) at maximum sustainable yield (MSY) and/or maximum economic yield (MEY) (i.e. B_{MSY} or F_{MSY}) may have limited application and success in much of the developing world fisheries, particularly with regard to facilitating timely local level fisheries management decisions, and that different approaches are needed (Mullon *et al.*, 2005; SEAFDEC, 2006; Honey *et al.*, 2010; Froese *et al.*, 2012).

One way to overcome this is through the use of simple indicators, or measures of performance, aimed at providing an insight into the development and management of the fishery. Simple indicators are consistently found to outperform more complex (model-dependent) indicators, which are sensitive to data quality (Fulton *et al.*, 2005; Link, 2005). While potentially less precise than complete stock assessments, simple indicators can still provide the necessary information for the formulation of fisheries management policy and enable timely day to day management of fisheries resources by local authorities using identified targets or goals. They may not simply be biological in origin – for instance, indicators can also be socioeconomic in nature, usually by measuring changes in the well-being of the people who are dependent on the fish populations – but indicators need to be locally specific, practical, easy to understand and comprehensible to all local stakeholders (Nielsen *et al.*, 2001).

2.2 Data requirements for development of indicators

Conventional stock assessments models require three primary categories of information, namely catch, abundance and biological data (Cooper *et al.*, 2006). Where the data are derived from the fishing process itself, they are classified as fishery-dependent data, and are collected through avenues such as self-reporting (e.g. log books filled by fishers themselves), landings surveys or vessel-monitoring systems (VMS). Fishery-independent data, on the other hand, are collected independently of fishing activities and ideally come from statistically well-designed research surveys and tagging experiments.

The fishery-independent approaches involve a range of standardised sampling gears such as trawls, seines, hydro-acoustics, video and side-scan sonar. Maintaining standard survey practices over time is crucial, so when new gear or sampling methods are adopted, they should be calibrated so that the results can be directly compared to results from the old gear or method (Cooper *et al.*, 2006). Expected outputs from the fishery-independent methods are then used for estimating fish abundance (can be relative or absolute), demographic structure at sea, as well as for the collection of other biological and biophysical information. For instance, by sampling stomach contents, one can determine a species' diet (e.g. Ibrahim *et al.*, 2004), while results from tagging experiments may be used to estimate movement or migration rates between stocks, and natural mortality rate of the fish (e.g. de Pontual *et al.*, 2003), all of which enhances stock assessment models (Cooper *et al*., 2006).

While stock assessments ideally require a combination of both fishery-dependent and fishery-independent data to answer the questions imposed for fishery management, fishery-dependent data are relatively easier and much less expensive to acquire. In most cases, much of the fishery data already exist, either from within or outside the fisheries sector. Undeniably, misreported landings, misinformation and illegal activity hamper the accuracy of such data, but their cautious use may still provide useful insights into the state of fish stocks and fisheries (Sadovy, 2005). Furthermore, considering that most, if not all, countries already have data collection systems of some forms in place, a sensible first step in improving the available information on the fishery sector is to use and assess the current available data (SEAFDEC, 2006). In the event where the statistics are found to be insufficient, corrective action can then be taken to improve their quality.

2.2.1 Assessing stock status using catch-effort data

Under limited resources and capacity, efforts have been made to ensure that the minimum requirements of national fishery statistics system are met, often through regional and international initiatives led by FAO and other fishery research and/or management agencies such as, among others, the Southeast Asian Fisheries Development Centre (SEAFDEC) and the Latin American Organisation for Fishery Development (OLDPESCA) (FAO, 2005a). Consequently, the most basic and informative data in fisheries science is the catch and effort data (Caddy and Gulland, 1983). Interestingly, there is an on-going debate on the usefulness of fishery catch data to evaluate stocks status, which specifically causes leading fisheries scientists to disagree over the size of the overfishing problem around the world (Pauly *et al.*, 2013).

In the last 60 years, unquestionably remarkable changes in the nature of fisheries have been observed, especially with the rapid geographical and bathymetric expansion (Morato *et al.*, 2006), along with the ever-increasing efficiency of more powerful fishing fleets (Pauly and Palomares, 2010). Using FAO catch data, the world catch has been observed as stagnating, then slowly declining since the late 1980s (Watson and Pauly, 2001; FAO, 2012b), and this has been widely interpreted as being the result of widespread overfishing leading to sequential depletion of exploited stocks (Jackson *et al.*, 2001; Worm *et al.*, 2006; Froese *et al.*, 2009). Worm *et al*. (2006) further claimed that most large fish populations are now 10% of their original size and that the oceans could collapse by 2048. However, their claims were challenged by a few authors asserting that the estimates of declining global fish stocks were overstated because they relied on a flawed methodology (Branch *et al.*, 2011). When assessments were based on biomass data (from stock assessments), instead of catch data in previous studies, the authors found that the global fish stocks are not as badly off as has been widely believed (Figure 2.1). Subsequently, Branch *et al*. (2011) and a few others (Hilborn, 2010; Daan *et al.*, 2011) suggest that fisheries management has led to stabilisation of fish stocks in most regions, and that the partial stock rebuilding scenarios that have recently occurred in the United States and a few other developed countries may be representative of a global trend.

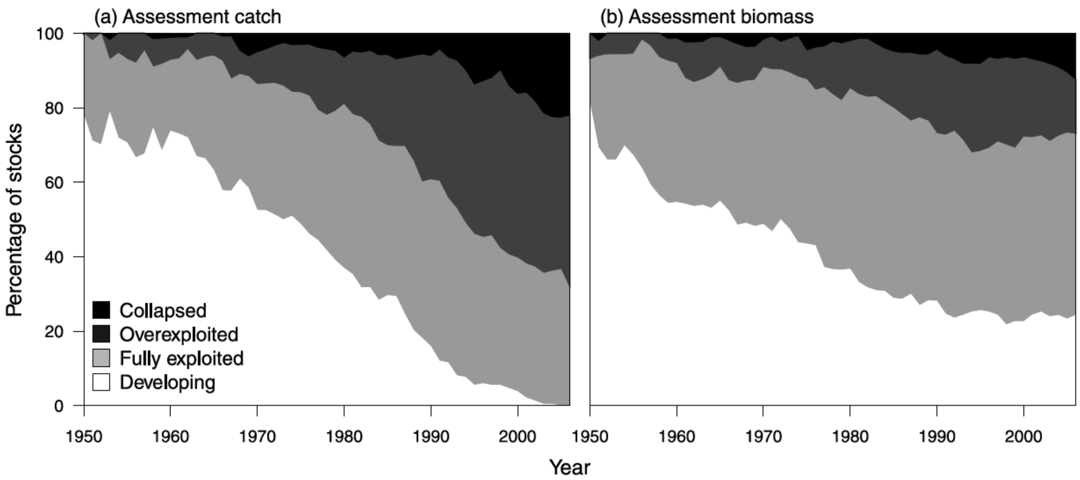

FIGURE 2.1: Trends in status of fisheries stocks on the basis of stock assessment time series of (a) catches and (b) biomass for the same set of stocks, taken from Branch et al. (2011).

While the former group acknowledged that the stock assessment techniques, and the biomass estimates upon which they depend, are preferable when assessing stock status, they maintained that with cautions and rigorous statistics, data from catches are equally useful, if not better, especially as they have greater coverage in space and time than fishery-independent surveys, and hence more applicable on a global scale than other datasets (Maunder and Punt, 2004; Ye and Dennis, 2009; Froese *et al.*, 2012; Kleisner *et al.*, 2012). Indeed, many reviews have found the efficacy and reliability of stock assessment techniques debatable (Parsons, 1996; Conn *et al.*, 2010). Their main critique is that it is difficult to obtain reliable estimates of stock biomass, even in the best of circumstances, as evidenced by the collapse of Canada's well-studied Northern cod (*Gadus morhua*, Gadidae; Myers *et al.*, 1997). In view of the enormous contributions of developing countries to world fisheries catches, it is unwise to draw credible inferences for the world as a whole from stock assessments which are mostly carried out properly in developed countries. In the context of this thesis, therefore, there is obviously a value in keeping on track with the trends and patterns extracted from fishery catch data.

2.2.2 The 'Catch per Unit Effort' model

Based on the observation that the size of catch from a fish population typically increases when either population density or effort increases (Hilborn and Walters, 1992), an approach was developed using catch-effort data whereby the catch rate or catch-per-unit-effort (CPUE) is used as an index of abundance, which then in principle can be used to detect declines in the same way as abundance itself. CPUE as an abundance index is based on the relationship that relates catch to abundance and effort:

$$C_t = qE_tN_t$$

where C_t is catch at time t, E_t is the effort expended at time t, N_t is the abundance at time t, and q is the portion of the stock captured by one unit of effort which are often called the catchability coefficient (Hilborn and Walters, 1992). By rearranging the equation,

$$\frac{C_t}{E_t} = qN_t$$

$$CPUE \propto N_t$$

CPUE is now proportional to abundance, provided that q is constant over time.

As a result, the assumption that CPUE is directly proportional to abundance is one that is most widely made in quantitative fisheries analysis, with CPUE forming the basis of stock assessments using catch data for many commercially important species worldwide (e.g. Stergiou *et al.*, 1997; Battaile and Quinn, 2004; Matsunaga and Nakano, 2006; Maunder and Hoyle, 2006; Ortiz de Zarate and Ortiz de Urbina, 2007; Md Nurul Islam *et al.*, 2011). Despite its extensive use, however, there are a number of conditions which may violate the proportionality assumption, namely hyperstability and hyperdepletion.

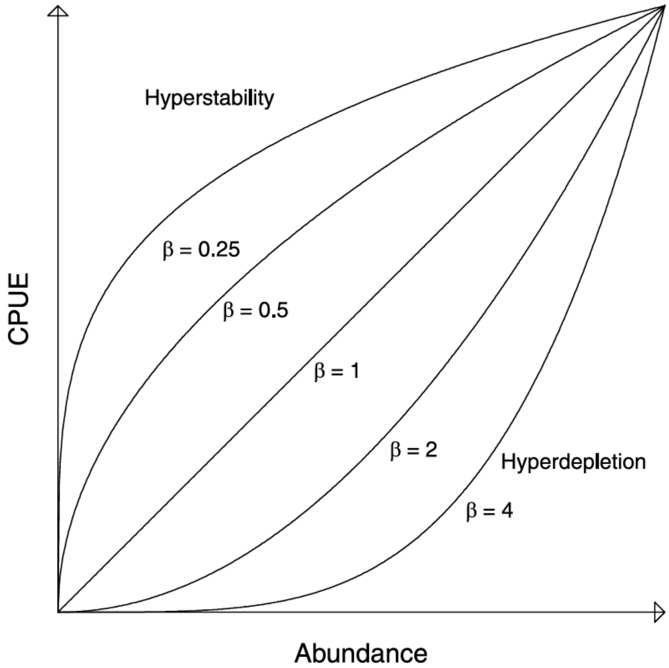

FIGURE 2.2: Relationship between CPUE and abundance based on different values of the shape parameter (***β***), taken from Harley *et al.* (2001).

Hyperstability refers to the situation when the CPUE index remains high while fish abundance is actually low (or abundance declines faster than CPUE). The first two curves where $\beta < 1$ in Figure 2.2 show hyperstability, and for resource managers, this means that a population is declining without any change in CPUE to arouse concerns. Hyperstability is considered to be one of the biggest problems for fisheries managers (Hilborn and Walters, 1992), whereby some of the most well known fisheries collapses in the world have been ascribed to hyperstability (Shelton, 2005). The last two curves where $\beta > 1$ show hyperdepletion, which happens when CPUE is actually underestimating abundance (or CPUE drops faster than abundance). The fish population appears to be depleted, despite the fact that abundance overall may be relatively stable. These non-linear relationships between CPUE and abundance may be a result of fishers' behaviour and/or fish distribution, biology and behaviour. For instance, the inherent schooling behaviour as present in many fish species or fishers' efficient search behaviour when fishing can lead to hyperstability (Hilborn and Walters, 1992).

Therefore, in the use of catch-effort data, thoroughly understanding the fishery system in question is necessary, especially since other than issues of non-proportionality, there may also be factors other than abundance that can affect CPUE trends over time. For instance, changes in species preference, changes in catchability of a population, and changes in fishing technology, can potentially lead to spurious conclusions regarding the state of fish stocks (Myers and Worm, 2003; Maunder *et al.*, 2006). For this reason, CPUE can only be used as valid indicators of abundance if they are adjusted to account for changes in factors other than abundance that can potentially drive changes in the fisheries (Maunder and Punt, 2004; McCluskey and Lewison, 2008). This is commonly done by standardisation of catch-effort data (see Chapter 4).

Regardless of its well-documented shortcomings, the CPUE index remains an important tool in fishery stock assessment. Since its first use in fisheries by Baranov (1918), numerous studies have then been made to resolve the problems of scale and distribution, non-random variations, and data incompatibilities, along with various procedures suggested for standardizing and model-fitting of the CPUE data

(Maunder and Punt, 2004). Ultimately, development of CPUE as an index of abundance lies in the improvement in the proportionality between the derived index and the true abundance of the stock in the ecosystem (Ye and Dennis, 2009).

2.2.3 The ecosystem-based approach

The failure of the traditional stock assessment and management is generally recognised (Garcia and de Leiva Moreno, 2003), and often they are attributed to the inadequacy of the approach to capture multispecies and ecosystem effects (Cury *et al.*, 2005a). This led to a current global call for more use of an ecosystem approach to fisheries management (EAFM) to provide holistic view of ecosystem-fisheries interactions. The EAFM is defined by FAO as "the extension and integration of conventional methods of management of marine resources, stressing the close interdependence between the welfare of humanity, the preservation of the environment and the need to maintain productivity of ecosystems for present and future generations" (Garcia *et al.*, 2003). To cater to this new type of ecosystem management, there is a need for descriptive indicators that reflect and describe the complex interactions between fisheries and marine ecosystems (Pauly and Watson, 2005). This is recognised and broadly accepted by the international community, thus leading to the recent development of several ecosystem-based indicators formulated for fisheries management purposes. In view of the relevance to the relatively data-poor multi-species tropical fisheries, several fisheries scientists agreed that trophic indicators are most useful in supporting the implementation of EAFM, especially as they are easily understood, measurable and can be used by non-scientists to make management decisions (Cury *et al.*, 2005b; Munyandorero and Guenther, 2010; Pennino *et al.*, 2011).

The Marine Trophic Index (MTI) is one of the eight indicators which the Conference of the Parties of the Convention on Biological Diversity (CBD) identified in February 2004, to monitor progress toward reaching the target of significantly reducing the current rate of biodiversity loss (CBD, 2004). Essentially, the term MTI is the CBD's name for the mean trophic level (MTL) of fisheries landings, which was originally introduced by Pauly *et al*. (1998), who had demonstrated that fisheries, since the 1950s, are increasingly relying on smaller, short-lived fishes and invertebrates from the lower parts of both marine and freshwater food webs. The origin of the trophic level concept and their usefulness in summarising fisheries impact on marine ecosystems has been reviewed by Pauly and Watson (2005). In brief, the MTL of fisheries landings can be used as an index of sustainability for the exploited ecosystems because fisheries tend to remove large, slow-growing fishes at first, thus reducing the MTL of the fish remaining in the ecosystem. This eventually leads to declining trends of MTL in the catches extracted from that ecosystem, a process now known as 'fishing down marine food webs' (Pauly *et al.*, 1998). Using FAO catch data and trophic levels (TLs) of all species or groups of species that contribute to global catches, Pauly *et al*. (1998) showed that the global MTL significantly declined from 1973 to 1994, at a rate of about 0.1 TL per decade. Their original work gave rise to criticisms (Caddy *et al.*, 1998; Caddy and Garibaldi, 2000), which led to further elaboration of the fishing down concept (see Pauly (2010) for discussion). Subsequently, Essington *et al.* (2006) pointed out that instead of sequential collapse/replacement of the high-trophic level fisheries, a declining MTL may also indicate a serial addition of the low-trophic level fisheries, a process they termed as 'fishing through marine food webs'. Essington *et al*. (2006) further emphasized that the sequential addition mechanism was by far the most common one underlying declines in catch MTL of large marine ecosystems worldwide. Specifically, they found that out of the 30 ecosystems studied where a decline in MTL was observed, only 9 ecosystems showed declining catches of higher-TL species, compared with 21 ecosystems that exhibited either no significant (n=6) or significant increases (n=15) in high-TL catches (Essington *et al*., 2006). Their work, however, was contradicted by the fact that globally, catches are not increasing, and in fact are going down (FAO, 2012b).

A more elaborate review on the use of catch MTL as an indicator appeared recently, refuting Pauly *et al.* (1998) by indicating that the MTL of the worlds' oceans are in fact stable or increasing (Branch *et al.*, 2010). Instead of using the catch data, as done in earlier studies, Branch *et al.* (2010) had used scientific estimates of abundance within ecosystems (i.e. from stock assessments) to come to their conclusion. In response, Pauly argued that their analysis might be flawed by their non-consideration of fisheries expansion, which are particularly evident in the 'Sea Around Us' data they used (see Swartz *et al.*, 2010; Stergiou and Tsikliras, 2011).

While such divergence in findings had attracted large media attention (e.g. Reuters[1], The Guardian[2], The Economist[3]), more important for fisheries scientists and managers alike is the fact that these studies have shown that MTL, especially with better taxonomic resolution of catch data, could be a well-suited indicator that can measure the overall health and stability of the marine ecosystem. Thus mandated by the CBD as a primary indicator of marine biodiversity and health, this index can indicate how abundant and rich the large, high trophic level fish are, and also

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[1] http://www.reuters.com/article/2009/07/30/idUSN30463
[2] http://www.guardian.co.uk/world/feedarticle/8635355
[3] http://www.economist.com/node/14159943?story_id=14159943

indicate the extent that the fishing effort within a country's fishing grounds is modifying its fish stocks (CBD, 2004; Pauly and Watson, 2005; Branch *et al.*, 2010).

In response to a critical review by a group of FAO staff (Caddy *et al.*, 1998), who argued that the FAO statistics used by Pauly *et al.* (1998) were not detailed and reliable enough to support the 'fishing down' interference drawn from them, a Fishing-in-Balance (FiB) index was also developed by Pauly *et al.* (2000) to assess whether a fishery is balanced in ecological terms or not. The theory behind the development of the FiB index is well described in a review by Pauly and Watson (2005) and Pauly (2010). Briefly, FiB is calculated on the basis that any decline in MTL of fisheries catches should be matched by an ecologically appropriate increase in these catches, and the appropriateness of that increase is being determined by the transfer efficiency between TL (Pauly, 2010). Subsequently, values of FiB index should (1) remain constant if the TL-change match 'ecologically correct' changes in catches; (2) increase (> 0) if either bottom-up effect occurs (i.e. increase in primary production), or if a geographical expansion of the fishery occurs; or (3) decrease (< 0) if discarding occurs that is not considered in the 'catches', or if the fisheries withdraw so much biomass from the ecosystem that its functioning is impaired. While FiB requires the assumption that transfer efficiency is constant across trophic levels (Pauly *et al.*, 2000), it is believed to provide a better indicator of ecosystem change than catch or catch composition, because of its integrative nature (Garcia and Staples, 2000).

2.3 Contribution of local ecological knowledge (LEK) in stock assessment and fishery management

Since the pioneering work of Johannes (1981b), the intrinsic value of local operators' knowledge of the ecosystem within which they work has been increasingly recognised and used (Haggan *et al.*, 2007). Within fisheries science and management, local ecological knowledge (LEK) research further progressed when Pauly (1995) published an article on "Anecdotes and the Shifting Baseline Syndrome of Fisheries", in response to the collapse of cod and other fish stocks, together with the fisheries and coastal economies they support, in the northwest Atlantic between 1992 to 1995 (Harris, 1998). Accordingly, key information missing from scientific datasets may be found in stories and anecdotes that described past conditions of marine species and ecosystems, although not in a form easily quantified (Pauly, 1995).

LEK can be defined as knowledge held by specific group of people about their local ecosystems (Olsson and Folke, 2001). As fisheries system worldwide move towards EAFM, large amounts of ecological and social information are required and the use of LEK has been described as an asset for an efficient implementation of EAFM (Garcia and Cochrane, 2005; Paterson and Petersen, 2010). Consequently, fisheries scientists and managers are increasingly engaging with fishers' LEK to provide novel and useful information to improve the legitimacy of fisheries governance, as fishers' LEK may encompass a finer scale resolution and provides a longer historical perspective than other data sources (Dulvy and Polunin, 2004; Ames, 2007; Lavides *et al.*, 2009).

By conducting personal interviews with fishers, researchers can elicit large amounts of information pertaining to the past and the present for both commercial and non-commercial species – information which can be very useful in scientific stock assessments (Johannes and Neis, 2007). For instance, local knowledge of the time and place fish are caught can indicate seasonal and directional fish movements, while information on spatial and other changes in effort and fishing practices can be beneficial in interpreting catch-rate data (Hutchings, 1996; Neis *et al.*, 1999). Fishers' LEK is now used for many purposes, including the deciphering of ecological interactions (Folke, 2004) and dealing questions concerning specific issues, such as fish aggregation (Moreno *et al.*, 2007), habitats (Bergmann *et al.*, 2003), trophic relationships (Pikitch *et al.*, 2004) or the identification of fishing areas (Davis *et al.*, 2004). Moreover, researchers are made aware not only of ecological processes but also of customary tenure and traditional management systems that have been eroded through the interactive effects of external management interventions and resource degradation (Johannes and Neis, 2007).

The accuracy and precision of qualitative information such as LEK, nevertheless, might not be comparable to scientific data. Several researchers (e.g. Silvano and Valbo-Jorgensen, 2008; Ruddle and Davis, 2011; Daw *et al.*, 2011) have warned that although fishers' local experiences and observations are important, they may not be able to characterise accurately such key attributes of the ecosystem processes such as predator-prey dynamics and seasonality. For instance, Ruddle and Davis (2011) demonstrated that the Canadian researchers had disproved fishers' contentions that white hake (*Urophycis tenuis*) was the main predator on juvenile lobster (*Homarus americanus*) in St. Georges Bay of Nova Scotia, while Daw *et al*. (2011) had identified factors which may have resulted in fishers' more pessimistic perceptions of trends in fish abundance in Seychelles artisanal trap fisheries compared to the landings data and underwater visual census (UVC).

As a result, dispute can arise between scientific perspectives on resources and those of resource users (Daw *et al.*, 2011), often focusing on the validity of either perception and the question of which is correct. Interestingly, dispute can arise simply because they are based on observations of different parts of the fisheries system (Daw *et al.*, 2011). Fishers and scientists may perceive the system at different scales (Berkes, 2006), or through monitoring different variables (Verweij *et al.*, 2010). Inaccuracies or biases can affect both scientific and fishers' perceptions, due to the context in which perceptions are formed. Undeniably, different assumptions underlying the analysis of interview data compared to conventional scientific data could also have led to qualitatively different trend perceptions (Daw *et al.*, 2011).

2.3.1 The "Shifting Baseline Syndrome"

While diverging perceptions of resources are common between fishers and scientists (Gray *et al.*, 2008), many studies have increasingly recognised and acknowledged the complementary nature of LEK to scientific knowledge (Silvano *et al.*, 2005; Berkes *et al.*, 2007; Hall *et al.*, 2009). Even though the reliable use of LEK as a basis of management decisions remains a matter of debate, various approaches for increasing its validity have been proposed (Davis and Wagner, 2003; Maurstad *et al.*, 2007). Moreover, in executing fishers' LEK research, scientists may uncover the shifting baseline syndrome (SBS) mentioned earlier.

SBS is a psychosocial phenomenon whereby each generation of stakeholders – whether fishers or scientists – accepts a lower standard of resource abundance as being normal (Pauly, 1995). SBS can operate at a societal level, resulting from younger generations being unaware of past abundance (termed generational amnesia), or as a result of individuals forgetting previous abundances (termed personal amnesia) (Papworth *et al.*, 2009). Subsequently, while it has been shown that reliance on scientific knowledge only, especially for mixed species and over a limited period, can be risky and easily mask true stock status (Saenz-Arroyo *et al.*, 2005a; Saenz-Arroyo *et al.*, 2005b; Venkatachalam *et al.*, 2010), presence of SBS in a LEK system invoke a potential problem in a variety of conservation and fisheries governance context (Sheppard, 1995; Pauly, 1995; Papworth, 2007).

Indeed, fishers may have experienced and understood behavioural changes and increased fishing power, which may have obscured declines from fishery statistics. However, various psychological factors affect memory and recall, thus may affect fishers' memory-based estimates of trends (see Daw et al. 2011). Nevertheless, LEK is relatively inexpensive to obtain and particularly beneficial when degradation may be rapid but time and resources for scientific understanding are limited (Johannes *et al.*, 2000). LEK is also perhaps most useful in understanding the non-commercially targeted species for which there are no alternative catch or relative abundance data available, since fishers are known to offer an unbiased view regardless of whether or not they depend on the stock for their livelihood (Ainsworth, 2011).

2.3.2 Formalisation of LEK with geographical information system (GIS)

Acknowledging the limitations imposed by LEK (see Rahman, 2000), some researchers argued that LEK needed to be formalised (Huntington, 2000; Hall and Close, 2007; Ainsworth *et al.*, 2008; Ainsworth, 2011), since it is essentially of a fragmentary and provisional nature. Yet, relatively little published research has discussed the use of LEK data collection and analysis methods for inclusion in fisheries management. Therefore, although fishers' verbal accounts can be used to reconstruct previous ecosystem trends, some effort is required first to convert anecdotal information in a systematic manner to produce data that is acceptable to fisheries managers and scientists. One approach is the use of spatial information technology, specifically geographical information systems (GIS), as a medium to integrate LEK with scientific knowledge systems.

Fishers, because they are on the water most days of the week, experience the marine ecosystem (i.e. climate patterns, fish migration patterns, species' behaviour, etc.) first hand that may not be fully represented during the times when a scientific study takes place (Johannes, 1989). Unless captured over substantial time periods, fishers, therefore, tend to have better local and temporal knowledge than scientific data gathering can capture. Fishers tend to perceive the environment as a non-linear representation of space, often orientating themselves based on places, such as how far a fishing spot is from a particular island (Brodnig and Mayer-Schönberger, 2000). These types of spatial interactions represent features at a finer, more localised scale than other types of information. In this context, LEK has the potential to be very effective in stock assessments, and if collected over a multi-year period, can even illustrate a temporal representation of the fish stocks.

GIS, on the other hand, has the capability of storing, analysing and manipulating information in various ways, thus serves as a tool to store LEK and to visualise LEK and scientific knowledge in the form of maps. Although GIS in fisheries science have been slow to evolve relative to terrestrial applications, largely due to the fluid nature of the aquatic systems (Nishida *et al.*, 2001), by having LEK and scientific knowledge unified in a GIS environment, the integration of these data can provide a rich and holistic knowledge base for planning and management of fisheries and marine resources.

2.3.3 Application of fuzzy logic concept in quantification of LEK

Beside systematic integration with scientific-base knowledge, formalisation of LEK also has to deal with the inherent issue of vagueness in data collection. Depending on age, experience and expectations, one fisher's 'high' could be another's 'low' (Ainsworth *et al.*, 2008). For instance, an experienced fisher who knows the best places to fish for certain species may report high abundance for that species, while a younger fisher who lacks experience may be less successful, hence reporting its abundance as low. Consequently, LEK does not lend itself well to mathematical representation, and hence for most part it has remained absent from stock assessment or during development of management plans.

To address this problem, several researchers turned to 'fuzzy logic' in quantifying LEK responses for use in fisheries research (Mackinson, 2001; Ainsworth *et al.*, 2008; Ainsworth, 2011). Fuzzy logic offers a standardisation approach which has been demonstrated as appropriate to address the uncertainty and subjectivity in complex marine environmental problems (Cheung *et al.*, 2005; Ainsworth *et al.*, 2008; Sylaios *et al.*, 2010). In comparison to classical logic, where input "linguistic variables" need to be arranged into crisp sets (e.g. a Boolean control variable belonging exclusively to either 'true' or 'false' categories), fuzzy logic enable a gradation of truth (or false) for each input variables. Originally developed by Zadeh (1965) for artificial intelligence and control systems, the fuzzy logic approach made possible for one fisher's 'high' to be treated the same as another fisher's 'low', by emulating an expert's judgement and combining inputs through a heuristic IF-THEN rule matrix to reach conclusion regarding the data. Depending on the set of linguistic input variables, relevant heuristic values will fire in the fuzzy expert system with certain strengths that reflect the certainty regarding the system condition. Each control rule leads to a conclusion about the system status, and after all relevant control rules fire, the resulting range of possible conclusions is then reduced to a single point output through a "defuzzification" process (see Ainsworth *et al*. 2008 and Ainsworth, 2011). Since all knowledge, whether scientific or LEK, can be incorporated into the system, the potential of all data sources is also maximized (Mackinson and Nottestad, 1998).

2.4 Marine environmental variability and fishery resources

The basis of stock assessment and fisheries management have long evolved around the response of fish populations to harvesting, while the influence of climate variability on the production of marine ecosystems remains poorly understood (Fogarty and Powell, 2002). Indeed, a reliable correlation between long-term stock fluctuations and global climate characteristics has been ignored until recently, especially with the advancement in remote sensing technology capabilities (e.g. Solanki *et al.*, 2003; Klyashtorin, 2001; Qiu *et al.*, 2010). Some studies found that climate variability affects primary through to tertiary productivity by controlling nutrient supply (Lehodey *et al.*, 2003; Qiu *et al.*, 2008). Others suggest that the physical environmental conditions directly influence larval survival and recruitment (Friedland *et al.*, 2003; Ottersen *et al.*, 2006). Regardless of the source, most agreed that identification of the physical forcing factors and understanding their driving mechanisms greatly benefit stock assessments.

Beaugrand and Kirby (2010) suggest that one likely reason for the causes and mechanisms responsible for variability in fish stock biomass to remain poorly identified may be due to interactions between fishing and the environment (Brander, 2007). For instance, fishing has been observed to reduce the spawning stock biomass and skews the age distribution towards younger ages and earlier maturity at a smaller size (Heath and Brander, 2001), and this can amplify the response of the populations to variability in environmental conditions (Ottersen *et al.*, 1994; Montevecchi and Myers, 1996; Hsieh *et al.*, 2006).

Quantifiable statistical studies linking climate and its variation to commercial fishery catches were first made by Hjort (1926) who demonstrated that environmental conditions, and not migrations, were responsible for the variability in Norwegian herring and cod catches. Much of the subsequent research then focused on the link between climate variability and the responses from large pelagic fisheries such as Peruvian anchovy, Icelandic herring and Japanese sardine (Klyashtorin, 2001). Not only are these pelagic fishes are dominant in marine ecosystems and hence more commercially important globally, but an even more interesting phenomenon is the regular synchronous outbursts of sardine and anchovy catches in different regions of the world, further suggesting that the fish populations are governed by the same global climatic events (Kawasaki, 1992). At such, the pattern of variation in the demersal fish community structure and its relations with environmental factors have received little attention in comparison with pelagic species (Tian *et al.*, 2011), presumably since changes in demersal fisheries tend to take place over a relatively longer period of time, as well as the lack of large interannual variation in recruitment for the demersal stocks (Myers *et al.*, 1995). Nevertheless, demersal stocks, especially those that form large spawning aggregations such as groupers and snappers, are extremely vulnerable to exploitation (Dulvy *et al.*, 2004). Given the increased knowledge of the linkages between resources and marine environmental parameters, disentangling the influence of fishing and environment therefore becomes essential for effective fisheries management, particularly at a time of rapid global climate change (IPCC, 2007).

2.4.1 Impact of climate change on tropical marine ecosystem and fishery

Empirical evidence for climate change effects on marine ecosystems and their component is growing (Blanchard *et al.* (2012) and references therein). As the many impacts of climate change on marine ecosystems may be additive, synergistic or antagonistic, Intergovernmental Panel on Climate Change (IPCC) in their recent Fourth Assessment Report (2007) concluded that climate change will affect the production of fish and the fisheries they support, and will likely confound the impacts of natural variation on fishing activities, thus further complicating management efforts.

Climate change threats in the tropics are increasing, with coral reefs predicted to be the first major ecosystem to suffer extensive damage, especially from increasing sea surface temperature and elevated concentrations of CO_2 (IPCC, 2007). Although there are no parallel climate change threats to mangrove forests and seagrass beds, coastal ecosystems can still be severely damaged by the predicted increase in the incidence of severe tropical storms (IPCC, 2007). Munday *et al.* (2012) gave an excellent review on impacts and adaptation responses of tropical coastal fish to climate change. Changes to sea surface temperature (SST), ocean pH, and circulation patterns are expected to influence a suite of biological and ecological characteristics of marine fishes, which include physiological condition, life history traits, timing of breeding, reproductive output, larval development, population connectivity and geographical distributions (see Table 1 from Munday *et al*., 2012).

Since capture fisheries depend on the productivity of the natural ecosystems on which they are based, consequently, climate change impacts will likely exacerbate existing stresses on fish stocks such as overfishing, diminishing wetlands and nursery areas, and pollution (IPCC, 2007). The long-term consequences of climate change to capture fisheries remain highly uncertain (Perry 2011). Climate change can likely cause collapses of some fisheries and expansion of others, as the level of impact vary widely and will depend on the complexity of each ecosystem, the attributes and adaptability of each species, and the nature of human communities that depend on them (IPCC-SAR, 1996). As a result, observational changes in marine environments associated with climate change need to be considered against the background of natural variation on a variety of spatial and temporal scales (IPCC, 2007; Perry 2011). Given that distinguishing the effects of climate change embedded in natural modes of variability such as ENSO, although challenging (IPCC, 2007), is essential in addressing the uncertainties of climate change on fisheries, these situations further reiterate the importance of being able to discern anthropogenic and natural causes on fishery stock abundance, especially if fishery-dependent data is involved.

2.5 Earlier studies on fishery and stock assessments in Brunei Darussalam

Fish stock surveys on the continental shelf of Brunei waters began in the 1950s, but without any significant effect on fisheries development and management in Brunei as these surveys were not conducted by the Brunei government nor any agencies associated with it. Instead, these surveys were carried out under the British Colonial Development and Welfare Scheme based in Singapore, to investigate the fishery potential in Malaya and Borneo waters (Beales, 1982). Brunei's DOF, as it exists today, was established in 1966, and its first official survey, although limited in scope, was carried out in 1968. Descriptions of these surveys are summarised by Beales (1982), in his seminal report on the "Investigations into Fisheries Resources in Brunei", which proved to be a watershed in the sense that the results from his report were used as a basis for large-scale fishery development in Brunei. These results were based on the exploratory 1979-1980 trawl survey conducted using DOF's first research and training vessel *K/P Lumba-lumba* (=*R/V Dolphin*).

The next comprehensive study was then conducted in 1989-1990 as part of the ASEAN/US Coastal Resources Management Project implemented in the country (see DOF-MIPR 1992; Silvestre *et al*. 1993). Demersal trawl and pelagic acoustic surveys were the two techniques employed. However, the analysis of these surveys has been limited to estimating biomass and potential yield (Silvestre and Garces, 2004), presumably because one of the objectives of the programme was to build up local human capacity in fisheries science and management (DOF-pers.comm.). Following Brunei's membership in SEAFDEC in 1995, periodic surveys and stock assessments were carried out in Brunei waters, as part of the collaborative research with regional and international organisations, often investigating on South China Sea on a whole (e.g. Ranimah and Cinco, 2006; Syah, 2007; Staples, 2009). As a result, these researches tend to generalise and apply the result of low density sampling to large areas.

The DOF also made an effort to run routine survey programmes for stock assessments, which is mainly made through FAO's operation of FiSAT. Unfortunately, the results of these surveys were never published other than as an internal government report, although a number of policy recommendations were made based on these results to assist in the management of fisheries at national level (DOF-pers.comm.). In fact, like most other countries in the region, the information content of the data collected from the previous surveys in Brunei waters remains to be fully extracted and utilised (Silvestre and Pauly, 1997b; Silvestre and Garces, 2004). This is because many of the survey data remain in the files of various fisheries agencies and are not being systematically collated and analysed using appropriate techniques – rendering these fisheries to be 'data-poor'.

Results from previous studies on the demersal stocks of Brunei waters revealed low exploitation rates and a relatively healthy stock biomass, at least up till the year 2000, as verified by the trawl survey carried out by DOF in 2000 (DOF-pers.comm.). This was further confirmed in an independent study by Chirstensen et al. (2003) who had shown that the predicted fish biomass of trophic level ≥ 3.0 in Brunei in 2000 was roughly 80% of its predicted biomass in 1960. When DOF carried out another demersal trawl survey in 2009, it was obvious that the demersal resources had declined (i.e. mean trawl catch rate significantly lower in 2009; DOF-pers.comm.), but the causes remain unclear. The data which DOF attempted to collect annually by trawl surveys since 2000 were problematic and deemed unreliable to infer trends and other information (DOF-pers.comm.). For instance, other than issues associated with sample sizes and replicates, there were data "gaps" which were often caused by factors beyond DOF's control (e.g. mechanical problems on research vessel, bad weather condition, withdrawal of permission to carry out survey due to political situations, etc.).

In the face of increased fishing effort, changing climate and environmental conditions, and the boom and bust of some species, it then became apparent that further research is in order to complement DOF's monitoring programme, and thus provide the stakeholders of Brunei fisheries with more recent and sound scientific outcome to base their decisions in future fishery development and management. As a type of natural resource exploitation, many acknowledged fishery as not only a biological system, but also socio-economic and political (Pauly and Zeller, 2003). Hence, to effectively develop and manage such complicated system, the assessment of the status of the resources will be a critical starting point.

Chapter 3
Overview of Brunei marine ecosystem in the past decade via trophodynamic indicators and community structure analyses[1]

"… the ocean is a restless and changing environment;
its changes may either be sudden and dramatic, or
covert and sustained for very long periods…"
– Alan Longhurst and others, 1972

Chapter Summary

Large-scale fishery catches in Brunei Darussalam between 2000 and 2009 were used to examine changes in community structure of Brunei's marine ecosystem. This study found that Mean Trophic Level (MTL) has declined at a rate of 0.08 trophic levels (TL) per decade, suggesting a 'fishing down the marine food web' process in Brunei waters. In order to focus on changes in relative abundance of the more threatened, higher TL finfish only, MTL was recalculated as $^{3.30}$MTL (to exclude catches of finfish and invertebrates species with TL less than 3.30). Here, no overall trend in the $^{3.30}$MTL was found over the study period. A more in-depth analysis suggested that MTL fails to capture substantial changes in underlying species assemblage. Over the course of the study period, marked changes in fish community structure were observed. Analysis of official statistics showed an increase in total catch was driven primarily by an increase in pelagic catches, with a similar trend observed when the catches were aggregated into either high- or low-TL. Additionally, the increasing trend of Fishing-in-Balance (FiB) index for Brunei waters, as well as shifts in trophic spectra (TS) patterns suggest expansion of the fishery effort offshore. Whilst this study was not aimed at demonstrating overfishing as the cause of observed trends, there is a danger that current best practice fails to detect what may be an imminent collapse of the demersal stock. In many fisheries around the world, there is a need for detection methods able to identify potential problems within a time scale short enough to be able to react effectively.

[1] Syazana Ebil, Charles R.C. Sheppard, Ranimah Wahab, Andrew R.G. Price, James C. Bull (2013) Changes in community structure of finfish catches in Brunei Darussalam between 2000 and 2009, *Ocean & Coastal Management*, **76**, 45-51.

3.1 Introduction

In response to the increasing recognition of the declining state of fisheries and marine ecosystems, there is a compelling need for conservation of ecosystem services, beyond the sustainability of fishery-targeted stocks. This is recognised and widely accepted by the international community, leading to the recent development of several ecosystem-based indicators. This chapter is dedicated to the application of the trophodynamic indicators and community structure analyses to assess the overall state of Brunei marine ecosystem in the past decade.

At present, there are no published analyses of fisheries shifts and their ecosystem effects in Brunei. By synthesising several types of analyses, changes over time in species composition, mean trophic level (MTL), Fishing-in-Balance (FiB) and trophic spectra (TS) of catches were explored. Consequently, this chapter shows that even a well-respected metric such as MTL may fail to capture critical aspects of community architecture. This highlights the importance of documenting and disentangling the variety of overlapping and confounding factors, that potentially affects fishery dynamics, in understanding and interpreting the message conveyed by TL-based metrics. Specifically, this chapter aims to address the following research questions:

1) Do Brunei catch MTL and FiB indices decline with time?
2) Do catches of invertebrates and low-TL species affect changes in MTL?
3) Is ‘fishing down the food web’ (FDFW) prevalent in Brunei waters (i.e. decrease in MTL due to decline in abundance of high-TL species)?
4) Which ecological domains (or functional group) are mostly affected?

3.2 Materials and methods

3.2.1 Study area

The study area (Figure 3.1) corresponds to the continental shelf and continental slope of Brunei waters (within 1000-m isobath), excluding the small-scale (SS)-only fishery zone (Brunei Bay and waters 0 – 3 nautical mile from shore). This study area is known active fishing grounds of pelagic and demersal resources for the large-scale (LS) fishery.

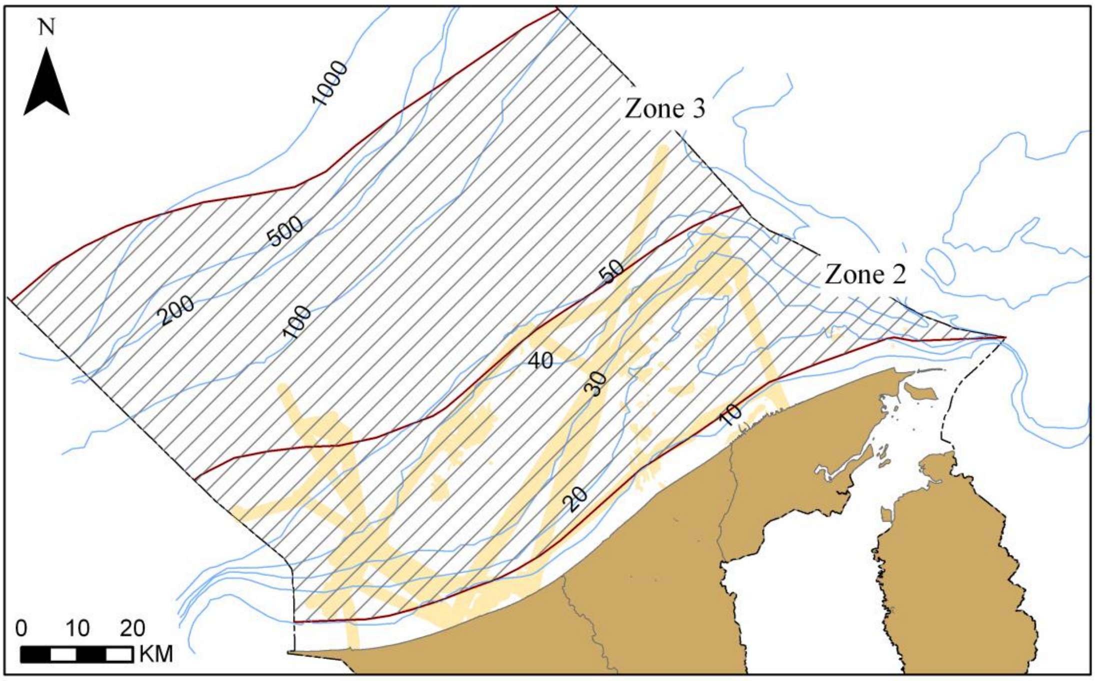

FIGURE 3.1: Study area corresponds to Zone 2 and 3 of Brunei fishing zonation (hatched lines). Shaded area (in yellow) indicates oil industry-related or coral reefs areas.

3.2.2 Catch data and trophic level estimates

This study is based on the monthly catch data recorded for the LS sector instituted by the Department of Fisheries, Brunei (DOF). In these fisheries, collection of catch data has been underway since 1984 when LS fishing operation officially started. However, compilation of fisheries data digitally was introduced only in 2000 and is on-going. Thus, this study is based on the data set from 2000 to 2009.

Catches and TL of 88 known species (or species groups) were used to calculate the trophodynamic indicators (Table 3.1). Despite comprising only 55 - 60% of total catches, these selected species were of high commercial importance and benefit from a fine level of taxonomic resolution associated with its catch data. The rest of the total catches comprise of ‘mix’ categories, all representing unidentified fishes, and hence were not included in the analysis due to the impossibility of assigning them a precise TL.

Estimates of TL of each species (TL_i) was taken from FishBase (v. 08/2011), which calculates TL from stomach contents data (Froese and Pauly, 2000). When estimates were not available for a species, a closely related species (same genus) was used. When the catch data represented a group of species (e.g. Lutjanidae spp.), an average of the TL of all the species (ever recorded for Brunei waters) within the group would be taken.

TABLE 3.1: Trophic level (TL) of the main species landed from Zone 2 and 3 of Brunei fishing zonation, from 2000 to 2009.

Groups[(a)]	Family name	Scientific name/group	Common name	Local name	Est. TL
DEM	Ariidae	*Arius thalassinus*	giant catfish	gagok	3.10
	Balistidae	*Abalistes stellaris*	starry triggerfish	ayam laut	3.54
	Caesionidae	*Caesio* spp.	fusiliers	sulit	3.40
	Carangidae	*Alectis indica*	Indian threadfish	taweh	4.09
	Carangidae	*Caranx ignobilis*	giant trevally	bamasa	4.22
	Carangidae	*Caranx* spp.	jacks	ikan putih	4.24
	Carangidae	*Caranx tille*	tille trevally	langguran	4.06
	Carangidae	*Gnathanodon speciosus*	golden trevally	bebatik	3.84
	Carangidae	*Parastromateus niger*	black pomfret	duai hitam	2.93
	Carangidae	*Selaroides leptolepis*	yellowstripe trevally	temanong besurat	3.53
	Drepaneidae	*Drepane punctata*	spotted sicklefish	saphee	3.32
	Ephippidae	*Ephippus orbis*	batfish	awat-awat	3.99
	Gerreidae	*Gerres filamentosus*	whipfin mojarra	kapas-kapas	3.26
	Haemulidae	*Diagramma picta*	painted sweetlips	lapih	3.46
	Haemulidae	*Pomadasys argenteus*	head grunt	garut-garut	3.42
	Haemulidae	*Pomadasys hasta*	silver grunt	umpak	3.55
	Lactariidae	*Lactarius lactarius*	false trevally	kelapa-kelapa	3.60
	Leiognathidae	*Leiognathus equulus*	common ponyfish	pulut-pulut	3.01
	Leiognathidae	*Leiognathus* spp.	ponyfish	bilis	3.02
	Lethrinidae	*Lethrinus lentjan*	pink ear emperor	anduping	3.65
	Lutjanidae	*Lutjanus argentimaculatus*	mangrove red snapper	ungah	3.80
	Lutjanidae	*Lutjanus johnii*	John's snapper	beberahan	4.18
	Lutjanidae	*Lutjanus lutjanus*	bigeye snapper	pisang-pisang	4.05
	Lutjanidae	*Lutjanus malabaricus*	Malabar red snapper	membangan	4.48
	Lutjanidae	*Lutjanus rivulatus*	blubberlip snapper	ketumbang	4.13
	Lutjanidae	*Lutjanus sebae*	emperor red snapper	santak	4.27
	Lutjanidae	*Lutjanus* spp.	red snapper	ikan merah	4.46
	Lutjanidae	*Pinjalo pinjalo*	pinjalo snapper	sulit merah	3.80
	Lutjanidae	*Pristipomoides multidens*	goldband snapper	kerosi bali	3.84
	Mullidae	*Upeneus sulphureus*	sulphur goatfish	bantang	3.16
	Muraenesocidae	*Muraenesox bagio*	common pike eel	tingkor-tingkor	3.99
	Nemipteridae	*Nemipterus* spp.	threadfin breams	kerisi	3.60
	Polynemidae	*Leptomelanosoma indicum*	Indian threadfin	kurau	3.60
	Priacanthidae	*Priacanthus tayenus*	spotted fin bigeye	semperiding takat	3.58
	Psettodidae	*Psettodes erumei*	Indian halibut	pila-pila	4.39
	Sciaenidae	*Johnius coitor*	coiter croaker	gelama	3.25
	Sciaenidae	*Otolithes ruber*	tiger-toothed croaker	jarang gigi	3.60
	Sciaenidae	*Pterotolithus maculatus*	blotched tiger-toothed croaker	keropok	3.73

TABLE 3.1 (*Continued*)

Groups[(a)]	Family name	Scientific name/group	Common name	Local name	Est. TL
	Serranidae	*Epinephelus bleekeri*	duskytail grouper	kerapu hitam	3.90
	Serranidae	*Epinephelus* spp.	grouper	kerapu	4.15
	Serranidae	*Plectropomus leopardus*	leopard coral grouper	penghantaran	4.49
	Serranidae	*Plectropomus maculatus*	spotted coral grouper	kerapu merah	4.11
	Siganidae	*Siganus* spp.	rabbitfish	belais	2.87
	Sillaginidae	*Sillago sihama*	silver sillago	usus	3.37
	Stromateidae	*Pampus argenteus*	silver pomfret	duai putih	3.12
	Synodontidae	*Saurida tumbil*	greater lizardfish	pangual badok	4.40
	Trichiuridae	*Trichiurus lepturus*	largehead hairtail	ikan timah	4.45
PEL	Carangidae	*Alepes kleinii*	razorbelly scad	pelata	3.54
	Carangidae	*Atule mate*	yellowtail scad	temanong	4.45
	Carangidae	*Decapterus maruadsi*	Japanese scad	basong-basong	3.40
	Carangidae	*Elagatis bipinnulata*	rainbow runner	salman	3.59
	Carangidae	*Megalaspis cordyla*	torpedo scad	geronggong	4.39
	Carangidae	*Scomberoides commersonnianus*	talang queenfish	bekalang	4.48
	Carangidae	*Selar crumenophthalmus*	bigeye scad	tulai	4.10
	Clupeidae	*Amblygaster sirim*	spotted sardinella	tamban bagol	3.30
	Clupeidae	*Anodontostoma chacunda*	gizzard shad	kuasi	2.83
	Clupeidae	*Sardinella fimbriata*	fringescale sardinella	aur-aur	2.70
	Clupeidae	*Sardinella gibbosa*	goldstripe sardinella	tamban	2.85
	Clupeidae	*Tenualosa macrura*	longtail shad	terubok	2.27
	Coryphaenidae	*Coryphaena hippurus*	common dolphinfish	suhong	4.37
	Engraulidae	*Thryssa setirostris*	longjaw thryssa	kirang-kirang	3.32
	Ephippidae	*Platax teira*	longfin batfish	buna	3.95
	Hemiramphidae	*Hemiramphus far*	black-barred halfbeak	suroi	2.91
	Istiophoridae	*Istiophorus platypterus*	Indo-Pacific sailfish	layaran	4.50
	Lobotidae	*Lobotes surinamensis*	tripletail	pelayak	4.04
	Megalopidae	*Megalops cyprinoides*	Indo-Pacific tarpon	bulan-bulan	3.30
	Pristigasteridae	*Ilisha megaloptera*	bigeye ilisha	bilak-bilakan	3.04
	Rachycentridae	*Rachycentron canadum*	cobia	banglus	3.96
	Scombridae	*Euthynnus affinis*	bonito	bakulan	4.50
	Scombridae	*Katsuwonus pelamis*	skipjack tuna	tongkol	3.75
	Scombridae	*Rastrelliger brachysoma*	short mackarel	rumahan bini	2.72
	Scombridae	*Rastrelliger kanagurta*	Indian mackarel	rumahan laki	3.19
	Scombridae	*Scomberomorus commerson*	narrow-barred Spanish mackarel	tenggiri	4.50
	Scombridae	*Scomberomorus guttatus*	Indo-Pacific king mackarel	lamading	4.28
	Scombridae	*Thunnus albacares*	yellowfin tuna	tuna sirip kuning	4.34
	Scombridae	*Thunnus tonggol*	longtail tuna	tuna	4.50
	Sphyraenidae	*Sphyraena* spp.	barracuda	titir	4.34

TABLE 3.1: (*Continued*)

Groups[a]	**Family name**	**Scientific name/group**	**Common name**	**Local name**	**Est. TL**
CON	Carcharhinidae	*Carcharhinus dussumieri*	whitecheek shark	yu	3.90
	Dasyatidae	*Dasyatis* spp.	stingray	pari	3.76
	Rhinobatidae	*Rhynchobatus djiddensis*	giant guitarfish	anunan	3.60
	Rhinobatidae	*Rhinobatus* spp.	guitarfish	paita	3.55
INV	Loliginidae	*Loligo* spp.	squid	sotong	3.80
	Penaeidae	*Penaeus* spp.	prawn	udang	2.50
	Portunidae	*Portunus pelagicus*	blue crab	ketam	2.50
	Holothurian	*Holothurian* spp.	sea cucumber	timun laut/balat	2.00
	Palinuridae	*Panulirus ornatus*	spiny lobster	bakara	2.00
	Scyllaridae	*Thenus orientalis*	flathead lobster	satak	2.00
	Sepiidae	*Sepia* spp.	cuttlefish	kelabutan	2.00

(a) Groups based on their ecological guilds; DEM – demersals, PEL – pelagic, CON – chondrichthians, INV – invertebrates.

3.2.3 Data analyses

The original data set provided by the DOF was stored in Microsoft Access. Data manipulation and analyses were done in other programs, mainly Microsoft Excel and SPSS v.18.

3.2.3.1 Mean trophic level (MTL) and Fishing-in-Balance (FiB) index

The MTL was estimated as follows (Pauly *et al.*, 1998):

$$MTL = \frac{\sum TL_{ij} Y_{ij}}{\sum Y_{ij}}$$

where MTL is the mean trophic level of catch in month j, Y_{ij} the catch of species i in the month j and TL_i is the trophic level of species i.

To account for the effect of non-fish species, as well as species of low-TL, MTL was recalculated using a cut-off trophic level of 3.30 (see discussion; Section 3.4). Termed $^{3.30}$MTL, this analysis enabled emphasis on changes in the relative abundance of the more threatened, higher TL species to be explored (Pauly and Watson, 2005).

Subsequently, fishing down the marine food web (FDFW) may be the result of a deliberate choice which can affect the MTL trend but might not reflect the true trophic structure in the ecosystem (Caddy *et al.*, 1998; Pauly and Watson, 2005). This can be explored via the FiB index as developed by Pauly *et al*. (2000). However, one drawback of the FiB index is its heavy reliance on the catches and their TL in the reference year (or month). Considering that trends in a FiB series are conserved irrespective of the reference year selected (Cury *et al.*, 2005), absolute FiB was calculated for Brunei instead:

$$^{abs}FiB = \log\left(Y_i\left(\frac{1}{TE}\right)^{TL_i}\right)$$

where Y_i is the catch at month *I*, TL_i is the mean trophic level of the catch at month *i*, and TE is the trophic efficiency (here set at 0.10; see Pauly et al., 2000). Consequently, FiB trends will remain constant (slope equals zero) if TL changes are matched by 'ecologically correct' changes in catch (Pauly *et al.*, 2000).

3.2.3.2 Trophic spectra (TS)

The catch TS were plotted from annual catch data, following the technique described by Gascuel *et al*. (2005). First, species catches were distributed by trophic class of

0.1 increments according to their trophic level. A smoothed spectrum was then obtained with a three-increment weighted moving average. This second step was required to account for the intraspecific variability (Gascuel *et al.*, 2005) and the uncertainty inherent in TL estimation (Pinnegar *et al.*, 2002).

3.2.3.3 Statistical analyses

Monthly MTL and FiB values were subjected to standard time series decomposition to control for the impacts of seasonal factors. Simple linear regression analysis was then used to determine the long term trend between catches, logit-transformed catch proportions and TS, and MTL and FiB indices against time. In monthly MTL and FiB analyses, if the long term trend were found to be non-significant, smoothing splines were used to illustrate shorter-term changes through time. The slope from the regression analysis was also used to calculate the rate of change in MTL per decade (ΔMTL) (Pauly *et al.*, 1998; Milessi *et al.*, 2005; Bhathal and Pauly, 2008; Freire and Pauly, 2010).

3.3 Results

3.3.1 Exploratory analysis: Trends in annual catch and effort

Annually, the total catch from Brunei waters has shown a significant increase over the years investigated (Figure 3.2a), driven primarily by the significant increase in the catches of pelagics, with a peak of ca. 1360 MT recorded in 2005 (Figure 3.2c). The rest of the catch, which comprised of the functional groups of demersals, chondrichthians and invertebrates (i.e. crustaceans and molluscs) did not show any significant annual trends (Figure 3.2, Table 3.2). Trends in annual effort (taken as maximum number of fishing vessels and total number of days out in the sea – see Chapter 4 for further discussion) varied amongst different gear categories (Figure 3.3, Table 3.3), whereby a pronounced increase in the purse seine fleet was observed.

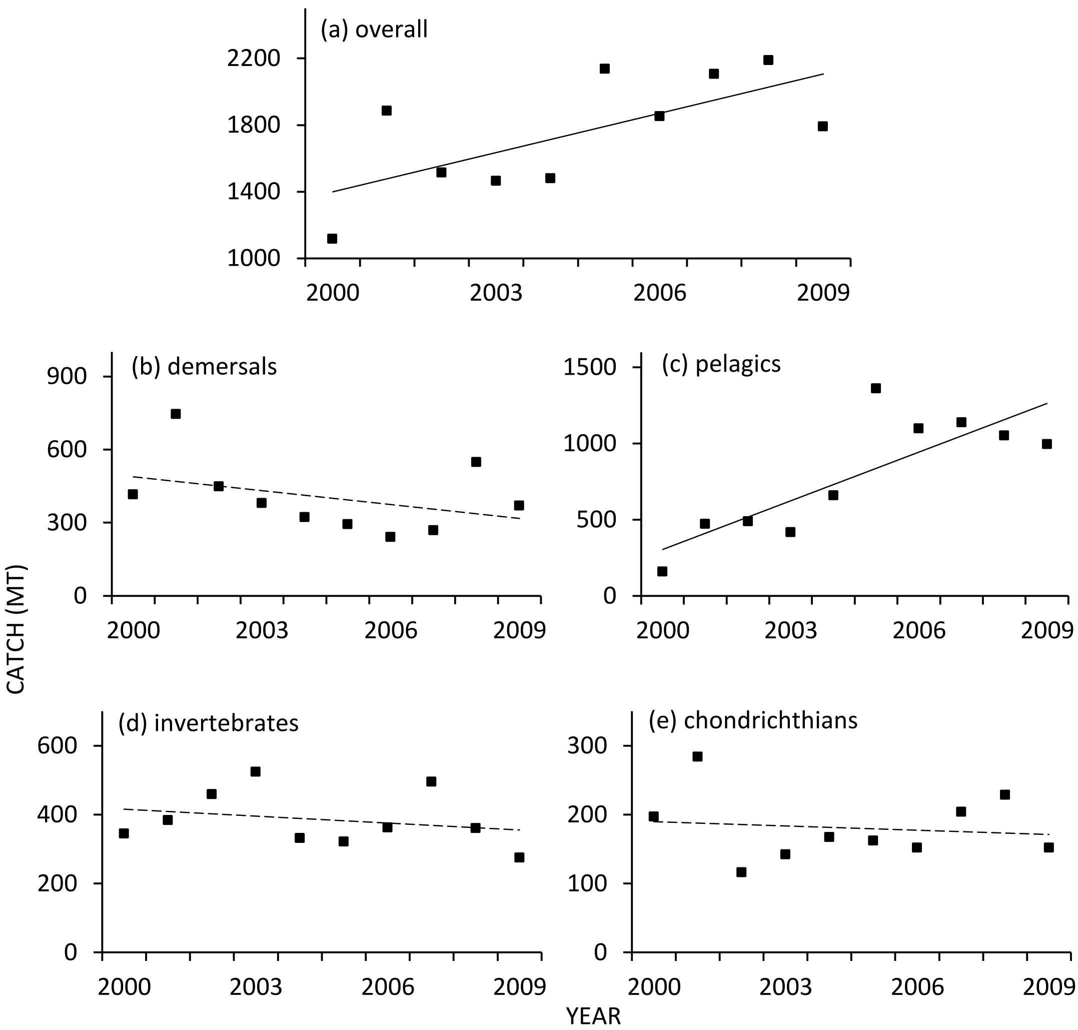

FIGURE 3.2: Annual fishery catches (in metric tons) of Brunei waters between 2000 – 2009 based on functional groupings: (a) overall; (b) demersal fishes; (c) pelagics fishes; (d) invertebrates (crustaceans and molluscs); (e) chondrichthians (sharks and rays). Non-significant trend is shown with a dashed line. Note the different scales on the y-axis.

TABLE 3.2: Results of linear regression analyses of catches of different groups as a function of years in Brunei waters. Significant p-values are in **bold**.

Factor (catches in MT)	R^2	**Annual change Slope *b* (SE)**	***t*-stats**	**p-value**
Overall	0.46	78.7 (30.2)	2.61	**0.031**
Demersal fishes	0.15	-19.0 (16.3)	-1.17	0.276
Pelagic fishes	0.67	106.6 (26.5)	4.03	**<0.001**
Invertebrates	0.06	-6.7 (9.1)	-0.74	0.480
Chondrichthians	0.02	-2.0 (5.7)	-0.36	0.731

*Degrees of freedom = 9 for all analyses

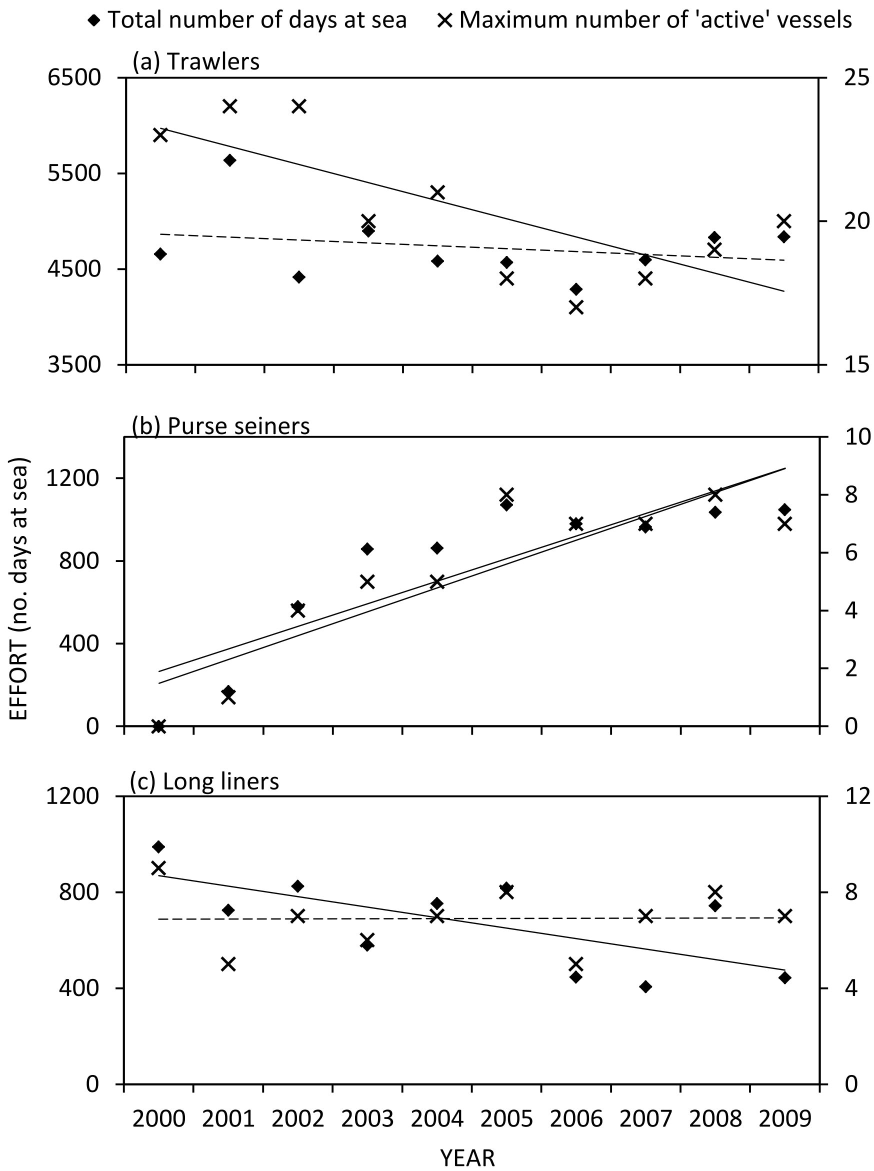

FIGURE 3.3: Annual trends in effort for the three LS fishery fleet: (a) Trawlers, (b) Purse seiners, and (c) Long liners. Non-significant trend is shown with a dashed line. Note the different scales on the y-axis.

TABLE 3.3: Results of linear regression analyses of efforts of different fishing fleet as a function of years in Brunei waters. Significant p-values are in **bold**.

Factor	R^2	Annual change Slope *b* (SE)	*t*-stats	p-value
Effort: Maximum number of 'active' vessels				
Trawls	0.56	-0.63 (0.2)	-3.20	**0.013**
Purse seines	0.78	0.82 (0.2)	5.37	**0.001**
Long lines	0.00	0.01 (0.2)	0.04	0.969
Effort: Total number of days at sea				
Trawls	0.06	-29.98 (42.0)	-0.71	0.496
Purse seines	0.74	109.10 (22.8)	4.79	**0.001**
Long lines	0.46	-43.71 (16.7)	-2.62	**0.031**

3.3.2 Trends of trophic-based indicators

After correcting for seasonal factors, the MTL of the total catch showed significant temporal decline (Figure 3.4a, Table 3.4), with an apparent drop in MTL values between 2006 and 2007. This resulted in ΔMTL = 0.08 TL per decade. In contrast, $^{3.30}$MTL values showed no significant long-term trend throughout the study period (Figure 3.4b, Table 3.4), although two distinct perturbations could be identified from the smoothed $^{3.30}$MTL trajectory. From 2002 to 2004, $^{3.30}$MTL values rose gradually, coinciding with the change in gear legislation in 2002. However, only two years after the restriction was introduced, the $^{3.30}$MTL values started to decline again, although a second smaller peak was detected in 2007. Finally, the absolute values of FiB index showed a gradual increase throughout the study period (Figure 3.5, slope (SE) = 0.001 (0.0004), t (df = 119) = 2.11, p = 0.036).

TABLE 3.4: Results of linear regression analyses of different type of MTL as a function of time in Brunei waters. Δ is the magnitude of decadal change. Significant p-values are in **bold**.

MTL	Δ	R^2	Monthly change Slope *b* (SE)	*t*-stats	p-value
MTL	0.08	0.05	-0.0007 (0.0003)	-2.445	**0.016**
$^{3.30}$MTL	0.11	0.11	-0.0010 (0.0003)	-3.727	0.083

*Degrees of freedom = 119 for all analyses.

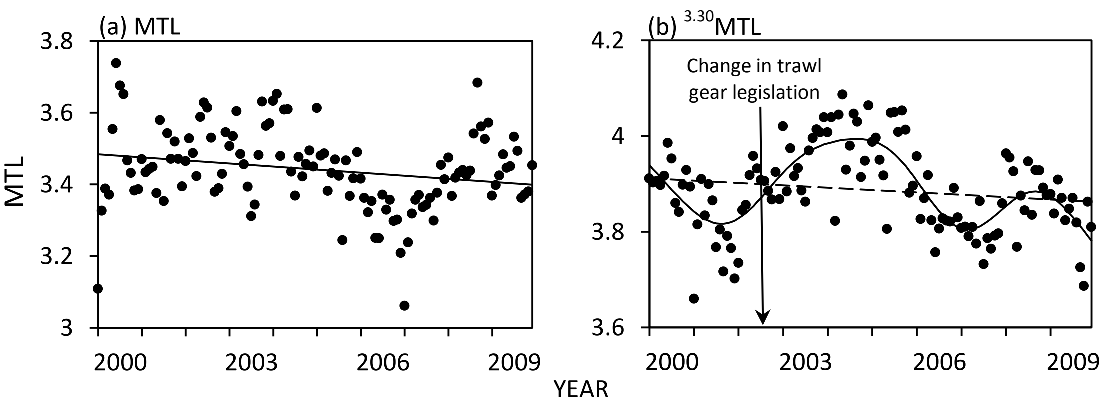

FIGURE 3.4: Seasonally-adjusted mean trophic level (MTL) of fishery catches in Brunei during the period 2000 – 2009. MTL of (a) total catches, and (b) catches excluding species with TL < 3.30 ($^{3.30}$MTL). Non-significant trend is shown in dashed line.

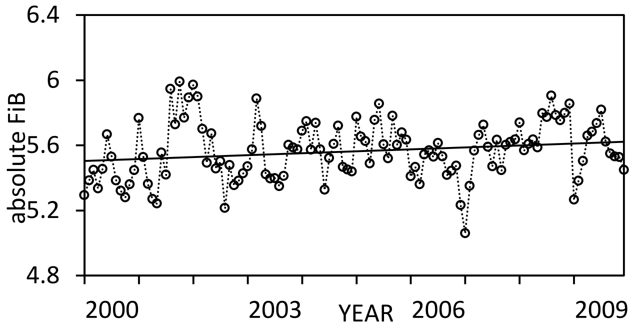

FIGURE 3.5: Absolute Fishing-in-balance (^{abs}FiB) index of fishery catches in Brunei (2000-2009).

3.3.3 Trends in species composition of catch

The varying trends in catches of different families within the different ecological groups resulted in a shift in species composition of catches over the years (Figure 3.6a). At the beginning of the time series, total catches were dominated by demersal fishes (mainly snappers and false trevallies) and penaeid shrimp, as these groups comprise about 60% of the total catches. However, in 2009, the proportion of catch contributed by these groups was less than 30%. The proportion of demersal fishes in catches had declined over the years (Figure 3.6c; logit-transformed values of demersal fishes proportions against time – slope (SE) = -0.12 (0.05), t (df = 9) = -2.72, p = 0.03), while on the other hand, the proportion of pelagic fishes such as tunas, sardines and small mackerels had increased with time (Figure 3.6b; logit-transformed values of pelagic fishes proportions against time – slope (SE) = 0.21 (0.05), t (df=9) = 4.30, p < 0.01), from just over 10% in 2000 to more than 50% at the end of the time series.

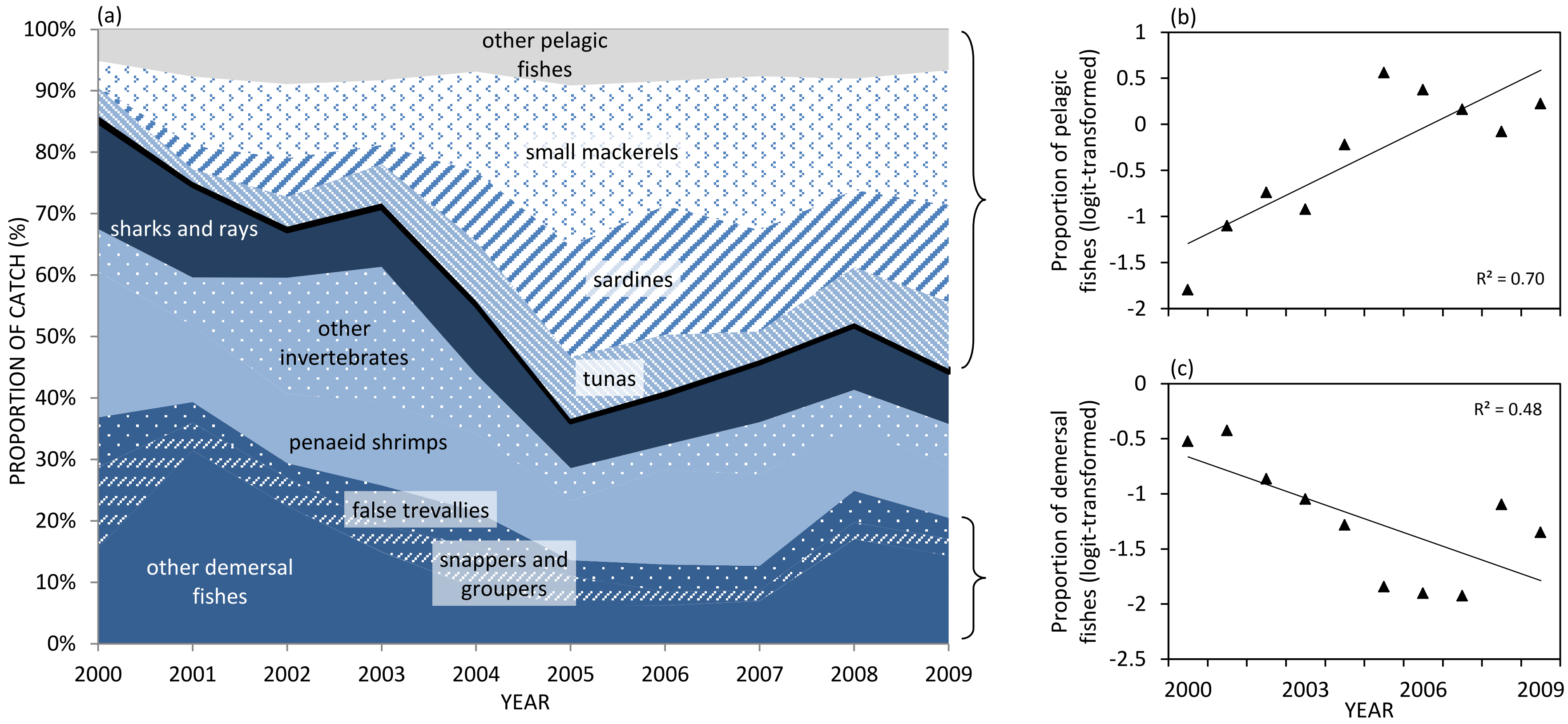

FIGURE 3.6: Changes in composition of species caught in Brunei waters between 2000 and 2009. (a) Composition of overall catches, aggregated based on functional groupings (from top) – pelagic fishes, chondrichthians, invertebrates and demersal fishes – which are further subdivided considering the species caught at higher proportion; and proportion of (b) pelagic fishes, and (c) demersal fishes, caught throughout the study period.

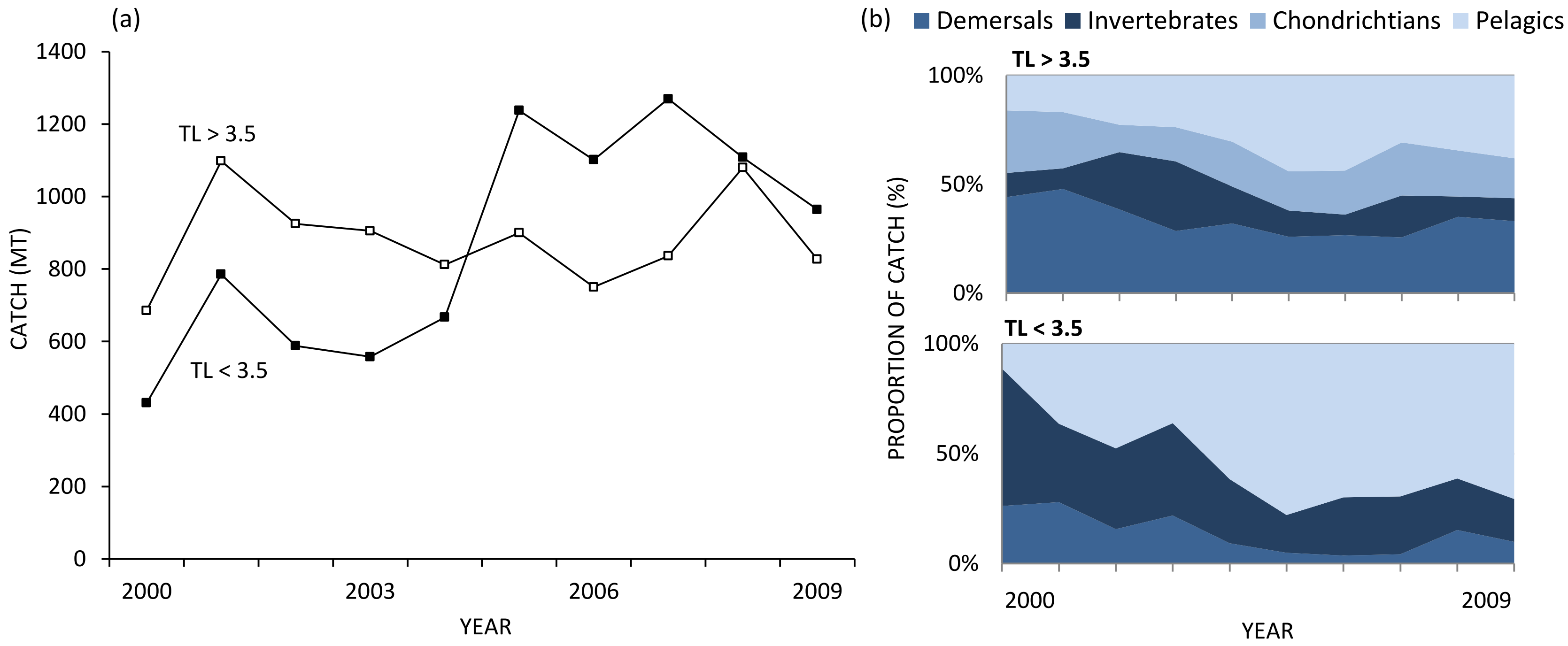

FIGURE 3.7: Analysis of Brunei fishery catches discriminated by trophic level: TL > 3.5 and TL < 3.5; (a) Total annual catch of high-TL and low-TL species for Brunei; (b) Species composition of catches for the different trophic level groups, with increasing proportion of pelagics observed toward end of time series.

Similar trends were also observed when the catches were aggregated into either high- or low-TL (i.e. species with TL > 3.5 as high-TL and TL < 3.5 as low-TL; Figure 3.7). No significant trend was detected for catches of high-TL species against time (slope (SE) = 1.96 (15.30), t (df = 9) = 0.13, p = 0.90), yet the proportion of pelagic catches had increased with time too (logit-transformed regression: slope (SE) = 0.14 (0.03), t (df = 9) = 3.96, p < 0.01), although not as pronounced as catches of low-TL species (logit-transformed regression: slope (SE) = 0.26 (0.07), t (df = 9) = 3.75, p = 0.01).

3.3.4 Catch trophic spectra analysis

The catch TS indicate that Brunei's LS fisheries catch included a wide range of TLs with multiple peaks (Figure 3.8, Appendix 3.1). Two major opposite patterns emerged from the TS over time. First, catch proportions for low-TL species of between 2.8 and 3.2 had significantly increased from 12.4% to 29.1%, which essentially composed of small pelagics such as sardines and small mackerels. Interestingly, the proportion of high-TL species with TL between 4.4 and 4.6 had significantly increased over time as well, from 4.7% to 12.4%. These are mostly composed of high-valued large pelagics such as tuna and barracuda. Second, catch proportions for species of TLs between 4.0 and 4.3 had significantly dropped from 14.9% to 4.8%. The bulk of these groups composed of sharks and the grouper-snapper complex. The rest of the TLs showed non-significant trends over the years.

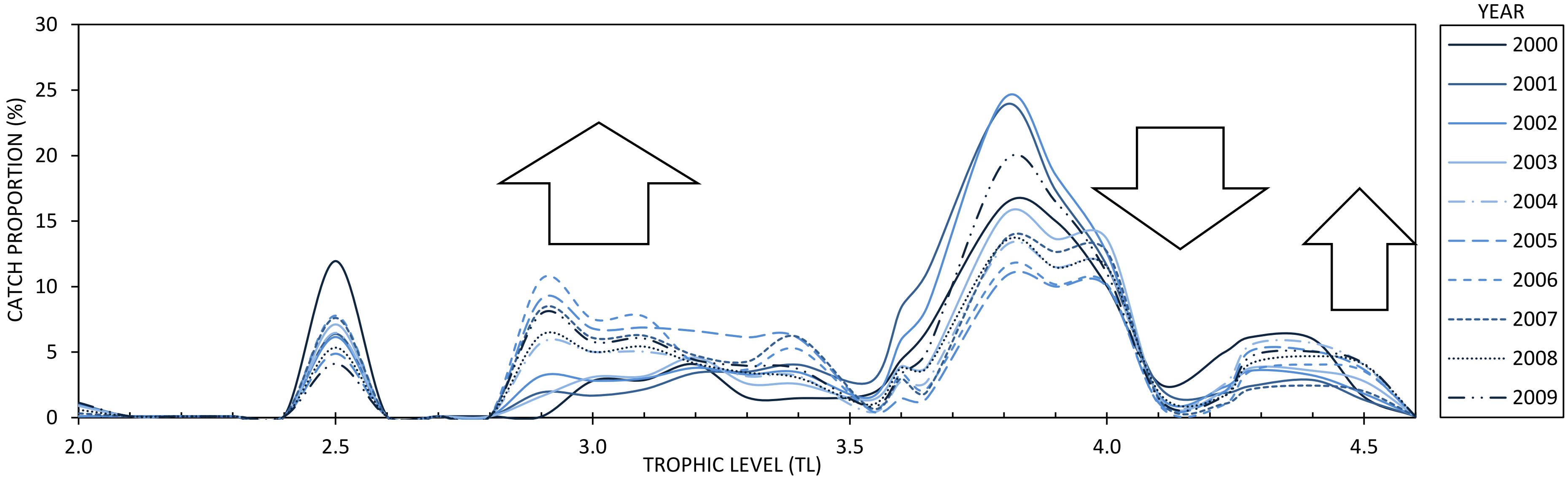

FIGURE 3.8: Catch trophic spectra of Brunei's LS fishery from 2000 to 2009. Downward and upward arrows on catch TS indicate the ranges of TL classes that showed significant declines and increases, respectively, in catch proportions over the studied period. Summary statistics of trends in catch proportions is given in Appendix 3.1.

3.4 Discussion and Conclusion

Preliminary exploration of the catch data revealed that the decline in MTL of Brunei marine ecosystem was due to the addition of lower TL catches rather than a decrease of high TL ones. This implies a 'fishing through' process, rather than FDFW (Essington *et al.*, 2006), and this is further suggested by a remarkably constant catch of high-TL species over the years (Figure 3.7). However, Stergiou and Tsikliras (2011) pointed out that the 'fishing through' mechanism is not exactly an alternative hypothesis to Pauly's FDFW phenomenon (Pauly *et al.*, 1998), but only appears so because of confusion. Effectively, 'fishing through' (or 'fishing up' in the case of increasing MTL trends) reflects biases in the data used and/or fishing behaviour see (Stergiou and Tsikliras, 2011).

Indeed, the decline in general MTL values in Brunei waters was accompanied by an increase in total catch, mainly due to the redirection of the LS sector to purse seine fishery in 2001 (Pg.Khairul-Rijal, 2007; JPKE, 2010) thus resulting in a significant increase in catch of low-TL pelagic fishes such as sardines and mackerels – main species targeted by the purse seine fishery. This is in agreement with majority of previous studies worldwide regarding MTL, which showed that an increase in catch is linked to higher catch of species with low TL (Christensen, 1998; Milessi *et al.*, 2005; Arancibia and Neira, 2005; Baeta *et al.*, 2009). Worryingly, the rate of decline in MTL for Brunei waters (ΔMTL = 0.08) is comparable to those estimated for the heavily exploited coastal waters of India (ΔMTL = 0.01 – 0.08; Bhathal and Pauly, 2005) and Gulf of Thailand (ΔMTL = 0.05 – 0.09; Pauly and Chuenpagdee, 2003), albeit lower than the coastal upwelling system such as central Chile (ΔMTL = 0.15; Arancibia and Neira, 2005), the Mediterrenean (ΔMTL = 0.15; Pinnegar *et al*., 2003) and coastal waters of Brazil (ΔMTL = 0.10 – 0.17; Freire and Pauly, 2010). Considering that Pauly *et al*. (2002) deemed changes in MTL of 0.05 – 0.10 as 'extremely worrisome', the 0.08 decrease in MTL found in this study is particularly notable, especially since Brunei is lightly fished relative to the rest of the region.

However, other than fishing, long-term environmental variations can also affect the structure and functioning of marine communities (ICES, 2000). Unfortunately, the influence of environmental factors on fishery productivity in Brunei waters is not clear from existing literature (but see Chapter 4). Generally, efforts to distinguish climate effects from fishery effects, to some extent, could be done by excluding from analysis the lower TL species whose abundance is known to vary widely in response to environmental factors (Pauly and Watson, 2005). In this study, a cut-off TL value of 3.30 was chosen to eliminate (besides invertebrates and other planktivores) the sardines, Clupeidae family (i.e. TL of spotted sardinella, *Amblygaster sirm*), which not only dominate the pelagics catch in Brunei, but are also said to be dependent on climatic fluctuations (Klyashtorin, 2001; Hobday *et al.*, 2009).

Interestingly, $^{3.30}$MTL revealed no significant long-term trend. Based on available information, regulatory changes, as well as extreme climatic condition, might be possible factors that influenced the $^{3.30}$MTL trajectory. First, due to the high discarding rate of the trawl fishery in Brunei (Kelleher, 2005; Matzaini *et al.*, 2007), the DOF implemented a new mesh size regulation on all LS trawlers in 2002, where a diamond mesh size of 38 mm was increased to a square mesh of 51 mm on the trawl cod end (Matzaini *et al.*, 2007). Following this management intervention, $^{3.30}$MTL is expected to rise as catches of smaller sized, lower-TL species by trawlers decrease, while recruitments, and hence catches, of high-TL species increase. However, the strength of the index to capture the positive effect on the community structure as induced by this management intervention thinned out when the fishery continued to expand. This expansion beyond the initial ecosystem to stocks previously unexploited or only lightly exploited is suggested by the gradual increase in absolute FiB trend (Pauly *et al*., 2000), and resulted in a declining $^{3.30}$MTL index between 2005 and 2006. The second smaller peak observed in 2007, on the other hand, might have been resulted from a combined 'bottom-up' effect (Caddy *et al.*, 1998; Pauly, 2010) of a strong El Niño event reported for that year, in addition to the increasing impacts of eutrophication in the coastal waters of Brunei (DOF-MIPR, 1992).

The trends behind the metric and species composition analyses are further supported by the temporal variations of TS observed. The TS have been shown to provide useful explanatory evidence underlying MTL and FiB calculations and trends (Laurans *et al.*, 2004; Gascuel *et al.*, 2005; Munyandorero and Guenther, 2010). In this study, the increase of high-valued large pelagics such as tuna and barracuda – species known to occupy further offshore waters – towards the end of the time series as shown in the catch TS suggested that a geographical expansion of Brunei LS fishery is the most likely explanation that influenced the $^{3.30}$MTL and FiB trajectories.

The gradual increase in absolute FiB trend would also imply that the decrease in MTL in this study was not matched by 'ecologically correct' increase in catch (Pauly *et al*., 2000). Accordingly, the absence of decreasing $^{3.30}$MTL and FiB trends could have been used to signify a potentially sustainable fishery, but to claim so may be misleading. Closer inspection of the composition of high-TL species catches (i.e. TL > 3.5) revealed clear shifts over the years, which may be interpreted as reflecting a shift in the underlying fish community structure in the ecosystem (Myers and Worm, 2003; Tsehaye *et al.*, 2007). The decline in catch of relatively sedentary demersal species such as snappers was followed by an increase in the migratory pelagic fishes such as tunas and barracudas, potentially suggesting a shift in ecosystem functioning. Admittedly, species composition of catches might be influenced by the fleet type, but then again shifting gears are fishers' adaptive response to shifted resources (Cinner *et al.*, 2011). Particularly in the case of Brunei's LS fishery sector, it is common for companies to own several fishing vessels of different gear types. As such, a decline in effort for the trawl and long line fleet is evident from the existing data.

In fact, given that Brunei fisheries are multi-specific, where ecological compensation phenomena are expected to occur (Jackson *et al.*, 2001; Perez-Espana *et al.*, 2006), the fact that a decline in MTL was evident in the data could only attest to the poor and deteriorating state of the marine ecosystem of Brunei. Recent stock assessments of the demersal resource revealed that Brunei has "joined the club" of regional decline in stock abundance, and that overfishing is apparent (DOF, 2011). Fishing is known to have indirect impacts on the whole ecosystem, and results from the analyses carried out in this study had demonstrated the marked changes in the structure of fisheries catches and fish communities from Brunei waters in the past decade. The removal of large predators from marine ecosystems would instigate cascade effects on food webs (Jackson *et al.*, 2001) and, as impacts on key elements of the food webs increase, the upward transfer of production becomes impaired (Pauly *et al.*, 2000).

Admittedly, the interpretation of trophic indicators can be subjective, and inevitably, this present study carried the caveats associated with MTL studies as pointed out by several authors (see discussions; Pauly and Watson, 2005; Cury *et al.*, 2005b; Baeta *et al.*, 2009; Munyandorero and Guenther, 2010; Angelini and Vaz-Velho, 2011). The dynamics of fishery resources are often caused by many overlapping factors, the effects of which are confounding and not always well documented or understood. Some of these factors are further examined in subsequent chapters of this thesis.

The decline of MTL might suggest that the fishery of Brunei waters is beginning to show signs of non-sustainability. Food web collapses might not have occurred yet because the decline in MTL has not been associated with overall declining catches (Pauly *et al.*, 2001). Furthermore, the multi-specific and high biodiversity nature of the tropical fisheries meant that a long time period may be necessary for a collapse to become noticeable in the exploited community after over-fishing occurs (Perez-Espana *et al.*, 2006). This study indicates that the FDFW process is relatively weak in Brunei waters throughout the study period because catches of high-TL species have been maintained. However, a closer look at species shifts revealed that within a short time scale of 10 years, significant changes on the structure of the fish assemblages beyond the direct effects on target species, particularly on the demersal ecological group, had occurred. Hence, discernible trends are evident even based upon a relatively short time series. The fishery of Brunei seems to have become more dependent on pelagic stocks, particularly those of low-valued low-TL species.

Worryingly, not only are such fisheries usually only marginally profitable (Christensen, 1998), but also pelagic stocks in general are vulnerable to environmental changes, making fisheries increasingly difficult to manage. Currently, other than restricting fishing zones and gear specifications, fisheries regulations in Brunei are relatively ineffective in limiting fishing efforts, especially from the small-scale fishery sector. There are no fishing quotas and enforcement is practically ineffective.

While attempting to capture the overall picture of Brunei marine ecosystem, this study had demonstrated a mixed outcome regarding the use of catch MTL as a tool for evaluating ecosystem health. The MTL approach is relatively data non-intensive, and the general MTL index had inferred a declining trend in Brunei's marine ecosystem state, despite the short time period. However, considering the apparent shift in community structure that had occurred throughout the study period, MTL appears to be a relatively weak measure of the ecosystem state that fails to detect what may be an imminent collapse of the demersal stock. In many fisheries around the world, there is a need for detection methods able to identify potential problems within a time scale short enough to be able to react effectively. This chapter has highlighted the deteriorating condition of Brunei coastal demersal fisheries between 2000 and 2009. How such conditions influence the abundance of the different demersal groups in the past 10 years will be examined next in Chapter 4 (Exploring human and environmental influence on recent abundance trends of selected demersal stocks in Brunei).

Chapter 4
Exploring human and environmental influence on recent abundance trends of selected demersal stocks in Brunei

"A population [of people] can be counted;
but who knows how many fishes are in the sea?
And yet it appears to me a project big with possibility…"
– Hjort, 1907

Chapter Summary

Recent trends in abundance of overall demersal finfish resources and 21 selected finfish families from the waters of Brunei Darussalam were evaluated. A general linear model (GLM) was used to standardise catch per unit effort (CPUE) data from the large-scale fishery sector for the years 2000 – 2009. Data were stratified temporally by year and month, and spatially by area (fishery management zones). Operational (types of gears) and environmental (local-scale sea surface temperature, chlorophyll-*a* concentration level, land rainfall and global-scale Southern Oscillation Index) variables were also considered in the full model. Where there are sufficient data, the total variance explained by the most parsimonious models range between 32 to 98%, with fishing zones identified as the most important factor in explaining CPUE variability. While the goal of standardisation in this study is to generate an index of relative abundance, emphasis is also being placed on the potential effect of the environment on fish stock abundance, which may act at several life history stages. In general, influence of environmental variables was not significant in explaining CPUE variation, except in mojarras (Gerreidae), bigeyes (Priacanthidae) and croakers (Sciaenidae), so cross-correlation analysis was used to further explore the lagged-effects of environmental variables on the demersal stocks. Overall demersal fishery resource abundance, as well as the abundance of several demersal zoobenthic feeders, exhibited a general decline over the study period. On the other hand, the majority of the intermediate demersal predator stocks were shown to increase. Identifying the sources of bias that exist when inferring short time series of catch-effort data enables better understanding of the complex fishery system, which in turn, may assist in formulation of fisheries management plans and can serve as hypothesis-generators for future research.

4.1 Introduction

Growing evidence has revealed that changes in fish stocks coincide with climate-induced changes in marine ecosystems, which are also affecting trophodynamics and community structure (Beaugrand *et al.*, 2008; Alheit, 2009). In addition to long-term changes, however, fish stock biomass can show pronounced, unexpected fluctuations in space and time over short-term time scales that makes it difficult to propose strategies for long-term fisheries management (Hsieh *et al.*, 2006).

In Brunei, this is further complicated by the fact that the fishery resources are exploited by both the small-scale (SS) and large-scale (LS) fisheries. Like other fisheries in the region (Silvestre and Pauly, 1997b; Garces *et al.*, 2006), the demersal fisheries of Brunei, therefore, are multi-gear and multi-species in nature (Table 4.1).

Demersal fishery resources have been classified as over-exploited in the Southeast Asia region since the 1960s (Pauly, 1988; Silvestre and Pauly, 1997a; Christensen, 1998; Christensen *et al.*, 2003; Abu Talib *et al.*, 2003; Lymer *et al.*, 2010), but the presence of offshore oil rigs in Brunei which caused a significant part of its shelf being effectively closed to fishing meant that the bulk of demersal stocks off Brunei waters were lightly fished, at least up till the year 2000 (Christensen *et al.*, 2003; Silvestre and Garces, 2004). However, the variability of climatic factors such as sea surface temperature (SST) and precipitation may also play an important role in the demersal catches in Brunei – for instance through the closely coupled interaction between SST and chlorophyll-*a* concentration (chl-a) in controlling nutrient supply, and therefore food availability, for the fish stocks (e.g. Solanki *et al.*, 2003; Qiu *et al.*, 2010; Sartimbul *et al.*, 2010). While there are few studies in the region which have discussed the response of fish production to climate variability, the existence of such link in southern South China Sea in general, and in Brunei waters in particular, is not clear from the existing literature. This is especially the case for demersal stocks.

TABLE 4.1: Break down of SS and LS fisheries by gears and principal family/group of demersal fish exploited in Brunei, adapted from Silvestre and Matdanan (1992), Ranimah (2008) and personal observations.

Level of capital input[1]	**Gear class**	**Gear type[2]**		**Principal family/group of demersal fish occurring in the catch**
		Local name	**English name**	
LS	Net	**Pukat tunda**	**Trawler**	Carangidae, Haemulidae, Lactariidae, Nemipteridae, Priacanthidae, Sciaenidae, Serranidae, Trichiuridae, Mullidae, Lutjanidae, Leiognathidae
	Net	Pukat lingkong	Purse seine	Carangidae, Trichiuridae, Leiognathidae
	Hook and line & Trap	**Rawai & Bubu**	**Long line & trap**	Haemulidae, Lethrinidae, Serranidae, Siganidae, Sparidae, Lutjanidae
SS (company / individual)	Net	Ancau	Seine net	Leiognathidae
	Net	Andang	Gill/trammel net	Carangidae, Leiognathidae
	Trap (portable)	**Bubu**	**Fish trap**	Haemulidae, Lethrinidae, Serranidae, Siganidae, Sparidae, Lutjanidae
	Trap (stationary)	Tugu/Kilong **Kabat/Lintau**	**Tidal / Palisade trap**	Leiognathidae, Haemulidae, Sciaenidae, Serranidae, Lutjanidae
	Hook and line	**Jaul/Rawai**	**Hand line/ Long line**	Haemulidae, Lethrinidae, Serranidae, Siganidae, Sparidae, Lutjanidae

1. Based on classification by Ranimah (2008).
2. Gears in **bold** specifically target demersal stocks as main catch, while any demersal fish found in the other gears occurred as incidental catch.

As a follow-up to the evaluation of the state of Brunei marine ecosystem in general (Chapter 3), this chapter draws on official fishery-dependent data to further analyse the state of several commercially-important demersal fish stocks of Brunei waters in the last decade. This involved investigating the joint responses of fish production to fishing and climate variability. While taking the limitations in the use of fishery-dependent data into account, the research questions considered in this chapter are the following:

1) What are the trends in catch and abundance (standardised CPUE for vessel-related and seasonal effects) of any of the top 20 commercially-important demersal families stocks over the years? What is their current state (in 2009)?
2) How do non-biological factors (i.e. vessel-related effects, seasonal effects, etc.) affect the index of abundance (i.e. CPUE, or catch per unit effort) calculated for the demersal stocks?
3) How have physical components in Brunei marine ecosystems varied in the past decade? How did demersal fish stocks respond to short-term (seasonal) and long-term changes in environmental factors?

4.2 Materials and Methods

4.2.1 Study area

The study area is similar to that described in Chapter 3 (Section 3.2.1).

4.2.2 Official fishery-dependent data and data selection

This study is based on the monthly catch and effort data collected from the LS fishery sector, covering the period 2000 – 2009, provided by the Department of Fishery, Brunei (DOF).

The fishery-dependent data collected included, among other things, fishing vessel's name, gross tonnage or horse power of vessel, gear type, general fishing ground, operating fishing days, and catch by species or species group and by marketing grades. Although designed for recording catches at the species level, there were some species, particularly those with a relatively low catch, that were grouped together, either according to family or market grades, depending on the expertise of the enumerators dispatched to the fishing port. Hence, due to such variability, some parts of the dataset are better suited to analysis at higher taxonomic levels.

In this study, the emphasis is on the demersal finfish resources (i.e. true fishes, thus excluding other aquatic animals such as whales, crustaceans and molluscs, but including sharks and rays) (FishBase v. 08/2011) of Brunei. The catch data recorded by the DOF under the 'mix' categories contain an unknown proportion of demersal finfish catches. For the purpose of finding the overall demersal finfish catch for each gear in this study, it is assumed that 50% of the 'mix' category catch is attributed to the demersal category throughout the study period (see Pauly, 1979). However, for a better understanding of the demersal stocks abundance in greater detail, only catch data of species with associated biological information available, and contained records in the dataset for at least 7 years, were considered.

As a result, data of 20 fish families (out of 25 demersal fish families recorded) and one family of rays from the LS fishery sector dataset were deemed most suitable for further investigation on the state of demersal stocks of Brunei waters (henceforth, termed 'demersal resources' throughout the thesis). The catch of these families makes up about 85 – 99% of the total known demersal finfish catch by weight.

4.2.3 Environmental data collation

Environmental variables including sea surface temperature (SST), rainfall and chlorophyll-*a* concentration (chl-a), were selected from a number of sources. Collation and preparation of environmental data prior to analysis is described below:

4.2.3.1 Sea-surface temperature (SST) data

As there was no comprehensive *in-situ* recording of SSTs for Brunei waters, monthly average SST data for 2000 – 2009 were obtained from the HadISST1 dataset, downloaded from the Hadley Centre for Climate Prediction and Research website[1]. HadISST1 dataset is a monthly SST and sea ice concentration data for 1° x 1° latitude and longitude cells from 1871 to present (Rayner *et al.*, 2003). Including the exclusive economic zone (EEZ), the SST data for Brunei encompasses 8 cells which were extracted using a Microsoft Excel spreadsheet, executed in Microsoft Office applications using the built-in code written in VBA (Visual Basic for Applications) macro.

4.2.3.2 Chlorophyll-*a* concentration (chl-a) data

Monthly chl-a data from 2000 to 2009 were generated from the Sea-viewing Wide Field-of-View Sensor (SeaWiFs) on Orbview-2 satellite, downloaded from the NASA Goddard Space Flight Centre (GSFC) website[2]. The data were at 0.1° x 0.1° latitude and longitude resolution (O'Reilly *et al.*, 2000). Since the resolution for chl-a data were higher compared to the SST data, the average of chl-a level for the main fishing area was used. Data extraction was also executed in Microsoft Office applications using VBA macro code.

[1] http://www.metoffice.gov.uk/hadobs/hadisst/
[2] http://oceancolor.gsfc.nasa.gov/SeaWiFS/

4.2.3.3 Precipitation data

The monthly precipitation data set for 2000 – 2009 were provided by the Department of Civil Aviation, Brunei. The rainfall data were recorded from Brunei's meteorological observation station at Brunei International Airport.

4.2.3.4 Indices of the Southern Oscillation (SOI)

The global-scale state of ENSO is measured in a number of ways including equatorial winds, trade wind anomalies and the Southern Oscillation Index (SOI). The SOI referred to throughout this study is the equatorial SOI, which is the standardised anomaly of the difference between the area-average monthly sea level pressure in an area of the eastern Pacific (80°W – 130°W, 5°N – 5°S) and an area over Indonesia (90°E – 140°E, 5°N – 5°S). The base period used for computing the anomalies is 1981-2010. Monthly average values of the equatorial SOI were extracted from NOAA's Climate Prediction Centre website[1]. Sustained high positive values of the SOI represent La Niña event and sustained high negative values an El Niño. Subsequently, the warm (or cold) episode of El Niño (or La Niña) is normally associated with prolonged dry conditions (or wetter than normal) in Brunei (Sirabaha, 2008).

4.2.4 Effort unit selection

There are considerable difficulties in defining suitable measures of effort, as fishing effort is a function of many variables which fishers can manipulate (Sparre and Venema, 1998; Maunder and Punt, 2004; Xiao, 2004). Usually, a single quantity (e.g. number of days at sea, total horse power, etc.) is used with the assumption that

[1] http://www.cpc.ncep.noaa.gov/data/indices/

relative change in other variables has exactly the same effects on the catch. In general, however, one does not always know *a priori* what the best measure of effort is. Therefore, it is always best to assess each effort variable and choose the best one as supported by appropriate hypothesis tests (Xiao, 2004).

In this study, four types of effort (f) unit were assessed. From the official database, the following were extracted; (f_1) number of active vessels per month, (f_2) number of fishing days at sea per month, (f_3) number of trips made per month and (f_4) total amount of horsepower of all vessels per month. Although the amount of horsepower (f_4) exerted by the fleet is simply a product of number of active vessels and engine type, it is the effort unit currently being employed by the DOF in their monitoring and assessment of catch and effort data, and hence, useful for comparison.

4.2.5 Standardisation of CPUE

Following previous section 4.2.4, the best measure of effort was found to be the number of days at sea per month (f_2), and that monthly 'nominal' CPUE was assumed to be best expressed as catch (metric ton) per days at sea (this study, Section 4.3.3). However, differences in gear types may create variations unrelated to fish abundance (Maunder and Punt, 2004). A generalized linear model (GLM) approach, which are most recent and commonly used in standardisation of CPUE data (review by Hilborn and Walters, 1992; Maunder and Punt, 2004; Ye and Dennis, 2009), was then used to minimize bias and enable valid comparisons across the entire fishery to be made. In addition, the influence of climate forcing and other environmental factors are also considered in the standardisation procedure. The nominal CPUE data were log-transformed to meet assumption of normality and homoscedasticity in the error distribution, while at the same time accounting for the multiplicative nature of the relationship between the response and explanatory variables.

Subsequently, a ‘standardised CPUE’ index was estimated for overall demersal (finfish) resources group and for each of the 21 selected families (20 demersal fish + 1 chondrichthians ray), based on the following full model:

$$log_{10}(CPUE_{ij}) = \beta_0 + \beta_1 g + \beta_2 z + \beta_3 i + \beta_4 j + \beta_5 (g * z) + \beta_6 (g * i) + \beta_7 (g * j) + \beta_8 (z * i) + \beta_9 (z * j) + \beta_{10-13} EV + \varepsilon$$

where *CPUE* is the nominal CPUE (catch per days at sea) in month *i* and year *j*, β_0 is the intercept, $\beta_1 - \beta_4$ are the effects of gear *g*, zone *z*, month *i* and year *j*, respectively, $\beta_5 - \beta_9$ are the effects of all two-way interactions except for the interaction between year and month, $\beta_{10} - \beta_{13}$ are the effects of the environmental variables (i.e. SST, chl-a, rainfall and SOI), and ε is a normally distributed error term. Other interactions were not considered since they have no intuitive biological meaning. All the explanatory variables were treated as categorical, except for the environmental variables.

Akaike’s information criterion (AIC) was used to determine the set of factors and interactions that explained a substantial amount of the nominal CPUE variability (i.e. most parsimonious model). Accordingly, the smallest value of AIC indicates best model fit.

4.2.6 Definition of stock status based on catch

Each family were assessed to see if they have been overexploited or collapsed to low population abundance using the original classification of stocks based on catch relative to the maximum catch (C_{max}) of Froese and Kesner-Reyes (2002) (Table 4.2).

TABLE 4.2: Original criteria used by Froese and Kesner-Reyes (2002) for assigning exploitation stages to fisheries, based only on catch data relative to maximum catch (C_{max}).

Status of fishery	Year	C/C_{max}
Undeveloped/No info	Before $C = C_{max}$	<0.1
Developing		0.1-0.5
Fully exploited	Before or after $C = C_{max}$	>0.5
Overexploited	After $C = C_{max}$	0.1-0.5
Collapsed		<0.1

4.2.7 Statistical analyses

Principal components analysis (PCA) was used to explore the relationship between the four different types of efforts and the best measure of effort was taken as the variable that accounts for the most variance in the first component.

Using standardised CPUE, the stock abundance of the overall demersal finfish resources, as well as the abundance of each of the different demersal families, was examined by analysing their trends in catch and CPUE. The trends in catch were assessed using simple linear regression against time. Changes in standardised CPUE over the years were examined using the test for linear trend in one-way ANOVA (as variable “year” was taken as categorical in the GLM procedure). In addition, time lags in standardised CPUE of up to 4 years (i.e. 48 months) behind the environmental variables were tested using cross-correlation analysis. Standard time-series cross-correlation function (CCF) is applied to the environmental variables as the leading indicator, and residuals of the standardised CPUE as the lagging indicator.

4.3 Results

4.3.1 Exploratory analysis: distribution by gear

Although the demersal assemblage are known to be targeted by both the trawl and long line fisheries only, a small proportion was also found in the purse seine fishery as incidental catch (Figure 4.1). However, in terms of volume, contribution by both the purse seine and long line fisheries are considered negligible (Figure 4.2).

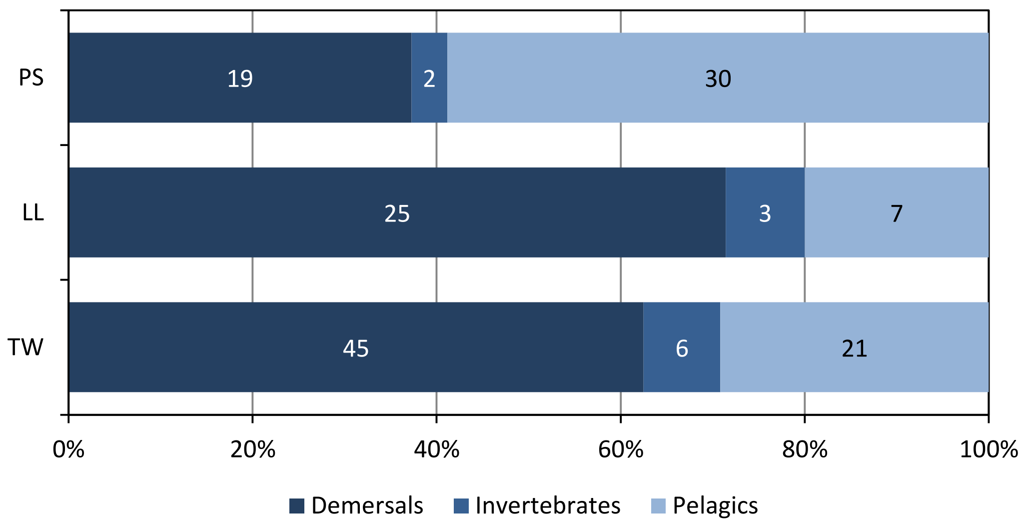

FIGURE 4.1: Proportion of number of different types of species caught by each gear in Brunei. Numbers inside the bars represent the actual number of species/groups of species. Overall, highest diversity of species are caught by trawlers (TW), followed by purse seiners (PS) and long liners (LL).

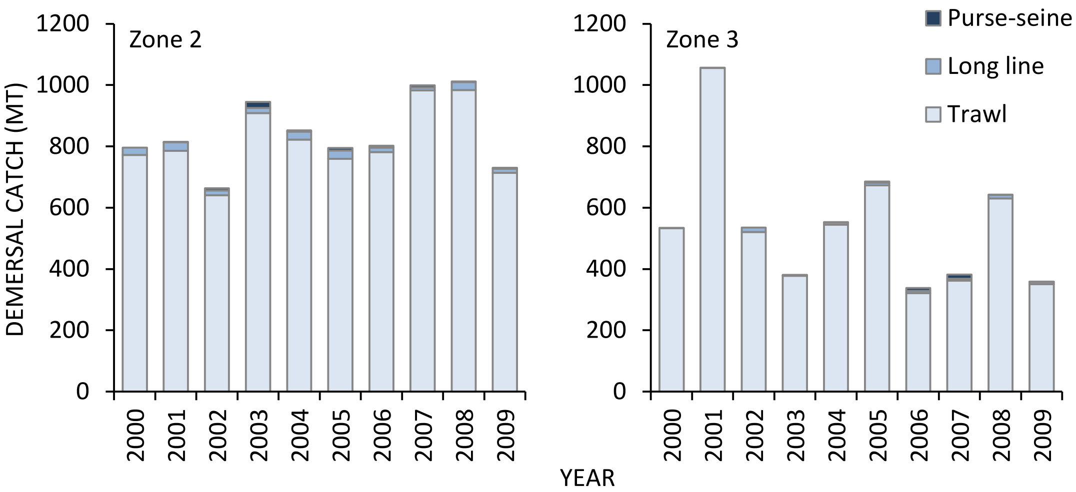

FIGURE 4.2: Contribution of the different gears on the overall demersal finfish catch (i.e. assuming 50% of the 'mix' category is attributed to demersal fish), by zone over the studied period (2000-2009).

4.3.2 Exploratory analysis: short- and long-term changes in environmental variables

Monthly variations in SST, chl-a, rainfall and long-term climate index SOI are presented in Figure 4.3. Except for SOI, all other variables revealed seasonal variations (one-way ANOVA, $p < 0.05$ in all cases except SOI index, where $p = 0.279$), which follows a monsoonal pattern. The monsoon seasons were defined as per Sirabaha (2000): Northeast monsoon (Nov – Jan), transition I (Feb – Apr), Southwest monsoon (May – Jul) and transition II (Aug – Oct). Throughout the study period and averaged over both fishing zones (i.e. Zones 2 and 3 of Brunei fishery management zonation), SST varied between 29.9 ± 0.24 °C in May and 27.1 ± 0.23 °C in February, while chl-a peaked in December around 3.03 ± 3.08 mg $m^{-3}$and were lowest around August at 0.76 ± 0.61 mg m^{-3}. Amount of rainfall recorded on land ranged between 17.8 mm (minimum recorded) and 977.0 mm (maximum recorded), and are generally high during the NE monsoon months and low during post-NE monsoon period.

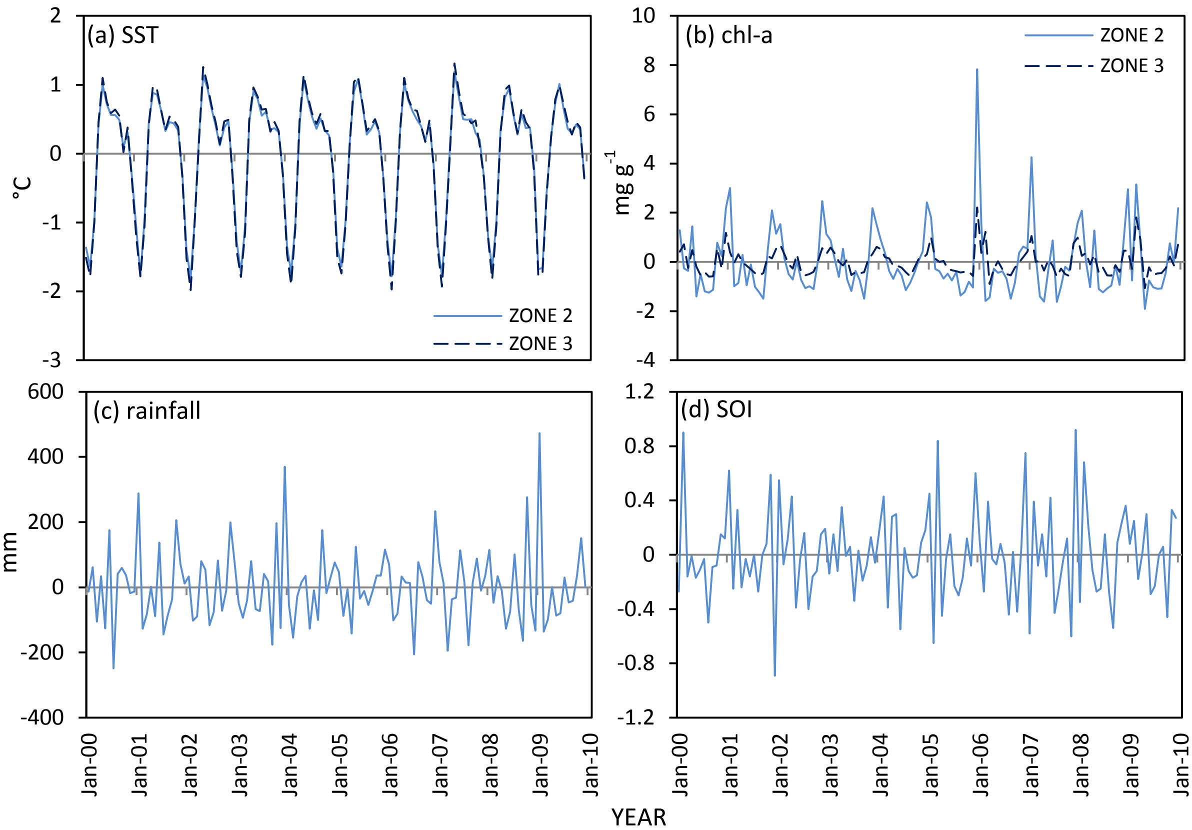

FIGURE 4.3: Seasonal variation (i.e. detrended time series) of (a) sea surface temperature (SST), (b) chlorophyll-*a* concentration (chl-a), (c) rainfall, and (d) the Southern Oscillation Index (SOI) in Brunei between 2000 and 2009.

After correcting for seasonal factors, none of the climate variables showed any significant trends throughout the study period (Table 4.3).

TABLE 4.3: Summary statistics of seasonally-adjusted environmental variables in Brunei over the study period, from January 2000 to December 2009.

Seasonally-adjusted variables against time	Area of reference	Monthly change (Slope *b*)	Standard error	*t*- stats	P-value
SST	Zone 2	0.000	0.001	-0.283	0.778
	Zone 3	0.000	0.001	0.007	0.994
Chl-a*	Zone 2	0.002	0.001	1.633	0.105
	Zone 3	0.003	0.003	1.268	0.208
Rainfall	All	0.494	0.355	1.391	0.167
SOI	All	-0.001	0.002	-0.470	0.639

* Natural log-transformation was applied on chl-a data.

4.3.3 Best measure of effort

Only one principal component was extracted from the four different types of efforts, which explained 93% of the total variance. This suggests that the use of any of the four types of effort to represent a measure of 'fishing effort' was justified, which is further supported by the direction of the component loadings of the four effort variables in the bi-plot graph (Figure 4.4). The best measure of effort was found to be f_2 (number of fishing days at sea), which has the highest loading in the extracted component (Table 4.4).

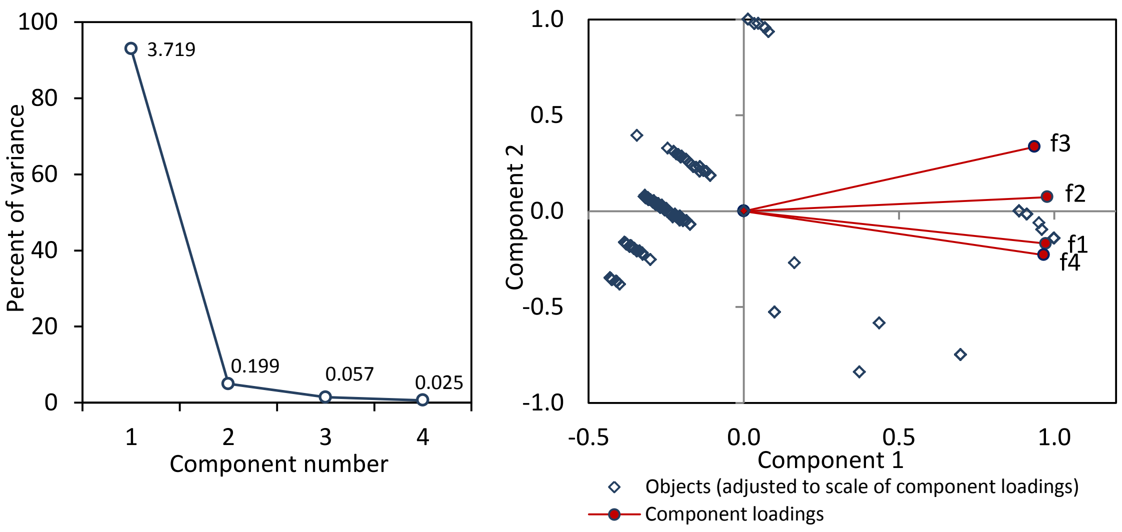

FIGURE 4.4: PCA outcome of four different types of efforts. (a) Scree plot of variance explained by successive components before rotation, with data points labelled with eigenvalues; and (b) Bi-plot of first two principal components, showing the equivalence of all four measures of fishing effort.

TABLE 4.4: Principal component loadings from the correlation matrix between the four different types of effort. Only one component extracted (i.e. eigenvalue > 1), but the second component is also shown for comparison.

Components	**Component 1**	**Component 2**
f1 (number of vessels)	0.973	-0.170
f2 (number of days at sea)	0.979	0.073
f3 (number of trips made)	0.937	0.336
f4 (amount of engine horse power)	0.967	-0.228

4.3.4 Standardisation of CPUE

Summary results from the GLM analyses of nominal CPUE were given in Table 4.5. In all analyses, the total variance explained by the most parsimonious models range between 32 to 98%. Summary statistics of these models are given in Appendix 4.1.

For the whole demersal finfish group, types of gear accounted for most of the variance in its nominal CPUE (47%). However, at family level, 15 out of 21 data sets analysed revealed that variation in nominal CPUE (family) was best explained by fishing zones (5 – 90% of overall variance), while the type of gears was the most important factor in explaining nominal CPUE (family) variation in only four families (18 – 66% of overall variance). In general, the effects of gear (where applicable), fishing zones, year, month, and all two-way interactions except between year and month, were significant ($p < 0.05$), unless stated otherwise.

The GLM results also revealed that, in general, the influence of environmental variables were not significant in explaining the CPUE (family) variation, except in mojarras (Gerreidae), bigeyes (Priacanthidae) and croakers (Sciaenidae), at 15%, 33% and 7%, respectively, of overall variance.

No standardised CPUE values for the sicklefishes family (Drepaneidae) were calculated, as the total variance explained in all the full and other tested models were found to be non-significant (Full model: explained variance = 55.5%, $F_{26,50} = 1.103$, $p = 0.409$). In the remaining 21 data sets, visual inspection of the residuals from the log-normal error models suggested a reasonable overall fit.

TABLE 4.5: Most parsimonious models used in the standardisation procedure of nominal CPUE of overall demersal resources and of specific categories at family level for Brunei waters between 2000 and 2009 (colon [:] signifies interactions between terms). Summary statistics of these models are given in Appendix 4.1.

Dependent variable (natural log of nominal CPUE)	Most parsimonious model	N	Variance explained (%)
Total demersal finfish resources	year + month + gear + zone + month:gear + year:gear + gear:zone + year:zone	515	72.4
Ariidae, sea catfishes	year + month + zone	103	78.6
Balistidae, triggerfishes	year + gear + zone + year:zone	73	66.4
Carangidae, jacks	year + month + gear + zone + month:gear + year:gear + gear:zone + year:zone + month:zone	292	71.7
Drepaneidae, sicklefishes	-	54	NS
Ephippidae, batfishes	year + month + zone	41	93.7
Gerreidae, mojarras	month + zone + SST	61	68.9
Haemulidae, grunts	year + month + gear + zone + year:gear + month:zone	128	61.7
Lactariidae, false trevallies	year + month + gear + zone	130	83.2
Leiognathidae, ponyfishes	year + month + gear + zone + month:gear + year:gear + year:zone + gear:zone	211	69.7
Lethrinidae, emperors	year + gear + year:gear	47	64.7
Lutjanidae, snappers	year + month + gear + zone + month:gear + year:gear + gear:zone + year:zone	399	81.4
Mullidae, goatfishes	year + zone	48	83.6
Nemipteridae, threadfin breams	year + gear + zone + year:gear + gear:zone + year:zone	167	78.4
Priacanthidae, bigeyes	year + month + gear + zone + month:zone + year:zone + rainfall	60	97.8
Psettodidae, halibuts	year + month + zone + year:zone	126	85.9
Sciaenidae, croakers	year + month + zone + year:zone + SOI	149	62.1
Serranidae, groupers	year + month + gear + zone + year:gear + gear:zone	354	71.7
Siganidae, rabbitfishes	gear + zone	58	31.8
Stromateidae, butterfishes	year + month + gear + zone + month:gear	72	58.7
Trichiuridae, hairtails	year + gear + zone + year:gear	124	32.8
Dasyatidae, rays	year + month + gear + zone + month:gear + year:gear + year:zone	249	84.1

Full model: $\ln(CPUE_{spp})$ = year + month + gear + zone + month:gear + year:gear + gear:zone + year:zone + month:zone + SST + chl-a + rainfall + SOI

4.3.5 Lagged-effects of environmental variables on stocks' CPUE index

Only values from the trawl fishery were used to explore the potential lagged-effects of environmental variables on the demersal stocks' CPUE index, due to the following reasons:

(1) In time-series analyses such as CCF, there is increasing inherent uncertainty as the proportion of missing values embedded in a time series increase, and
(2) Most, if not all, of the demersal stocks are being exploited by trawlers, as the contribution by purse seines and long lines to total demersal catch can be considered negligible.

Even then, analysis of missing data patterns only identified a handful of stocks that would be seen sufficient for CCF analyses (Appendix 4.2). As a result, CCFs of SST, chl-a and rainfall (i.e. environmental parameters) were generated only against the overall demersal resources abundance and the abundance of nine selected demersal family stocks (Appendix 4.3).

In general, a discernible cyclic pattern of the CCF plots can be seen between the CPUE and SST time series, although the strength, direction and length of period vary between the different stocks. Such pattern is less obvious in CCF plots between the CPUE and chl-a time series, and almost non-existent in CCF plots between the CPUE and rainfall time series.

Understanding the effects of climate on a fishery requires first an understanding of the biology of the fish, and secondly its life stages that are likely to be affected by the environmental conditions. However, this requires in-depth analysis of an integrated life cycle and climate model of the stock, usually developed based on results from previous physiological, growth and tagging studies, which is beyond the scope of this thesis. Therefore, associations identified in this study are used to generate testable hypotheses for follow-on studies instead, and this is summarised in Table 4.6. Subsequently, environmental variables labelled “+” are expected to enhance reproductive success and cohort size of the stock and lead to an increase in CPUE values a number of months later, while those labelled “–“ are expected to hinder reproductive success and cohort size.

TABLE 4.6: Hypotheses linking climate variability and demersal stocks CPUE generated from the CCF analyses. Months with strong significant correlation between the environmental parameters as leading indicators and residuals from CPUE standardisation for each fish stocks as lagging indicators are given in parantheses. (E.g. SST value for Zone 3 has strong positive correlation with CPUE of snappers 6 months later.) CCF plots are given in Appendix 4.3.

Category	**Area (fishing zone)**	**General hypotheses made**				
		(a) *Environmental variability influence stocks at different life stages or in different area, affecting CPUE a number of months later*			**(b)** *Primary productivity (i.e. chl-a) affect stocks lower in the food chain first*	**(c)** *Overexploited stocks are more susceptible to environmental variability*
		SST	**Chl-a**	**Rainfall**	**Species guild [(a)]**	**State of stock in 2009[(b)]**
Overall demersal resources	2	+ (34)	− (36)	− (14)	n/a	Exploited
	3	− (22)	+ (22)			
Carangidae, jacks	2				Intermediate predator	Exploited
	3					
Sciaenidae, croakers	2				Intermediate predator	Exploited
	3					
Lutjanidae, snappers	2		− (13)		Intermediate predator	Over-exploited
	3	+ (6)				
Serranidae, groupers	2		− (13)		Intermediate predator	Exploited
	3					
Haemulidae, grunts	2				Zoobenthic feeder	Exploited
	3					
Lactariidae, false trevallies	2				Zoobenthic feeder	Exploited
	3					
Leiognathidae, ponyfishes	2		+ (6), − (13)		Zoobenthic feeder	Over-exploited
	3	+ (6)	− (6)	+ (1)		
Nemipteridae, threadfin breams	2	− (4)	+ (6)	+ (7)	Zoobenthic feeder	Over-exploited
	3		− (9)	− (10)		
Dasyatidae, rays	2	− (5)	+ (6)		Large zoobenthos	Exploited
	3					

(a) Species guild based on Ecopath trophic groups for Brunei (Silvestre and Garces, 1993)
(b) Stock status based on C/C_{max} (see next section)

4.3.6 Trends in catch and CPUE index of demersal stocks in Brunei between 2000 and 2009

The overall demersal catch by the LS fishery sector annually showed no significant trend over the years investigated (Table 4.7; Figure 4.4). The highest annual catch of 1029 MT was attained in 2001, while the lowest annual catch of 392 MT occurred in 2006. On the other hand, the trends in annual catch varied among the different fish families (Table 4.7; Figure 4.5).

When normalised for the different gears and over both fishing areas, the annual standardised CPUE for the overall demersal group showed a declining trend over the years investigated (Table 4.8; Figure 4.5). Similar to the annual catch, the trends in CPUE varied among the different fish families (Table 4.8; Figure 4.6). Notably, whereas the standardised CPUE for most of the families showed a steady or increasing trend, the standardised CPUEs for ponyfishes (Leiognathidae), threadfin breams (Nemipteridae), croakers (Sciaenidae) and rays (Dasyatidae) exhibited significant declining trends. However, it is important to note that these trends were calculated for both fishing areas, and that localised decrease (or increase) in abundance were also observed in some stocks.

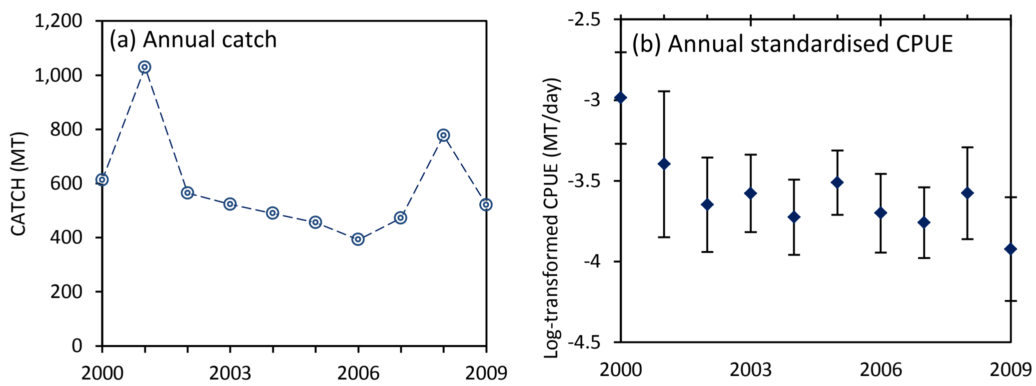

FIGURE 4.5: Overall demersal (a) catch (in MT) and (b) standardised CPUE (MT/day) of Brunei waters between 2000 and 2009. Annual standardised CPUE is the estimated marginal mean (i.e. predicted mean) for factor “year”, adjusted for other factors. Error bars show 95% confidence intervals.

TABLE 4.7: Trends in annual catch of specific categories of fish and in total demersal finfish catch (MT) from 2000 to 2009 were shown to vary. The summary statistics for the best fit linear regression model are given. Also shown are mean annual catch over the years and state of stocks in 2009. Bonferroni correction states that alpha (α) should be set to 0.0023 for the p-value to be significant (i.e. α/n = 0.05/21). Only significant terms are shown. Significant p-values are in **bold**.

Category	Mean annual catch (MT)	Annual change (Slope *b* x120)	p-value	Std. error	*t*-stats	R^2 (%)	Status in 2009[a]
Total demersal finfish resources	583.5	-18.29	0.024				Exploited
Ariidae, sea catfishes	9.8	-2.12	0.006				Overexploited
Balistidae, triggerfishes	2.4	-0.83	0.025				Overexploited
Carangidae, jacks	23.9	1.65	**0.001**	0.004	3.552	9.7	Exploited
Drepaneidae, sicklefishes	1.7	-0.35	0.257				Overexploited
Ephippidae, batfishes	0.3	0.24	0.003				Overexploited
Gerreidae, mojarras	4.2	-1.54	0.111				Collapsed
Haemulidae, grunts	2.7	0.41	**<0.001**	0.001	4.996	21.0	Exploited
Lactariidae, false trevallies	77.5	0.09	0.963				Exploited
Leiognathidae, ponyfishes	47.5	-3.10	**0.001**	0.008	-3.256	8.3	Overexploited
Lethrinidae, emperors	0.7	-0.09	0.574				Overexploited[b]
Lutjanidae, snappers	60.8	-6.30	**<0.001**	0.008	-6.857	28.5	Overexploited
Mullidae, goatfishes	19.0	-0.22	0.900				Exploited
Nemipteridae, threadfin breams	59.4	-15.45	**<0.001**	0.020	-6.362	27.8	Overexploited
Priacanthidae, bigeyes	18.8	-3.50	0.033				Exploited
Psettodidae, halibuts	10.7	2.49	**<0.001**	0.003	7.713	39.5	Exploited
Sciaenidae, croakers	35.2	-2.62	0.005				Exploited
Serranidae, groupers	14.7	-0/16	0.470				Exploited
Siganidae, rabbitfishes	0.7	0.05	0.450				Exploited
Stromateidae, butterfishes	0.9	-0.13	0.248				Overexploited
Trichiuridae, hairtails	10.8	-0.46	0.590				Collapsed
Dasyatidae, rays	132.5	1.18	0.313				Exploited

(a) Based on C/C_{max}
(b) Based on catch in 2008

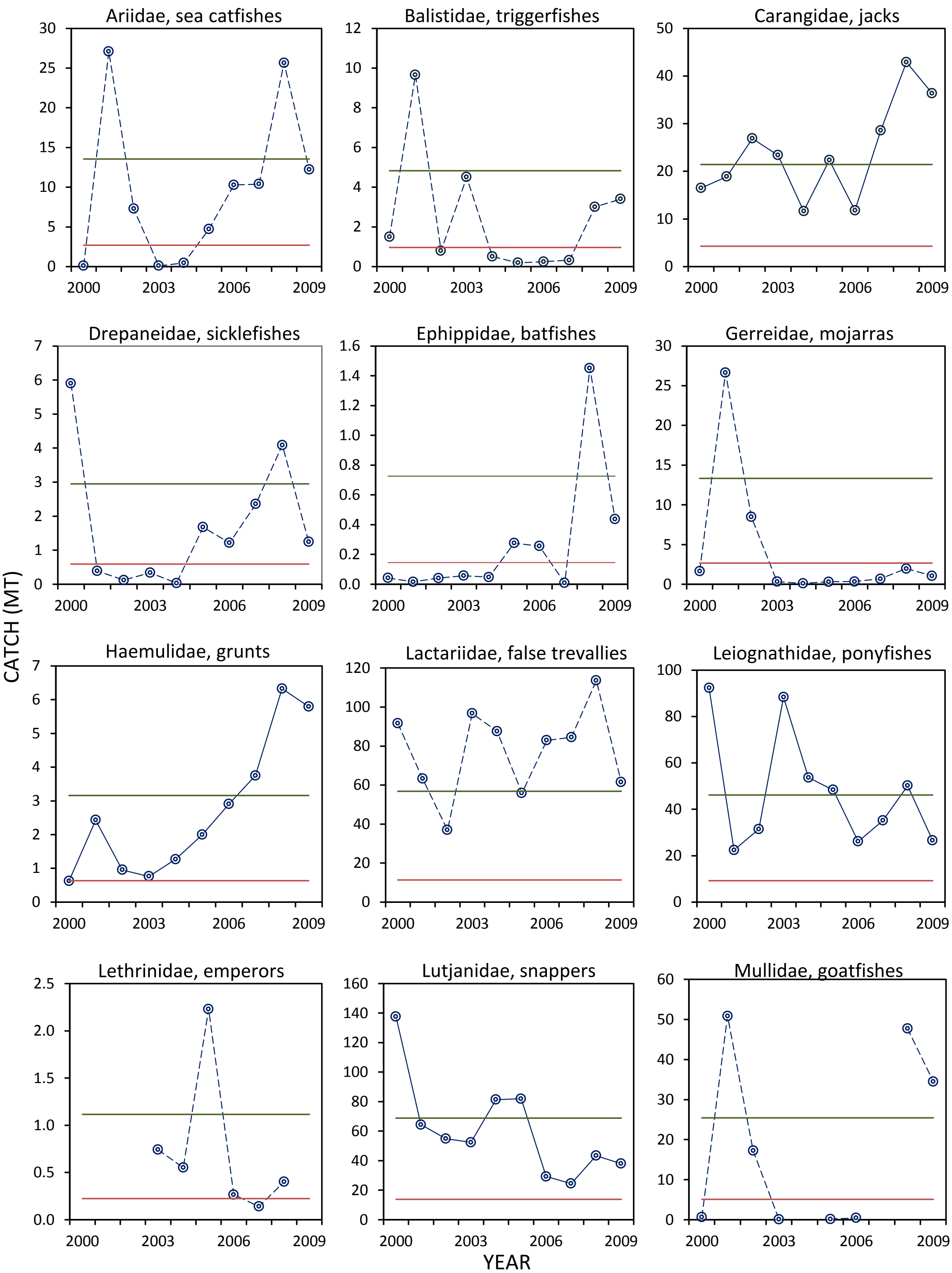

FIGURE 4.6.1 – 4.6.12: Annual catch (MT) of selected family stocks between 2000 and 2009. Dashed line is shown if trend over study period is not significant. Two horizontal lines show range of catch when stock is overexploited (below top green line, where $C = 0.5 \times C_{max}$) or collapsed (below bottom red line, where $C = 0.1 \times C_{max}$), based on C_{max} recorded within the study period. Note the different scales on the y-axis.

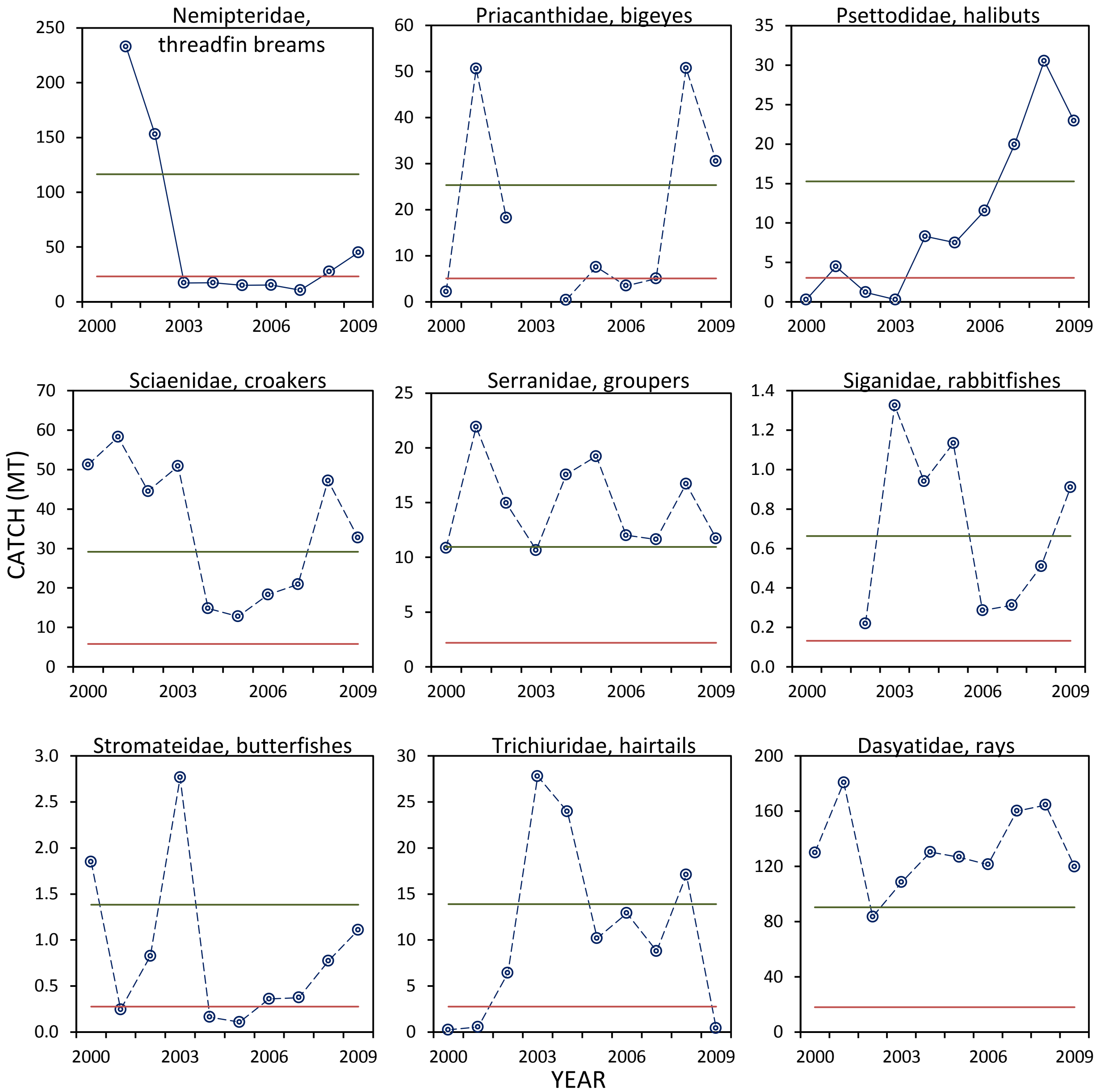

FIGURE 4.6.13 – 4.6.21: (*continued*) Annual catch (MT) of selected family stocks between 2000 and 2009. Dashed line is shown if trend over study period is not significant. Two horizontal lines show range of catch when stock is overexploited (below top green line, where $C = 0.5 \times C_{max}$) or collapsed (below bottom red line, where $C = 0.1 \times C_{max}$), based on C_{max} recorded within the study period. Note the different scales on the y-axis.

TABLE 4.8: Summary statistics of test for linear trend in one-way ANOVA to assess trends in annual standardised CPUE of specific categories of fish and in total demersal finfish catch (MT/day) from 2000 to 2009 in Brunei. Direction of trends are indicated by "–" and "+" for decreasing and increasing trends, respectively. "0" denotes lack of significant trend. Bonferroni correction is applied with $\alpha = 0.0023$. Significant p-values are in **bold**.

Category	**General Trend**	**d.f. (numerator, denominator)**	**F stats**	**p-value**
Overall demersal resources	–	9, 411	2.958	**0.002**
Ariidae, sea catfishes	0	9, 68	2.823	0.007
Balistidae, triggerfishes	0	9, 51	2.370	0.025
Carangidae, jacks	+	9, 190	7.874	**<0.001**
Drepaneidae, sicklefishes[(a)]	0	9, 44	2.995	0.091
Ephippidae, batfishes	+	9, 16	8.150	**<0.001**
Gerreidae, mojarras	0	9, 51	0.764	0.650
Haemulidae, grunts	+	9, 84	3.730	**<0.001**
Lactariidae, false trevallies	+	9, 95	4.109	**<0.001**
Leiognathidae, ponyfishes	–	9, 146	9.745	**<0.001**
Lethrinidae, emperors	0	5, 36	3.729	0.008
Lutjanidae, snappers	+	6, 315	6.086	**<0.001**
Mullidae, goatfishes	0	7, 31	2.675	0.027
Nemipteridae, threadfin breams	–	8, 133	6.637	**<0.001**
Priacanthidae, bigeyes	0	1, 18	1.129	0.302
Psettodidae, halibuts	+	9, 85	39.050	**<0.001**
Sciaenidae, croakers	–	9, 107	7.146	**<0.001**
Serranidae, groupers	+	9, 298	5.034	**<0.001**
Siganidae, rabbitfishes	0	7, 49	0.813	0.581
Stromateidae, butterfishes	0	9, 39	2.205	0.043
Trichiuridae, hairtails	0	9, 99	2.458	0.014
Dasyatidae, rays	–	9, 190	31.121	**<0.001**

(a) Nominal CPUE values were used instead of standardised CPUE values.

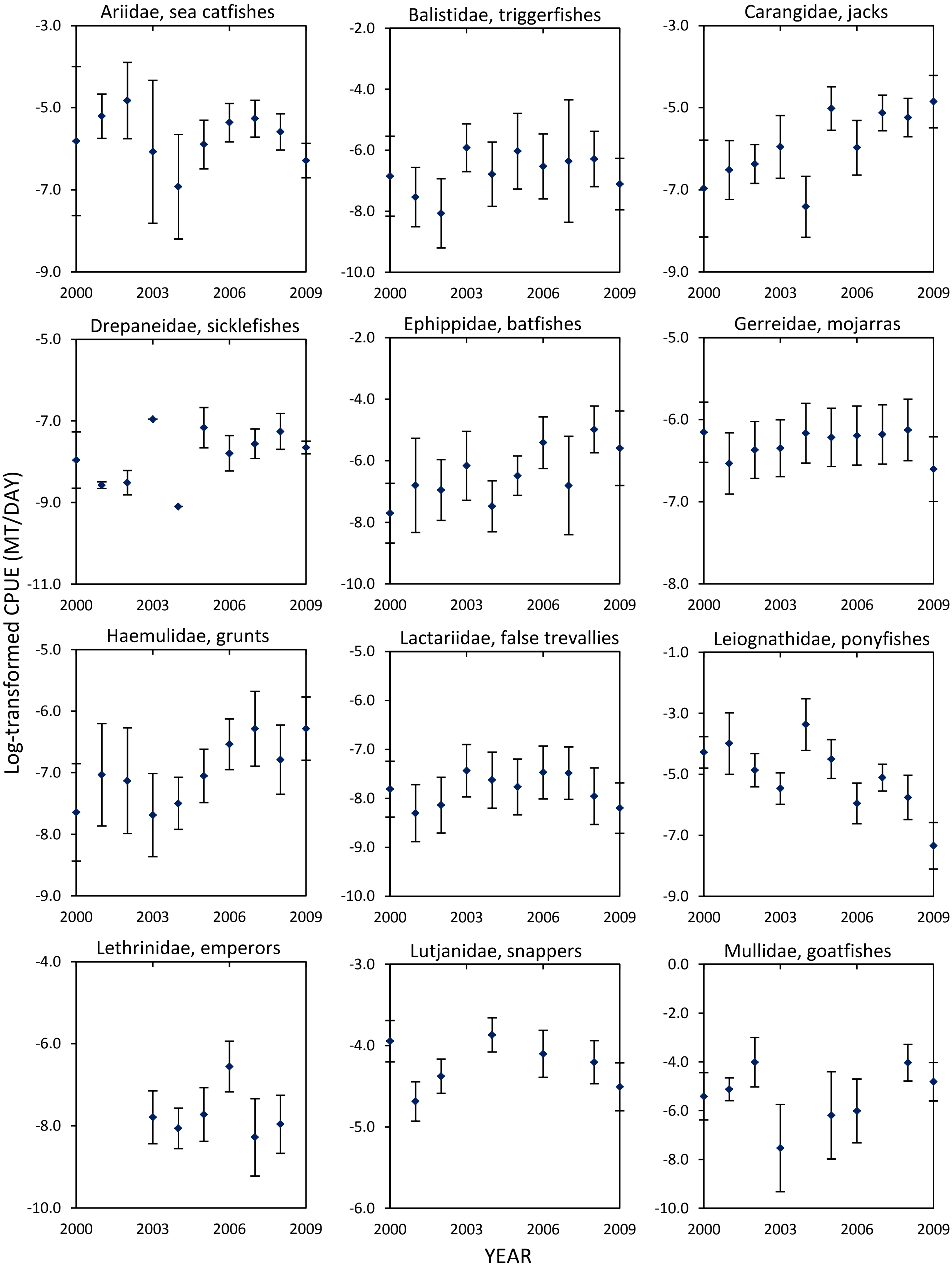

FIGURE 4.7.1 – 4.7.12: Annual standardised CPUE (MT/day) of selected family stocks between 2000 and 2009 in Brunei. Value given is the estimated marginal mean (i.e. predicted mean) for factor “year”, adjusted for other factors. Error bars show 95% confidence intervals. Note the different scales on the y-axis.

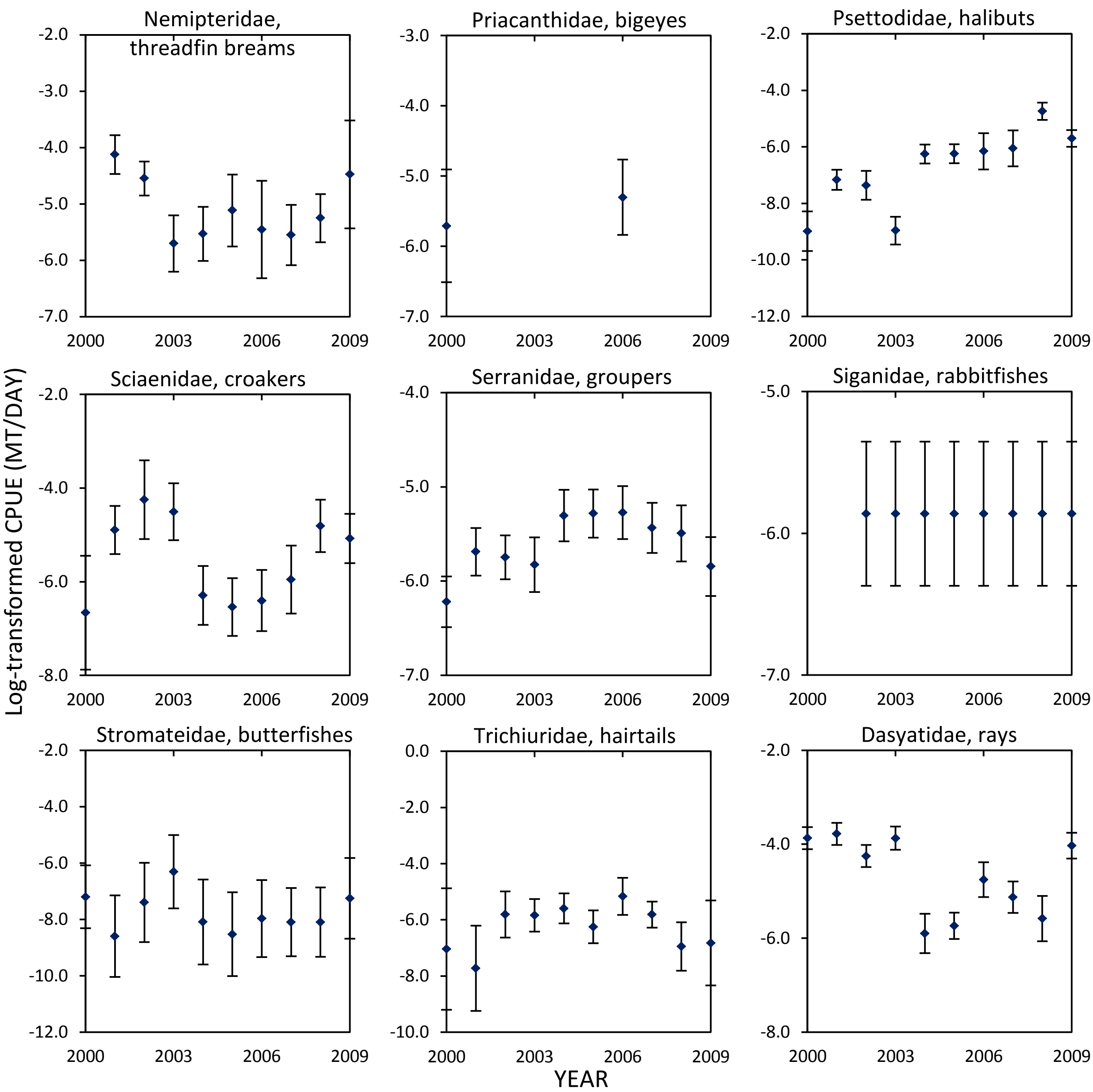

FIGURE 4.7.13 – 4.7.21: (*Continued*) Annual standardised CPUE (MT/day) of selected family stocks between 2000 and 2009 in Brunei. Value given is the estimated marginal mean (i.e. predicted mean) for factor "year", adjusted for other factors. Error bars show 95% confidence intervals. Note the different scales on the y-axis.

The standardised CPUE indices at family levels revealed that generally, abundance is higher in the deeper waters of Zone 3. Also noted was the lack of significant difference in abundance between both fishing areas for grunts (Hamullidae), ponyfishes (Leiognathidae), butterfishes (Stromateidae) and rays (Dasyatidae) (Table 4.9).

TABLE 4.9: Comparison in stock abundance between Zone 2 and Zone 3 of Brunei fishing zonation, using standardised CPUE. Bonferroni correction is applied with α = 0.0023. Significant p-values are in **bold**.

Category	Mean standardised CPUE (x 10^{-3}MT/day)		d.f.	*t*-stats	p-value
	Zone 2	Zone 3			
Total demersal finfish resources	45.17	76.20	483	-3.845	**<0.001**
Ariidae, sea catfishes	1.49	13.73	88	-11.309	**<0.001**
Balistidae, triggerfishes	0.65	3.71	65	-11.146	**<0.001**
Carangidae, jacks	3.20	13.06	65.8*	-5.357	**<0.001**
Drepaneidae, sicklefishes[(a)]	0.45	-	-	-	-
Ephippidae, batfishes	0.83	12.57	36	-4.668	**<0.001**
Gerreidae, mojarras	0.59	8.64	59	-9.453	**<0.001**
Haemulidae, grunts	0.75	5.42	4.1*	-2.327	0.079
Lactariidae, false trevallies	15.92	0.75	116	5.204	**<0.001**
Leiognathidae, ponyfishes	7.72	14.62	47.4*	-1.360	0.180
Lethrinidae, emperors	0.95	0.30	3.6*	3.540	**<0.001**
Lutjanidae, snappers	10.02	35.21	319.2*	-17.618	**<0.001**
Mullidae, goatfishes	1.66	37.82	38	-16.847	**<0.001**
Nemipteridae, threadfin breams	2.87	64.48	61.8*	-17.575	**<0.001**
Priacanthidae, bigeyes	2.34	32.63	50	-10.328	**<0.001**
Psettodidae, halibuts	2.45	6.55	110	-3.900	**<0.001**
Sciaenidae, croakers	5.35	22.63	133	-7.143	**<0.001**
Serranidae, groupers	6.49	5.52	325.9*	-3.766	**<0.001**
Siganidae, rabbitfishes	1.45	10.69	55	-11.795	**<0.001**
Stromateidae, butterfishes	0.25	1.13	62	-2.418	0.019
Trichiuridae, cutlassfishes	2.25	4.50	114	-3.213	**<0.001**
Dasyatidae, rays	21.47	22.96	204.1*	-2.193	0.029

(a) Nominal CPUE values were used instead of standardised CPUE values.
* Where $p < 0.05$ for Levene's test for equality of variances, adjustments were made to the degrees of freedom and *t*-statistics were calculated without assuming equal variances between the two groups.

4.4 Discussion and Conclusion

This chapter further confirms the presence of shifts in species composition of Brunei's demersal habitat (Chapter 3) as well as highlighting the sources of bias that can exist when using short time series of fishery-dependent catch and effort data, as it has been done here. It is worth stressing, however, that standardised CPUE calculated in this study were used to assess relative trends in biomass or abundance of the stocks and not to estimate absolute stock size or the contribution of different fleets on fishing mortality. Indeed, some have warned against the use of commercial catch and effort data as an index of abundance, especially if the fundamental assumption of direct proportionality is violated (Chapter 2, Section 2.2.2). Judicious use of catch and effort data, however, may still provide useful insights and can be beneficial in some situations, particular in data-poor fisheries such as Brunei.

4.4.1 Best measure of effort

Accurate estimates of fishing effort are essential for accurate biological (e.g. stock assessment), economical (e.g. estimating profitability of a fishery) and social (e.g. designation of marine protected areas) assessments in facilitating sustainable fisheries management (as reviewed by McCluskey and Lewison, 2008). A common challenge, however, is to choose an appropriate measure of fishing effort that reflect a measure of direct effect of fishing on stocks mortality. Measuring effort is not a new problem – considerable energy has been applied by fisheries researchers to develop reliable measures of effort (Beverton and Holt, 1957; Bordalo-Machado, 2006; McCluskey and Lewison, 2008). However, the diversity of effort measures currently being used in fisheries illustrates that the choice to date has been justified to concentrate more on what is easiest to measure rather than what is ideal in terms of identifying a measure of effort that is correlated to fish mortality. Common measure of effort would usually describes the resources allocated to fishing such as time (days or hours fished), capital (number of vessels, length or horsepower of vessel), labour (number of crew, distance travelled, number of trips made) or gear (mesh size or number of hooks) (McCluskey and Lewison, 2008).

The most frequently used quantitative measure of effort is that of time spent fishing (e.g. Xiao, 2004; Battaile and Quinn, 2004; Ortiz de Zarate and Ortiz de Urbina, 2007; Rist, 2007). Since the total time spent on a fishing trip would usually compose of time taken to the fishing ground and time spent searching and fishing, there have been studies which argue that the use of time measures could lead to considerable biased estimates of biologically relevant fishing effort (Hilborn and Walters, 1992). Accordingly, the proportion of total time on a fishing trip that is spent fishing would decrease with increasing distance to the fishing ground. If this is unadjusted, fishing effort may be increasingly overestimated with increasing distance (Hilborn and Walters, 1992; Rist, 2007). However, considering the small area of the fishing grounds in this study, the total time spent on the fishing trip (i.e. number of operating days out in the sea per month) as a proxy for time spent actively fishing is deemed reasonable. For instance, in good weather, it may take less than 15 hours to reach the furthest point of the far fishing ground (i.e. Zone 3). Typically, in the case of the trawl fleet, fishers would leave the port in the morning and carry out trawling both during the day and at night for three consecutive days before returning to Muara FLC. Given adequate supply and maintenance, each vessel makes between four to eight trips per month on average (DOF-pers.comm.).

4.4.2 CPUE standardisation

Fishery-dependent data collection is one of the most valuable tools available to fishery managers, especially since fishery-independent data are often extremely costly or difficult to collect (Maunder and Punt, 2004). Collection of even the simplest data set can help eliminate the threat of overfishing and subsequent population collapse. To allow valid comparisons of catch rates over time or across fishing grounds and to account for changes in vessel catchability, it is essential to standardise CPUE values to adjust for the impact on catch rates of changes over time of factors other than abundance (Beverton and Holt, 1957; Hilborn and Walters, 1992; Maunder and Punt, 2004; McCluskey and Lewison, 2008).

The GLM models in this study explained between 32 – 98% of the overall variation in the official catch and effort data. Ye and Dennis (2009) remarked that the lower range fraction of explained variation is low by normal statistical standards, but is in the range that most CPUE standardisations can achieve. In fact, Ye and Dennis (2009) also pointed out that the reliability of CPUE standardisation should not be judged based on the model's capacity to explain data variation. For instance, explained variance of models used by Battaile and Quinn (2004) for CPUE standardisation of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea ranges between 20 – 70%, while standardisation used by Yamada *et al.* (2006) for Pacific bluefin tuna (*Thunnus orientalis*) explained 17 – 24% of the overall variation. In fact, the average percentage of explained variation obtained in this study (i.e. ~73%) is considered relatively high in comparison to other studies, although this is suspected to be due to the large number of model parameters resulted from the inclusion of two-way interactions between the main effects.

In principle, the fraction of variability explained can increase substantially by including more explanatory variables (Maunder and Punt, 2004). The number of explanatory variables to be considered in CPUE standardisation often varies in literature and usually depends on the type of fishery. In this study, the number of explanatory variables considered is relatively low compared to other studies. For example, Horn (2003) considered 23 possible explanatory variables when standardising the catch and effort data for ling (*Genypterus balcodes*) off New Zealand, while Siddeek *et al.* (2012) used 10 explanatory variables to standardise CPUE data of golden king crab (*Lithodes aequispinus*) in the Aleutian Islands. Nevertheless, the main effects of year, month, gear types and fishing area are the standard set of explanatory variables commonly used in catch and effort standardisation (Maunder and Punt, 2004).

All two-way interactions between the main operational, temporal and spatial effects were considered in the analyses, except for the year x month interaction as there is no *a priori* reason to include the year x month interaction in the standardisation process.

The year x zone and month x zone interactions were significant when the yearly or monthly variation in CPUE varied in different fishing area. This suggests that there are changes in the geographical distribution of stocks, either as a result of localised overexploitation or annual and seasonal migration pattern (Hvingel *et al.*, 2000). Seasonal migrations of some of the demersal stocks between Brunei Bay and the nearby coastal waters of Brunei have been proposed by Silvestre and Matdanan (1992). Seasonal migration between the shallow waters of fishing area Zone 2 and the deeper waters of fishing area Zone 3, however, has not been demonstrated.

Consequently, there is a need to further clarify whether such variation is an outcome of overexploitation or natural migration pattern, especially if Brunei were to effectively manage its demersal stocks based on management zones.

This study found that the year x gear interaction was significant in about half of the data sets analysed since a different CPUE trend between the different gear types (which is essentially referring to the different fishery fleets) is to be expected. A year x gear interaction may also account for the improvements in technology or skipper experience between the different fishery fleet. A significant month x gear interaction, on the other hand, reflects the differing fishing strategy between the different fishery fleet annually. While trawlers tend to operate the whole year round, the peak of purse seiners and long liners fishing activities are mostly between March and October. The lack (or availability) of target species seems a likely reason for the fishing activity patterns of purse seiners, since pelagic stocks availability have been observed to depend on the cycle of the monsoons in South China Sea (Ruddle, 1986; Ruddle and Davis, 2011). However, the same might not be relevant to the long liners, since they also target the same finfish stocks as the trawlers. Instead, it was reported that such variation was due to operational difficulties of the long line fleet (DOF-pers.comm.). It should be noted, however, that trawlers appear to work all year round because of the non-selective nature of their gear, rather than the availability of demersal finfish stocks all year round (i.e. they also switch target species depending on stocks availability; DOF-pers.comm.).

In this study, variations within each fleet (i.e. individual vessels) were not considered, which is unlike those commonly done in some of the catch-effort standardisation studies (e.g. Sbrana *et al.*, 2003; Ortiz de Zarate and Ortiz de Urbina, 2007). However, the effect of vessel characteristics may be accounted to some degree in the gear x zone interaction. Accordingly, vessels operating in fishing area of Zone 3 are bigger and have greater fishing capacity then vessels operating in Zone 2 (DOF-pers.comm.). Nevertheless, it is highly recommended that future studies on CPUE standardisation of Brunei catch-effort data should include individual vessel characteristics, especially with the varying level of experience between the skippers in the different sectors.

The GLM analyses also showed that the full model for CPUE standardisation of sicklefishes (Drepeneidae) is not significant, thus suggesting that the model is inadequate. This inadequacy may be in the relationship between CPUE and abundance or due to additional variation in CPUE not explained by the explanatory variables.

4.4.3 Potential influence of environmental variability on selected demersal stocks in Brunei

GLM results from this study indicate that environmental variables are only significant in three out of 21 demersal stocks analysed and that, generally, the influence of environmental factors appear negligible on the demersal stocks abundance. Both SST and rainfall produce identical negative correlational response on mojarras (Gerreidae) and bigeyes (Priacanthidae), respectively. On the other hand, croakers (Sciaenidae) were found to be positively correlated with SOI values during the study period, which is essentially associated with La Niña phase of ENSO. Such outcomes most likely identified the intermediate effect of climate and the environment on fish catchability. For instance, mojarras (Gerreidae) are known zooplankton feeders in Brunei waters (Silvestre *et al.*, 1993), and with few evidence suggesting that high temperature will accelerate planktonic larval development and reduce larval duration for many tropical fish (Munday *et al.*, 2012), the combined effect of food availability reduction as well as fishing may have resulted in instantaneous increase in mortality (and hence, decrease in catchable population for the fishery).

However, species responses to environmental parameters do not appear to be easily generalized in the literature, especially since the way in which the environment can affect stock abundance is particularly complex as it involves mechanisms that may act at several life history stages (e.g. Beentjes and Renwick, 2001; Balston, 2007; Beaugrand and Kirby, 2010; Olsen *et al.*, 2011). As a result, inclusion of environmental variables in CPUE standardisation procedure is rarely done (Damalas *et al.*, 2007), especially for demersal species, as evident from the paucity of such studies in the literature. Often, these environmental variables do not have as much explanatory power as, or may be confounded with, other operational, spatial and temporal effects. It should be noted, however, that the possible presence of co-linearity should not be a problem in this study since the goal of the standardisation is to generate an index of relative abundance rather than to investigate the variables that explain variation in CPUE (Maunder and Punt, 2004). Nonetheless, this study could be considered an initial step towards understanding the effect of the environment on a multi-specific demersal community in the tropics, which has been left out of focus of the scientific community up to now, perhaps due to the small range of variability of environmental factors compared to the temperate regions.

One exploratory approach to disentangle the confounding human and environmental effects on fish stocks is to test correlation between stocks' CPUE and the environmental parameters at various lags, based on the hypothesis that these environmental factors influence fish production by controlling nutrient supply for prey production for fishes, and that fishery catches are age-structured (Balston, 2007; Qiu *et al.*, 2010).

Analyses from the 1989/1990 trawl survey in Brunei waters revealed that the majority of the demersal stocks, which comprised roughly 70% of total demersal biomass estimated, have relatively fast turnover rates, typical of small-sized and short-lived tropical fish species (Silvestre and Garces, 2004). Although higher-TL species such as snappers (Lutjanidae) and groupers (Serranidae) may be fully recruited to the fishery from ages 3 onwards, it is assumed that the fishes, in general, would have a dominant age-at-catch of ≤ 3 years (see Qiu *et al.*, 2010). Hence, time lags were tested for up to four years (i.e. 48 months) to allow for time taken for the input nutrients to be circulated among the ecosystem and transferred into prey supply (Beentjes and Renwick, 2001; Balston, 2007; Qiu *et al.*, 2010). Furthermore, it was unknown whether environmental variability has a direct effect upon spawning success or upon juvenile survival in the year following spawning (Beentjes and Renwick, 2001; Olsen *et al.*, 2011). Lagged-effects of ENSO via SOI were not considered in this study since there are difficulties in separating spuriously high (or low) SOI values from those that occurred during a developed La Niña (or El Niño) phase.

The CCF analyses returned a number of significant correlations between the environmental parameters, and the CPUE of overall demersal resources, as well as the nine selected demersal stocks. Such relationship, however, should be treated with caution, since relating large number of CPUE time series to environmental variables, and testing several time lags, may add to the chance of type I error in statistics. Additionally, marked periodicity in the correlation values were observed for some of the analyses, particularly for CCF plots with SST time series, which partly may be due to temporal (seasonal) correlations present in the data.

For intermediate predators (i.e. based on Ecopath trophic groups used by Silvestre *et al*. (1993)), such as snappers (Lutjanidae) and groupers (Serranidae), the strongest correlation with chl-a occurred at 13-month lag, corresponding to the condition one year prior to the catch. Demersal zoobenthic feeders stocks, such as ponyfishes (Leiognathidae) and threadfin breams (Nemipteridae), on the other hand, revealed its top two strongest correlation values at 6-/9- and 13-month lag. Such outcomes: (1) support the observation that annual recruitment can either be in single or dual pulses for these stocks in Brunei (Silvestre and Matdanan, 1992; Silvestre and Garces, 2004), and/or (2) suggest the hypothesis that approximately a year (or six month) is needed to transfer chl-a to intermediate predator (or demersal zoobenthic feeder) stocks (Sartimbul *et al.*, 2010). However, while it may be reasonable to presume abundance being driven by the occurrence of such lagged-effects on short-lived species (Postuma and Gasalla, 2010; Quetglas *et al.*, 2013), precaution is necessary for longer lived species where recruitment, and hence abundance, highs and lows can be buffered by a large number of year classes (Arreguín-Sánchez *et al.*, 1996; Chambers and Trippel, 1997). Moreover, since little knowledge is available of the spawning ground location and the life-history stages for these local stocks, one can only speculate on the reasons to explain how the environmental factors relate to the stock abundance.

Also particularly noteworthy is the state of the stocks which exhibited significant CCFs with the environmental variables. Out of the eight fin-fish stocks analysed, those that were significantly correlated with an environmental factor coincidentally were in an ‘overexploited’ state during the last year of the study period (except groupers (Serranidae) but see below). Likewise, there have been several studies which demonstrated that stocks that are in an overexploited state seem to have been more susceptible to environmental variability (Hsieh *et al.*, 2006; Perry *et al.*, 2010). There is increasing evidence that harvested species fluctuate more than unharvested ones, which is probably due to the elevated sensitivity to environmental variability resulting from the demographic truncation caused by fishery exploitation (Hsieh *et al.*, 2006; Anderson *et al.*, 2008; Quetglas *et al.*, 2013).

Based on the catch data throughout the study period, the grouper (Serranidae) stock is classified as exploited for the year 2009. However, considering that groupers (Serranidae) are *K*-species, with well-studied characteristics of being prone to overexploitation even under relatively light fishing effort (Arreguín-Sánchez *et al.*, 1996; Jennings *et al.*, 2001), it is not surprising then if the catch (and hence the calculated CPUE value) may be overestimated (i.e. hyperstability).

4.4.4 Probable cause of non-proportionality

While strict proportionality between CPUE and abundance is frequently assumed, it has long been recognised that CPUE may not accurately reflect changes in abundance (Beverton and Holt, 1957), thus resulting in either a hyperstability or hyperdepletion scenario (Chapter 2, Section 2.2.2).

For CPUE to be proportional to abundance in an area, it assumes that the effort is distributed at random within that area with respect to the stocks. However, it is almost impossible for this to be true, since fishers will go where they believe the fish stocks to be, thus resulting in effort to be concentrated on those sites of highest abundance. Consequently, different spatial allocation of effort and efficient search by the fishers can lead to hyperstability (Salthaug and Aanes, 2003), causing the CPUE to be a poor measure of population abundance. For instance, consider that two areas initially had the same level of stock abundance, where one is closer to shore while the other is far away, expensive to exploit, or for some other reason undesirable. Effort will first be spent in the nearby area, but after a while the fishers are willing to trade off the undesirable aspects of the other area for its higher CPUE. Accordingly, the CPUE may remain stable or even increase, even though the total abundance may still be declining (Hilborn and Walters, 1992; Walters, 2003). To avoid this, one common approach is to spatially disaggregate CPUE data and patterns of effort, to reveal localised declines (Walters, 2003; Maunder *et al.*, 2006). The spatial resolution of the existing data in this study, unfortunately, is too crude to discern fine spatial changes. Nevertheless, the relatively higher CPUE values shown for fishing area Zone 3 in Brunei waters suggests that abundance may still be greater in Zone 3, even if the total abundance of overall demersal stocks for the whole of Brunei water may be declining. This scenario, however, will become a major concern if one considers the two fishing areas to be of different productivity and hence different level of stock abundance initially. Considering that almost all of the reefs and ‘no-take’ zones are located in the coastal area of Zone 2, and that stock abundances are likely to decrease with depth (Silvestre and Matdanan, 1992; Arreguín-Sánchez *et al.*, 1996; Silvestre and Pauly, 1997a), the lower CPUE values observed in Zone 2 would then suggest localised overexploitation of the demersal stocks. In this case, hyperdepletion is unlikely, since the assumed area of higher productivity (i.e. Zone 2) would be nearer, less expensive to exploit, and hence more desirable (Hilborn and Walters, 1992).

Interestingly, this study also identified several demersal stocks which exhibited similar level of abundance between both fishing zones. This could be due to the following: (1) level of exploitation on fish stocks is similar in both zones (i.e. for the first scenario where the initial level of abundance is assumed to be the same), or (2) stocks in area of higher productivity (i.e. Zone 2) may be overexploited to low abundance, thus closely match those in area of lower productivity (i.e. Zone 3). In the case of the ponyfish (Leiognathidae) stock, overexploitation to localised depletion is likely since a significant declining trend was observed in Zone 2 during the study period. However, similar conclusion could not be found for the grunt (Haemulidae), butterfish (Stromateidae) and ray (Dasyatidae) stocks.

Conversely, variable catchability between stocks, either through behaviours of fishers (i.e. gear saturation effect) or fish (i.e. different species respond differentially to the gear), could also cause bias in the relationship between CPUE and abundance towards hyperdepletion (Hilborn and Walters, 1992). Given that the main contribution to catch are those caught by trawlers in this study, if assuming that hyperdepletion exists, this is more likely due to the gear saturation effect then, as trawlers are only sensitive to size and not species type. However, hyperdepletion in fisheries rarely occurs. There are some examples, such as the south Australian rock lobster fishery (Hilborn and Walters, 1992), but hyperstability appears to be the most common relationship (Harley *et al.*, 2001). Some of the well known fisheries collapses in the world are ascribed to hyperstability (e.g. the northern cod stock collapse (Shelton, 2005)), and hence considered to be one of the biggest problems for fisheries managers.

While there is much evidence to suggest that hyperstability frequently occurs in the relationship between CPUE and abundance, the assumption of proportionality may still be valid in some cases (e.g. Haggarty and King, 2006; Ye and Dennis, 2009). Unfortunately, lack of access to fishery-independent data available meant that the use of CPUE as abundance indicators in this study could not be evaluated. In fact, in many cases, the use of fishery-dependent data represents the only method available for abundance estimation (Maunder and Starr, 2003; Tsehaye, 2007). Nevertheless, standardised CPUE values may still provide a more accurate measure of uncertainty around the indices.

4.4.5 Spatio-temporal changes in CPUE of demersal stocks in Brunei

In this study, the trends in CPUE may appear slightly more optimistic than the demersal abundance trends calculated from the trawl surveys conducted by the DOF in 1999 and in 2008 (DOF, 2011). The DOF reported that the geometric mean catch rate in Brunei waters (fishing zones 2 and 3 combined) in 2008 had declined by about 60%, whereby only 38.6% of the overall demersal stocks are left when compared to the abundance in 1999 (DOF-pers.comm.). Although the reduction in overall demersal resources between the start (2000) and the end (2009) of the study period is comparable to the DOF report (i.e. abundance level in 2009 is 39.2% of the abundance level in 2000), the rate of change over the years greatly varies between different stocks and fishing areas.

With few exceptions, it is interesting to note that majority of the fish families which are shown to increase in abundance are of the intermediate predator category, such as jacks (Carangidae), groupers (Serranidae), halibuts (Psettodidae) and batfishes (Ephippidae). On the other hand, demersal zoobenthic feeders such as ponyfishes (Leiognathidae) and threadfin breams (Nemipteridae) had significantly decline over the study period. Such pattern appears contradictory to the “fishing down the marine food web” phenomenon described earlier in the thesis (Chapter 3), while Gulland (1972) similarly argued that fishing would have reduced fish that are expensive and attractive to fishers first. However, such changes are, in fact, not new and have been identified previously in the overexploited demersal fishery of the Gulf of Thailand (Pauly, 1988). Specifically, Tiews *et al.* (1967) who first presented evidence for the massive changes in the species composition of the Gulf of Thailand demersal resources due to fishing in the 1960s noted that while some of the previously abundant groups such as the ponyfishes (Leiognathidae) had declined, there was a marked increase of snappers (Lutjanidae) and squid (*Loligo duvauceli*). Similar findings were also observed by Pauly (1979) in a later analysis for the Gulf of Thailand, and by Koranteng (1998) on the outcomes of several trawl surveys carried out in the large marine ecosystem of Ghana. It should be noted, however, that the analyses presented in this chapter have treated each family as an entity, by portraying trends in overall abundance. However, the various species in each family could have acted differently from the group behaviour as a result of possible differences in response to factors such as life history, environmental changes, and reaction to fishing gear.

4.4.6 General limitations of analyses

Limitations and source of bias of using fishery-dependent data and CPUE as an index of abundance has been covered extensively in the literature (e.g. Harley *et al.*, 2001; Maunder and Punt, 2004; Froese *et al.*, 2012). Inherently, some of the methods used in this chapter may be open to criticism. For instance, the combination of catch data across species to monitor community abundance means that the trends perceived can be misleading as it may reflect changes in abundance of one or few dominant species. Moreover, since the fleet mainly exploit stocks that can be caught with their gears, the index of abundance are therefore indicative of the older and larger sized-stocks.

While GLMs are considered a powerful statistical technique, the fraction of overall variation in the data explained by a catch-effort standardisation eventually depend on the explanatory variables, and the key assumption that the relationship between some function of the expected value of the response variable (i.e. CPUE) and the explanatory variables is linear. Nonetheless, many different approaches have been considered in catch-effort standardisations as this is a rapidly developing field. For example, there are many studies which have used extensions of the GLM approach such as general additive models (GAMs) and generalized linear mixed models (GLMMs). Subsequently, GAMs enable the linear predictor in GLM to be replaced by an additive predictor, giving it a partially non-parametric aspect, while GLMMs extend the GLM approach by allowing some of the parameters in the linear predictor to be treated as random variables. Other recent approaches in catch-effort standardisation have been reviewed by Maunder and Punt (2004).

Even though great care has been taken in extracting the right data to answer the questions posed in this study, the results obtained ultimately depend upon the data provided. For instance, Brunei has been noted for its high discard rate (Kelleher, 2005; DOF-pers.comm.), while the extent of illegal, unreported and unregulated (IUU) fishing in Brunei and Southeast Asian region is of considerable concern (APFIC, 2007). Unfortunately, the fishery authorities do not appear to have suitable means to check the authenticity of the data supplied – a common setback of fishery-dependent data worldwide.

In brief, while the abundance trend of overall demersal resources in Brunei waters is in decline between 2000 and 2009, the trends for the different demersal family stocks vary greatly over time and between fishing areas. Potential influences of environmental parameters, separated from fishing effect, have been identified and could serve as hypothesis-generators for future research. However, inferring changes based on short-term data can be risky, which leads some authors to tap into memories of fishers. This is further considered in the next Chapter 5 (Utilisation of local ecological knowledge to assess status of selected demersal stocks in Brunei).

Chapter 5
Utilisation of local ecological knowledge to assess status of selected demersal stocks in Brunei

"People don't know the past,
even though we live in literate societies,
because they don't trust the sources of the past."
– Daniel Pauly, 2010

Chapter Summary

Fishers' local ecological knowledge (LEK) was collected through a rapid appraisal process using map-based semi-structured interviews on 259 currently active fishers in Brunei Darussalam. Based on fishers' perceptions, this study examined changes in relative abundance between the 1960s and the 2000s, of four demersal stocks (red snappers *Lutjanus erythropterus*, groupers *Epinephelus* spp., ponyfishes *Leiognathus* spp. and rays *Dasyatis* spp.) and two pelagic stocks (Japanese scads *Decapterus maruadsi* and narrow-barred mackerels *Scomberomorus commerson*). Red snappers were cited more than any other species as depleted. Highly experienced fishers (>40 years) recalled greater past abundance than less experienced fishers (<10 years) and were more likely to have caught larger red snappers from shallow inshore waters than further offshore. While none of the fishers acknowledged an increase in abundance for any of the six selected stocks, the more experienced fishers' perceptions on ponyfishes, Japanese scads, narrow-barred Spanish mackerels and rays showed a significant downward trend. This indicates that experienced fishers acknowledged a greater depletion since 1960s than less experienced fishers, and provides another compelling case of the 'shifting baseline syndrome' (SBS), whereby different generations of fishery stakeholders have altered perceptions of their environment. A fuzzy logic expert system was used to standardise and quantify the anecdotal evidence to produce a decadal time series of resources abundance from 1960 to present. This study also incorporated the use of geographic information system (GIS) for collecting and systematizing fishers' LEK, which enabled identification of the preferential habitats of demersal fish stocks and the high-pressure harvest zones for Brunei fisheries. Fishers' opinions on current management practice revealed that the fishery suffers from a "trust gap" between the fishery authorities and the fishing communities. Understanding the prevalence and implications of SBS can make better use of resource user knowledge, while the extraction of LEK as a source of viable information can provide insights for the fishery authorities in the development of spatially explicit management measures in Brunei waters.

5.1 Introduction

Understanding of the full influence of fishery activities in Brunei, as elsewhere in the region, is often hindered by the short time-series of many of the datasets on fishery catch statistics. One means of overcoming constraints in data-poor fisheries, which characterise many developing countries, is to tap into the memories of fishers – an approach linked to the emerging discipline of historical ecology (Johannes *et al.*, 2000; Silvano and Valbo-Jorgensen, 2008; Venkatachalam *et al.*, 2010).

Besides determining past abundance patterns of target fish, long before the onset of data recording by scientists, local ecological knowledge (LEK) studies may uncover the "shifting baseline syndrome", whereby each generation of stakeholders accepts a lower standard of resource abundance as being normal (Pauly, 1995).

This chapter describes a questionnaire developed for the collection and analysis of information derived from LEK of fishers operating in Brunei waters, and its application to four selected demersal stocks and two pelagic stocks, with special reference to the demersal red snapper (*Lutjanus erythropterus*). By using Geographical Information Systems (GIS) as well as a fuzzy expert system, this study aimed to systematically convert, standardise and quantify LEK into a form that is suitable for consideration and analysis by fisheries managers and scientists. Specifically, this chapter addresses the following research questions:

1) How can fishers' LEK in Brunei be collected and analysed in a meaningful way for application in fisheries management and science?
2) Has there been discernible change in the relative abundance of selected stocks between the 1960s and the 2000s based on fishers' perceptions?

3) Is the "shifting baseline syndrome" (SBS) evident or prevalent in marine resource users of Brunei?
4) Where are the high-pressure harvest zones and are there any conflicts between different fishery sectors?

5.2 Materials and Methods

5.2.1 Data collection

Opinions of large-scale (LS) and small-scale (SS) fishers of different ages on Brunei fisheries resources were assessed and quantified through a semi-structured map-based interview survey. The survey was carried out in Malay, which is the local language spoken in Brunei, without the need of a translator.

5.2.1.1 Interview preparation

Prior to undertaking the fieldwork in Brunei, background information was collected on the people and culture within the study area. This was achieved through internet searching and the use of published and some unpublished references on fishers' fishing practices and lifestyles. Interview questions were developed in consultation with Professor Andrew Price (School of Life Sciences, University of Warwick) and Dayang Ranimah Haji Abdul Wahab (then Head of Marine Fisheries Development and Management Division, DOF) and were pilot-tested on 65 fishers during an initial fieldtrip in Brunei in May 2010. Issues that had arisen from the pilot survey were identified and interview design and procedures were refined accordingly. This enabled better preparations to be made for the second fieldtrip which took place over a longer time-frame between March and May 2011.

The survey was carried out with the help of two research assistants. Prior to undertaking the survey, the research assistants were briefed on the research objectives as well as the interview procedures to be employed during the survey. Ethical and technical standards were followed in accordance with (Bunce *et al.*, 2000).

5.2.1.2 Interview design and procedures

The interview questions developed are modifications made on questionnaires from previous studies focusing on the use LEK to detect SBS (Saenz-Arroyo *et al.*, 2005b; Ainsworth *et al.*, 2008; Venkatachalam *et al.*, 2010). As few technical terms as possible were used to make the questions comprehensible to respondents with varying education levels. In addition, local fishery officers were consulted to help with appropriate word usage and clarify any technical or difficult terms. Interviews generally lasted between twenty minutes and one hour.

During the oral portion of interviews, the researchers would first chat informally with respondents to help establish a relaxed atmosphere conducive to openness and frankness. Interview questions were asked either as part of the dialogue during the conversation or as direct questions once a good rapport had been established. Whenever possible, interviews were conducted in private to ensure respondents were not influenced by responses of others (Figure 5.1).

Figure 5.1: Obtaining local ecological knowledge from fishers in Brunei. Whenever possible, interviews were conducted in private, either on a one-on-one or two-on-one arrangement, to ensure respondents were not influenced by responses of other fishers.

In this survey, the questions were divided into three main sections (Appendix 5.1). The first section of questions was designed to be easy to answer, to allow the respondents and researchers to settle into the interview dialogue. Examples of information requested in this section included *age*, *number of years the respondent had fished for* and *type of fishing gears* commonly employed in their fishing operations. The second section involved questions on perception of changes of Brunei marine resources since the respondents first started fishing. During pilot interviews, respondents were originally asked an open-ended question of naming all the fish species that they believed to have been depleted by fishing and the associated year or time period. However, it became apparent that while verbally fluent respondents provided very specific answers, the majority of respondents provided minimal responses and often replied with “I don’t know” or “All species”. Consequently, feedback was better when the question was structured to be closed-ended, although the varieties of species studied were compromised. Hence, in addition to naming all the fish species they believed to have been depleted throughout their fishing career, the respondents were also asked to characterise the abundance of six selected stocks (i.e. red snappers, groupers, ponyfishes, scads, mackerels and rays) into one of the three categories (high, medium, low) for each time period: 1960s, 1970s, 1980s, 1990s and 2000s. These stocks were selected as they can be easily identified by all fishers, whether old or young. Respondents were also asked to score their perceived changes in general fish abundance and fish size throughout their whole fishing career. In the last section, questions were structured to extract LEK specifically related to the red snapper stocks, to further explore the extent of SBS in Brunei. Questions in this section included maximum size and best day's catch of red snapper.

The survey also incorporated map-based interviews (Close and Hall, 2006), where respondents recorded on an individual hardcopy map, with the help of the researcher, their approximate most frequently visited fishing site and previous harvesting locations for red snappers. To check for logical consistency of fishing areas drawn, fishers were asked again to describe the fishing location verbally and in relation to notable oil fields, islands, shorelines or reefs nearby (Appendix 5.2). A nautical chart of Brunei waters was provided by the DOF to be used in the map-based portion of the interview.

5.2.1.3 Survey sampling strategy

The survey can be divided into two types; (i) LS fishery survey, and (ii) SS fishery survey. The LS fishery survey was conducted over two weeks, from 28th March to 8th April 2011, while the SS fishery survey was carried out between 21st March and 5th May 2011. In general, all respondents were cooperative as the researchers encountered only two refusals.

(i) LS fishery survey

Skippers of LS vessels (trawlers, purse seiners and long-liners) harboured at Muara FLC were identified with the help of DOF staff, Awang Bidin bin Suru. For 2011, there were a total of 43 LS vessels (21 trawlers, 12 purse seiners and 10 long liners) registered with DOF. However, during the two-weeks surveying period, only twenty trawlers, six purse seiners and three long liners were actively operating, and only 23 skippers managed to be interviewed.

(ii) SS fishery survey

A stratified convenience sampling approach, either by roving at access-points or by contacting key informants identified from the official registration list for the whole of Brunei (provided by DOF), was used to sample the SS fishermen population. Four access-points were selected out of several known landing sites, based on site inspection visits during the first fieldtrip. The four access-points were Jerudong landing, Pengkalan Sibabau landing, Kuala Tutong landing and Kuala Belait landing (Figure 5.2).

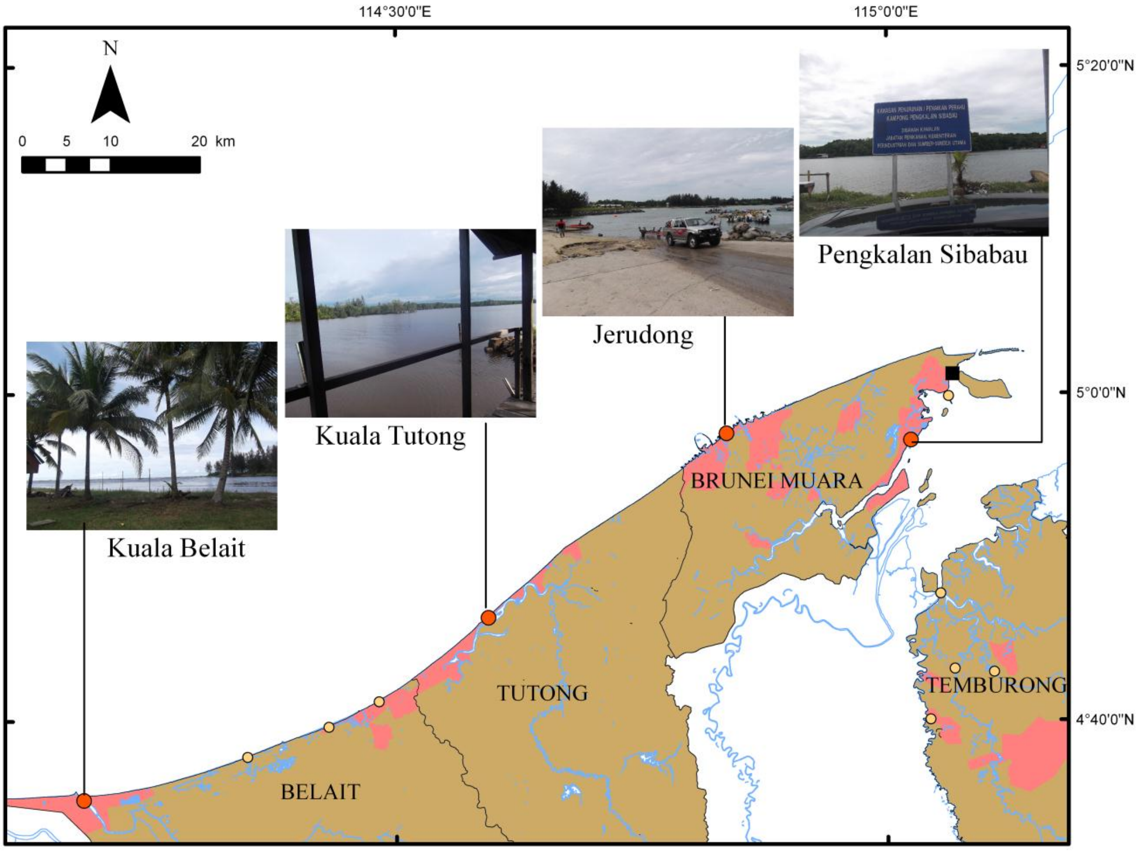

FIGURE 5.2: Map showing four access-points (big red circles) which were selected out of several known landing sites (small yellow circles) for the interview survey of fisheries in Brunei. Villages in which the respondents currently reside are shaded in pink.

To ensure the interview survey was representative and generated data with sufficient statistical power, a minimum effective sample size was calculated (Raosoft, 2004). Based on the total number of fishermen engaged in the capture fishery in 2010 (c. 2527 full-time and part-time fishermen; DOF pers. comm.), 246 respondents were required for the fishermen population to be representative at 90% confidence interval and an accepted error of 5%. However, as the fieldwork progressed, it became apparent that having a valid fishing gear license does not guarantee an active fishing operation by the license holder. Allowing for non-compliance, a total of 236 respondents were obtained. Therefore, the sample size was representative at 90% confidence interval with an accepted error of 5.1%.

The total number and distribution of SS fishers interviewed for the whole of Brunei are summarised in Table 5.1.

TABLE 5.1: Distribution of small-scale fishers interviewed between March and May 2011 in Brunei.

District - **Villages**	**Small-scale companies**	**Small-scale individuals**	**Total SS fishers**
Brunei Muara - Batu Marang - Bebatik Kilanas - Bengkurong - Jerudong - Kapok - Kiulap - Lambak Kanan - Mata-mata - Mentiri - Muara - Pandai Besi A - Pengkalan Sibabau - Pudak - Serasa - Serdang - Setia A & B - Sungai Besar - Sungai Bunga - Sungai Kebun - Sungai Siamas - Tamoi Tengah - Tungku	53	85	138
Tutong - Bukit Beruang - Danau - Keramut - Kuala Tutong - Penanjong - Sengkarai - Telisai	10	25	35
Temburong - Amo A - BatangTuau - Belais - Menengah - Negalang Ering - Rataie	-	13	13
Belait - Kuala Belait - Lumut - Mumong - RPK Pandan - Sungai Liang - Sungai Teraban	17	33	50
Total SS fishers	80	156	236

5.2.2 Data assembly and analyses

Data assembly and analyses were done using Microsoft Excel, SPSS v.19 and ArcGIS 10.1 software. Results from the interview survey were organised into two main groups, forming either the attribute dataset or spatial dataset. Quantitative attribute data collected were tested and analysed using standard non-parametric tests where necessary, as used in previous LEK studies (Saenz-Arroyo *et al.*, 2005b; Ainsworth *et al.*, 2008; Venkatachalam *et al.*, 2010). In addition, a subset of these data was subjected to fuzzy logic analysis using methodology adapted from Ainsworth *et al*. (2008). Qualitative attribute data were transcribed, arranged by key themes and visually assessed. The spatial dataset, which contains the map portion of the interviews or, more precisely, specific spatial information from the interview, were input from the hardcopy maps as ArcView GIS shapefiles using “heads-up” digitizing as described by Close and Hall (2006).

5.2.2.1 Fishers’ perceptions of fish depletion and changes in indicator species (*Lutjanus erythropterus*) – descriptive approach

Respondents were asked the year they started fishing actively, which was later placed into one of the three ‘experience years’ groups (<10, 11 – 39 and >40 years) for comparison. Differences in variables (other than the red snapper catch variables), between the groups were determined using non-parametric Kruskal-Wallis test. Each of the red snapper catch response variables (i.e. best day’s catch, weight of biggest fish ever caught, and distance offshore and water depth associated with best day’s catch) was regressed against fishing experience years using linear regression analysis by using transformed data to meet the assumptions of normality and heterogeneity of variance tested. Besides comparing by fishing experience, separate analysis was undertaken on the catch response variables to determine strength of association with years.

Reported abundance categories were converted into the same numerical interpretation of responses where “low”, “medium” and “high” score as -1, 0 and 1, respectively. Trends in perceived change of stock abundance from when fishers started fishing and present were then assessed – a logistic regression analysis was used to model the probability of fishers perceiving ‘no change’ or ‘some change’ against their fishing experience.

5.2.2.2 Estimating past abundances from LEK - Fuzzy logic approach

Fishers’ responses were subjected to fuzzy logic analysis using methodology adapted from Ainsworth *et al.* (2008), whereby perceptions of fish abundance were categorized into fuzzy datasets so that the threshold between abundances categories is not crisp, but instead adjusted to a gradation of membership in several abundance categories.

When fishers scored the abundance as ‘high’, this corresponded to a numeric abundance score of 1, ‘medium’ corresponded to 0.5 and ‘low’ corresponded to 0. The average score was taken for all the contributing interviews, and partial memberships in five fuzzy set linguistic abundance categories (i.e. low, medium-low, medium, medium-high and high) were determined using the membership functions such as that shown in Figure 5.3. Agreement between fishers was also used as an indicator of data quality, by changing the shape of the membership functions according to the variance among fishers’ scores. If fishers agreed well with each other, the membership functions more closely resembled Figure 5.3a. When there was a high variance among fishers' abundance scores, a wider form of membership functions as in Figure 5.3b was used. This enabled the membership of the abundance score in as many as four overlapping abundance categories. Consequently, this approach enabled the influence of a small number of interview comments that contradicted with majority response to be ignored.

Variance (V) among abundance scores assumed a binomial distribution by having the majority abundance category as marked by fishers (low, medium or high) as 'correct' and all other estimates as 'incorrect'. Variance was calculated as $V = np(1-p)$, where p is the fraction of responses indicating the 'correct' response and n is the total number of responses. Membership for the fuzzy abundance categories was calculated following Ainsworth *et al.* (2008) given below:

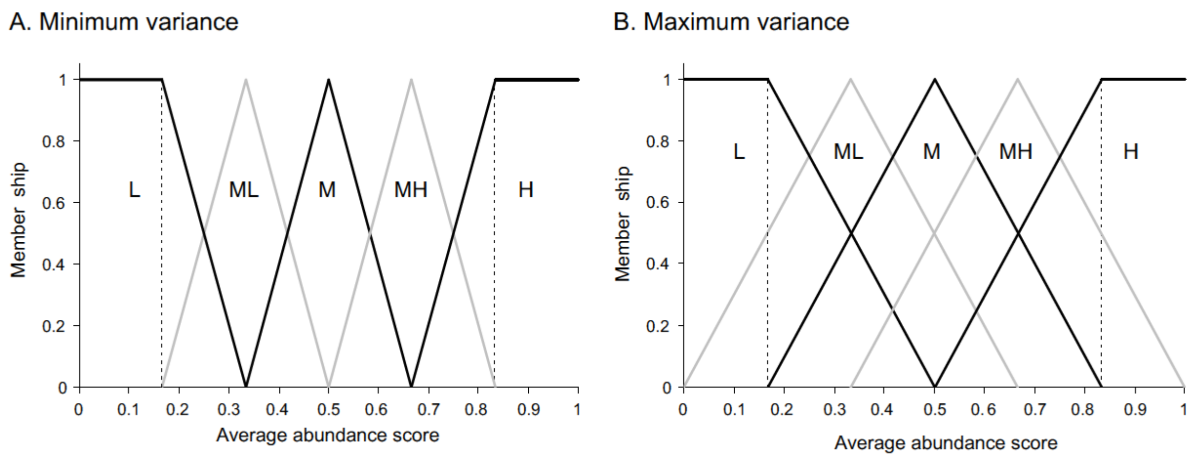

FIGURE 5.3: Fuzzy set membership for fisher abundance scores. Memberships in the low (L) and high (H) linguistic abundance categories are defined by trapezoidal functions; memberships in medium-low (ML), medium (M) and medium-high (MH) categories are defined by triangular functions. X-axes represent average abundance scores from interviews for time period and species. As variance among fisher responses increases, the subtended angle increases from a minimum (left) to a maximum (right). Taken from Ainsworth *et al.* (2008).

The partial memberships for each species group and time periods are then combined through the ‘de-fuzzification’ process – a process by which the range of possible conclusions for a particular species group-time period element is reduced to a single point output representing the relative abundance. This was done using the centroid weighted average approach (Cox, 1999). The weightings (partial memberships) were multiplied with the centroid of the corresponding abundance category in the de-fuzzification membership function – which is identical to Figure 5.3 – to obtain a weighted average of the abundance output categories. The lower and upper error range was established by multiplying the weightings in each abundance category by the lower and upper values of the membership function, respectively, as opposed to the centroid for the weighted average.

5.2.2.3 LEK assessment using spatial information technology – GIS approach

Each fishing area drawn by fishers onto the individual hardcopy map was constructed using careful on-screen digitization and stored as ArcGIS shape files, following Close and Hall (2006). Fishing area may be identified as points or lines on the base (hardcopy) map. Thus, the construction of point and line layers in ArcGIS reflected two forms of fishing activity. Lines were used to represent fishing paths along shorelines, between oil platforms or over reefs, where a fisher would start fishing from one end and work his way to the other end, or move from location to location in a linear fashion, often drifting with the current and/or wind. Points represent a particular area of fishing activity. Attribute entry that were acquired indirectly from the spatial dataset (i.e. distance and depth of location associated with best day's catch of red snappers) were linked to the main attribute dataset.

Raw spatial data (Appendix 5.3) and associated attribute data were then converted into a more meaningful form that fisheries managers and planners could use for planning. To achieve this, arbitrary 'likelihood' surfaces were created using a combination of GIS-based map overlaying and buffering of features on individual fishers' map layers (Close and Hall, 2006). In this study, the 'red snapper harvesting location' (points feature class) and 'most frequently visited location' (lines feature class) data were used for the construction of two types of surface classifications, namely the 'red snapper distribution classification' and 'high-pressure zone classification'. These two classifications were used to illustrate red snapper distribution across the study area and areas that receive a high degree of fishing pressure. The general analysis sequence for the two classifications is shown in Figure 5.4.

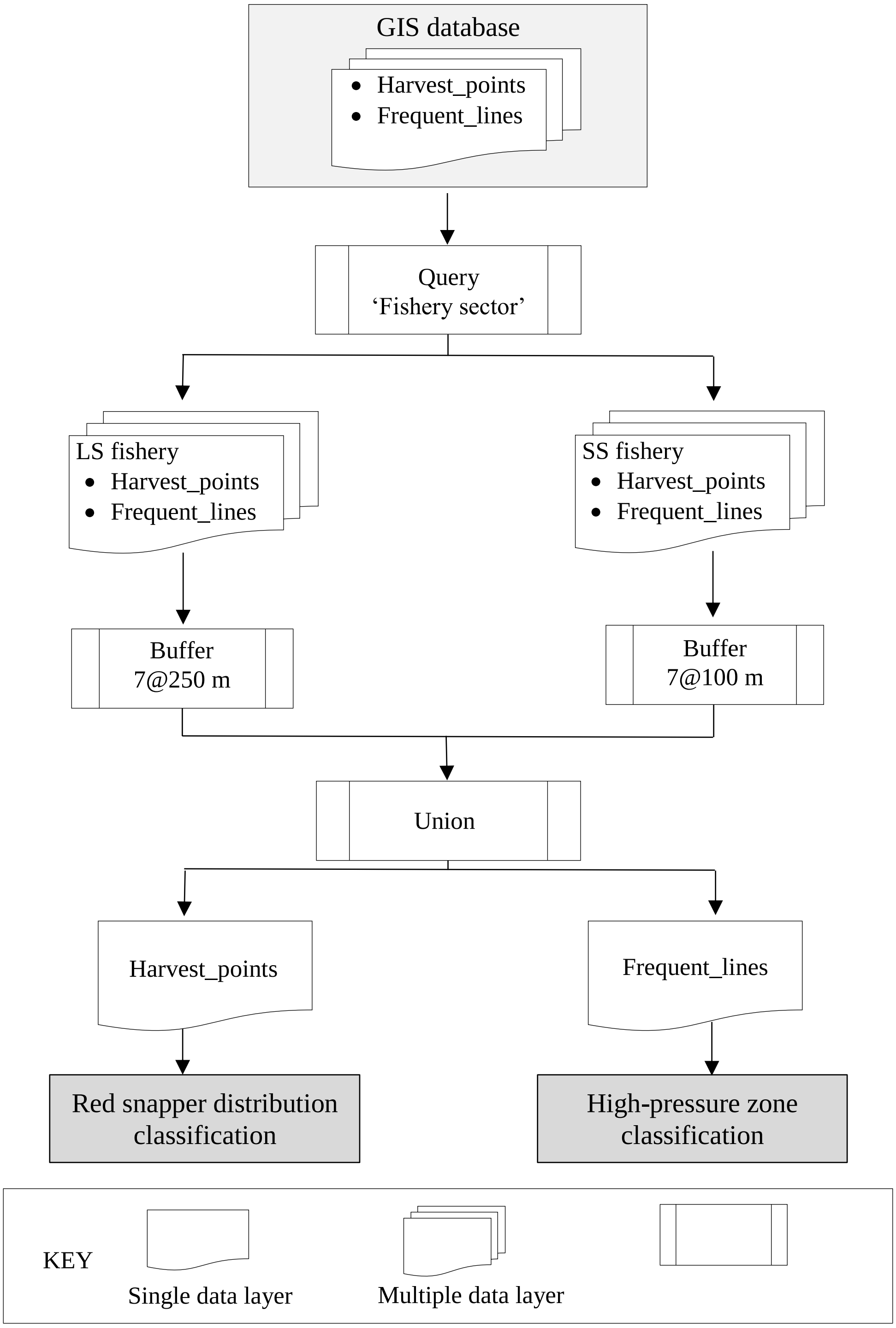

FIGURE 5.4: Process flow for the construction of the two classifications using GIS, namely the red snapper distribution classification and the high-pressure zone classification. 'Harvest_points' refer to red snappers best day's catch harvesting sites which are points feature class. 'Frequent_lines' refer to fishers' most frequently visited area when the go out in the sea, which are lines feature class.

The multi-buffer approach was employed to adjust for map bias and boat drift (Close and Hall, 2006). Although there is no scientific basis for determining the number of buffers and their absolute or relative widths, seven buffers of 100 m and 250 m, for SS small boats and LS large vessels, respectively, were used in this study. These values were based on the observed maximum distance of lateral boat drift of typical fishing boats used by the fishers (i.e. boats are ~8 m long for SS fishery and ~20 m long for LS fishery), Brunei's generally moderate weather (Panaga, 2007) with slight wave and gentle breeze (except during the Northeast monsoon), and the relatively shallow bottom depth of main fishing area. Furthermore, expert opinions of the DOF officers were consulted, and published literatures were reviewed, to ensure that the buffers yield a realistic representation of the harvest area.

The cumulative buffer 'likelihood' values, or 'scores', were summed in the union of individual fisher's maps (224 layers for the red snapper harvest location and 236 layers for the most frequently visited sites) such that the highest possible score would occur in locations with the highest chance of red snapper being present and locations of the highest fishing pressure.

Proportional symbol maps were also used to uncover the spatiotemporal variation in fishers' best day's catch.

5.3 Results

5.3.1 Exploratory analysis: distribution of small-scale fishers by gears

Most (77%) of SS fishers own either one or two gears (Figure 5.5a) which usually include gill net and/or hand line. Major gears operated by the SS sector are fish gill net (*andang ikan*), hand line (*jaul*) and portable fish trap (*bubu*) (Figure 5.5b). Accordingly, most of the gears are passive and selective, and about 40.9% of SS fishers employ gears specifically targeted at the demersal stocks.

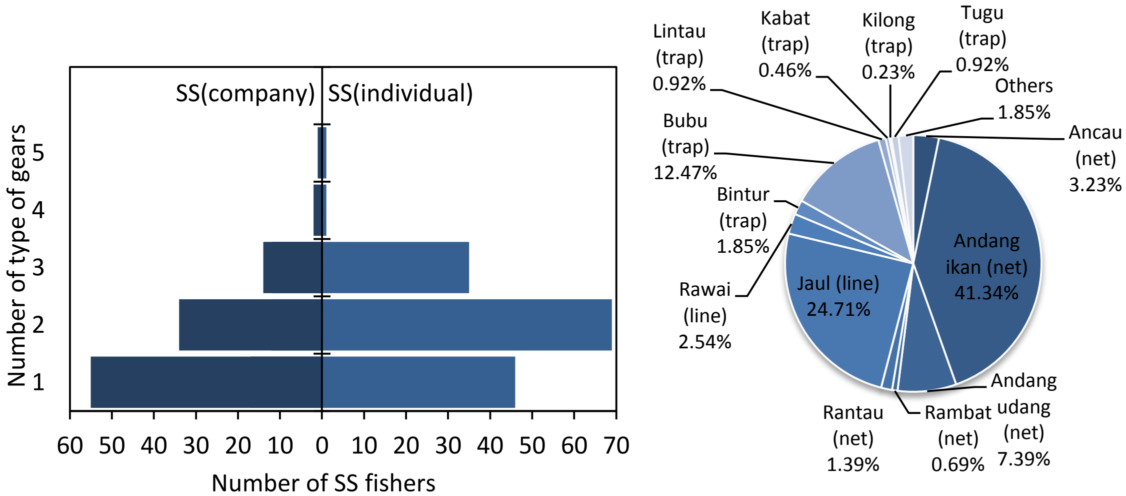

FIGURE 5.5: Distribution of gears among small-scale fishers interviewed in Brunei between March and May 2011 (a) Frequency of fishers that own between one and five different types of gears, and (b) Proportion of the different types of gears operated by overall SS fishers.

5.3.2 Perceptions of decline in indicator species (*Lutjanus erythropterus*) and changes in selected stocks from fishers' interviews

The majority of fishers interviewed (90.7%) agreed that fishing had led to depletion or loss of some species. Altogether, respondents cited a total of 80 species which they perceived had been depleted in their lifetime, with 18 species being cited by all groups (Appendix 5.4).

Red snapper was cited more than any other species as depleted, with the less experienced fishers being less likely (77%) than more experienced fishers (91%) to have caught one (Kruskal-Wallis test; χ^2 (d.f.) = 9.40 (2), $p = 0.009$). Highly experienced fishers were more likely to have caught larger and more red snappers on a trip nearer to the shore, where it was shallower, than further offshore (Table 5.2, Figure 5.6; linear regression analysis, $p < 0.05$ in all cases).

Because experienced fishers would likely have a greater chance of landing larger and bigger catches than the newer/younger fishers, catch parameters were then assessed against actual years (Table 5.3, Figure 5.7). Both best catch and weight of largest red snappers caught have decreased according to fishers' perceptions. Additionally, both the depth and distance offshore associated with fishers' best catch have been greater in recent years (linear regression analysis, $p < 0.05$ in all cases).

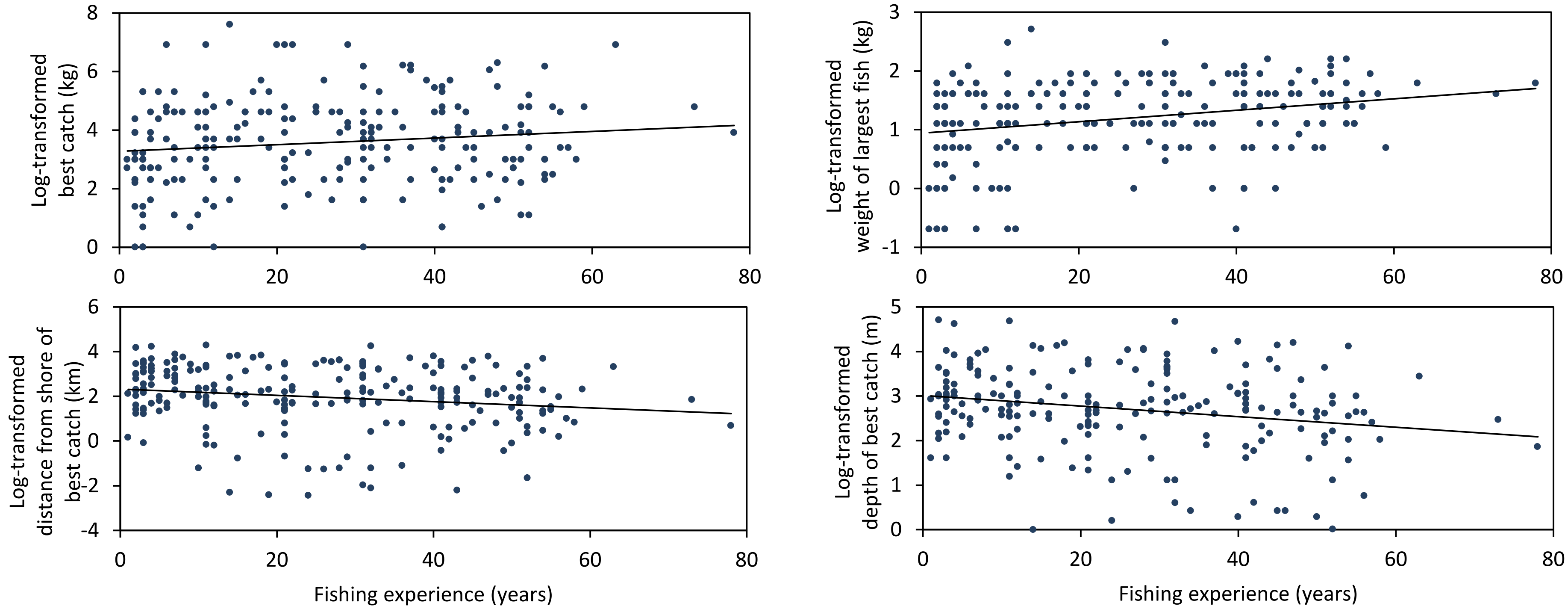

FIGURE 5.6: Linear regressions of interview data showing (a) best day's catch, (b) weight of largest red snapper, (c) distance offshore associated with best day's catch, and (d) water depth associated with best day's catch, against fisher experience.

TABLE 5.2: Results of linear regression analyses of four different red snappers catch variables as a function of fishing experience, as obtained from fishers interviews. Significant p-values are in **bold**.

Attribute (log-transformed)	N	Slope *b* (S.E.)	*t*-test stats	p-value
Best day's catch (kg)	226	0.011 (0.006)	2.036	**0.043**
Largest red snapper ever caught (kg)	225	0.010 (0.002)	4.143	**<0.001**
Distance offshore associated with best day's catch (km)	224	-0.014 (0.005)	-2.693	**0.008**
Depth associated with best day's catch (m)	206	-0.012 (0.004)	-3.268	**0.001**

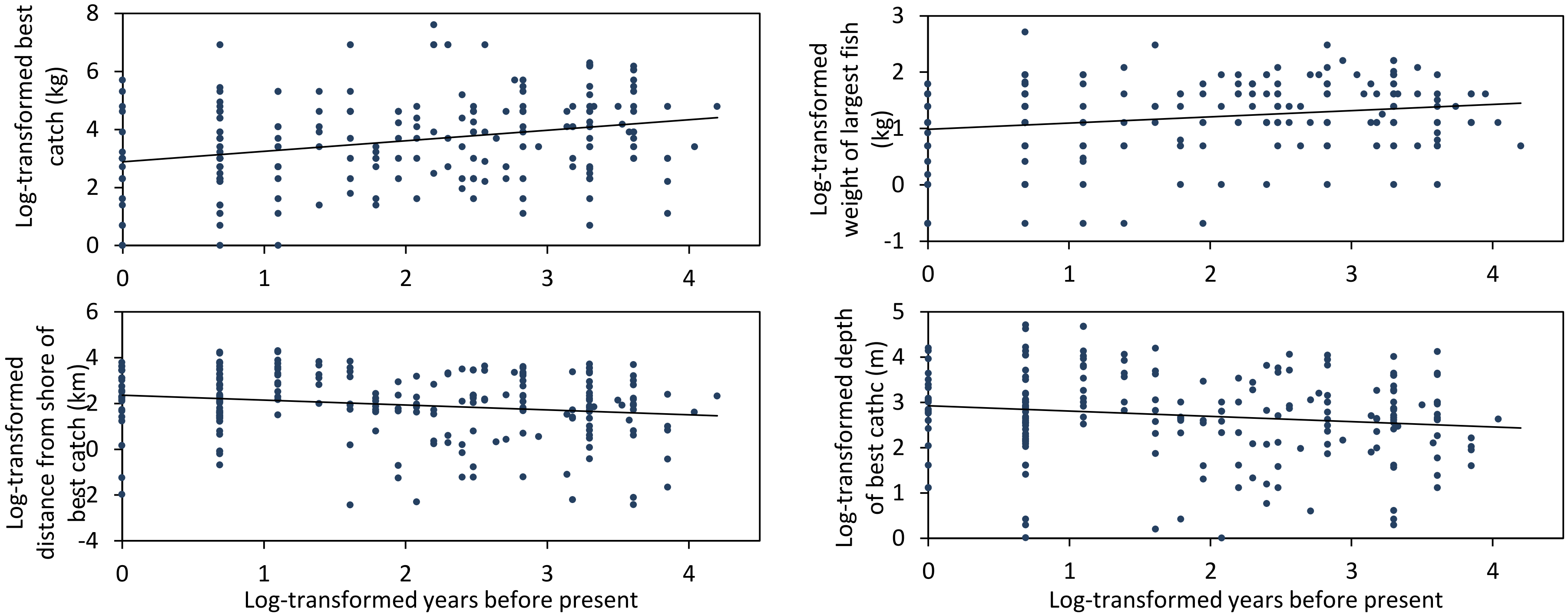

FIGURE 5.7: Linear regressions of interview data showing (a) best day's catch, (b) weight of largest red snapper, (c) distance offshore associated with best day's catch, and (d) water depth associated with best day's catch, against reported year.

TABLE 5.3: Results of linear regression analyses of four different red snappers catch variables as a function of actual years, as obtained from fishers interviews. Significant p-values are in **bold**.

Attribute (log-transformed)	N	Slope *b* (S.E.)	*t*-test stats	p-value
Best day's catch (kg)	226	0.365 (0.079)	4.619	**<0.001**
Largest red snapper ever caught (kg)	225	0.110 (0.034)	3.218	**0.001**
Distance offshore associated with best day's catch (km)	224	-0.214 (0.078)	-2.759	**0.006**
Depth associated with best day's catch (m)	206	-0.117 (0.054)	-2.154	**0.032**

Figure 5.8 shows the distribution of perceived changes for the two depletion indicators (abundance decrease and size reduction) by fishing experience categories. In general, the majority of fishers agreed that overall fish abundance had declined (79.9% of all fishers), but with no perceived reduction in fish size (72.2% of all fishers) since fishing began.

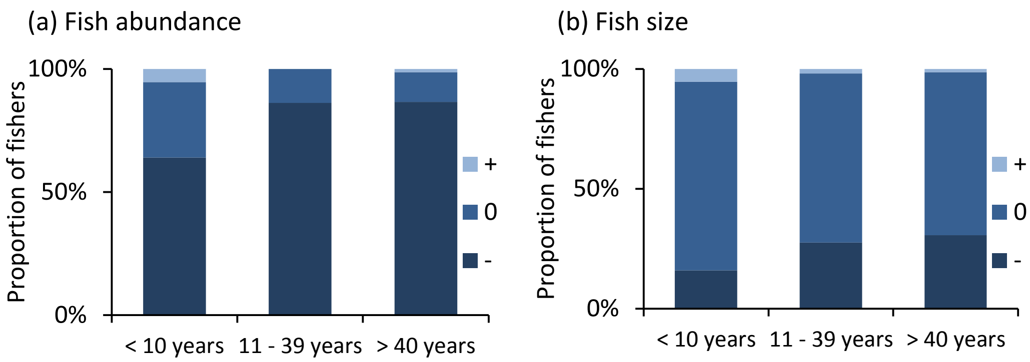

FIGURE 5.8: Proportion of fishers reporting changes in depletion indicators; (a) fish abundance, and (b) fish size, since when they first started fishing. Dark blue bars indicate decrease (-), blue bars indicate no change (0) and light blue bars indicate increase (+).

The perceived abundance change from when fishers started fishing and present using the reported abundance scores ("low", "medium" and "high" score as -1, 0 and 1, respectively) for the six species were tested against experience years (Figure 5.9). The Y-axis represents the probability of fishers perceiving changes in the selected stocks. All fishers acknowledged abundance to either decrease or remain the same, when present abundance was compared to the abundance when fishers first started fishing. However, only Japanese scads, narrow-barred Spanish mackerels and rays showed a significant change in perceptions (Table 5.4), whereby experienced fishers acknowledged a greater depletion since when they first started fishing, compared to less experienced fishers. A significant trend in this figure, however, does not indicate an abundance decrease, only that there is disagreement between fishers of differing fishing experiences.

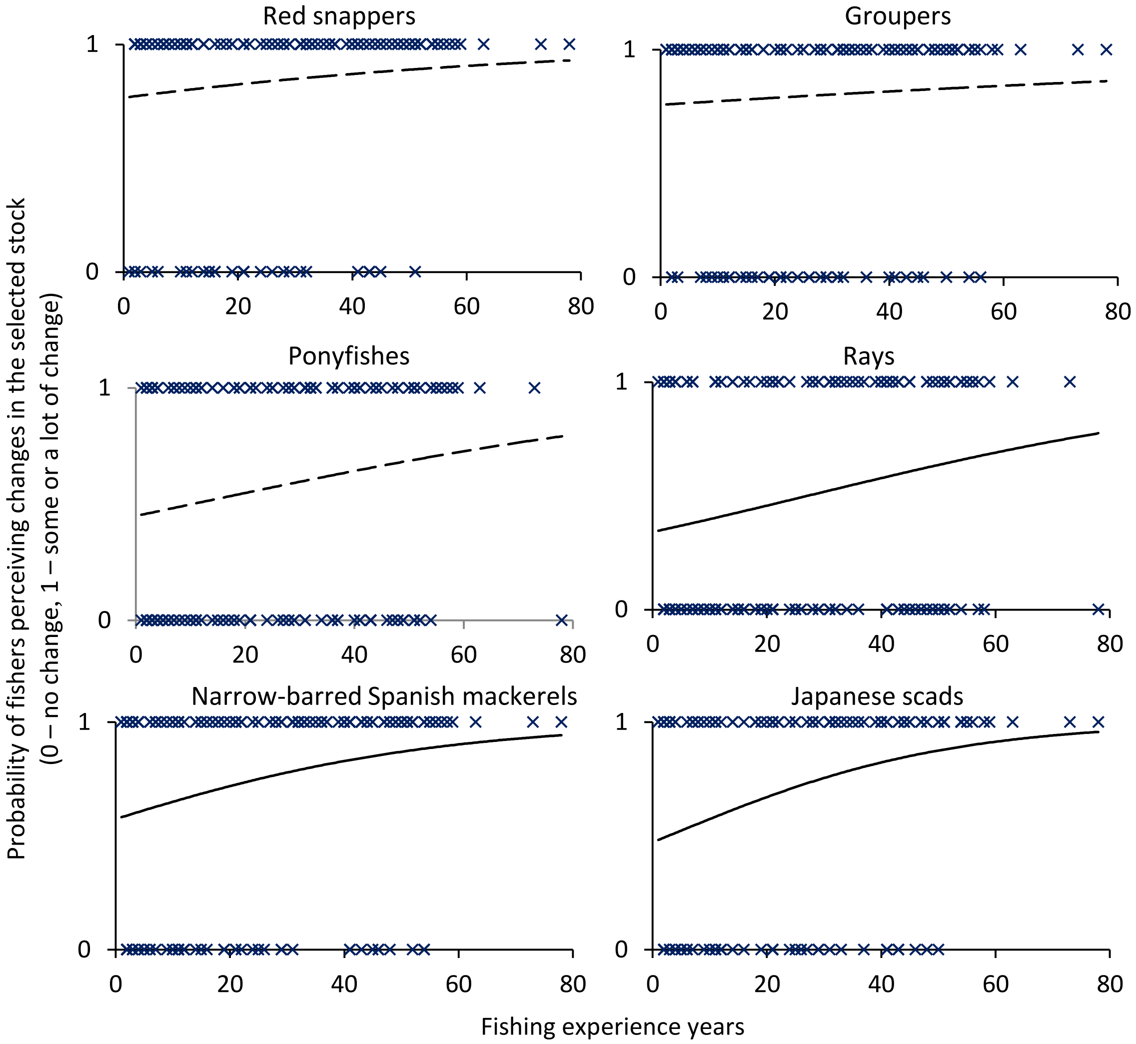

FIGURE 5.9: Evidence of shifting cognitive baselines in Brunei fishers. Y-axis shows the probability of fishers perceiving some change in abundance between when they first started fishing and present; X-axis shows fisher experience. Solid lines represent significant logistic regression model. 'Some or a lot of change' corresponds to a reduction from 'high' to 'low', 'high' to 'medium' or 'medium' to 'low' category of abundance in the interview, and presented as 1 in the logistic regression.

TABLE 5.4: Effect of fishers' experience (β) on their perceived change in abundance between the time when they first started fishing and present, quantified using logistic regression analysis. Significant p-values are in **bold**.

Species group	$\beta_{experience}$ coefficient in model	Standard errors	Wald χ^2 test	d.f.	p-value
Red snappers	0.018	0.012	2.313	1	0.128
Groupers	0.009	0.010	0.769	1	0.381
Ponyfishes	0.012	0.008	1.910	1	0.167
Rays	0.024	0.008	8.910	1	**0.003**
Narrow-bared Spanish mackerel	0.032	0.010	9.498	1	**0.002**
Japanese scads	0.041	0.011	12.840	1	**<0.001**

5.3.2 Change in abundance of selected stocks from fuzzy logic output

Change in relative abundance determined from the fuzzy expert system for all six species groups are presented in Figure 5.10. Despite the wide confidence intervals, there is a consistent trend of sudden decline in relative abundance in the 2000s. This is in agreement with published surveys which have shown that Brunei fishery was lightly exploited up till end of the 1990s (see Discussion, Section 5.4.2). Abundance scores from the fuzzy expert system revealed that the abundance of both snappers and groupers species declined the most compared to other species (relative score in 2000s < 0.3).

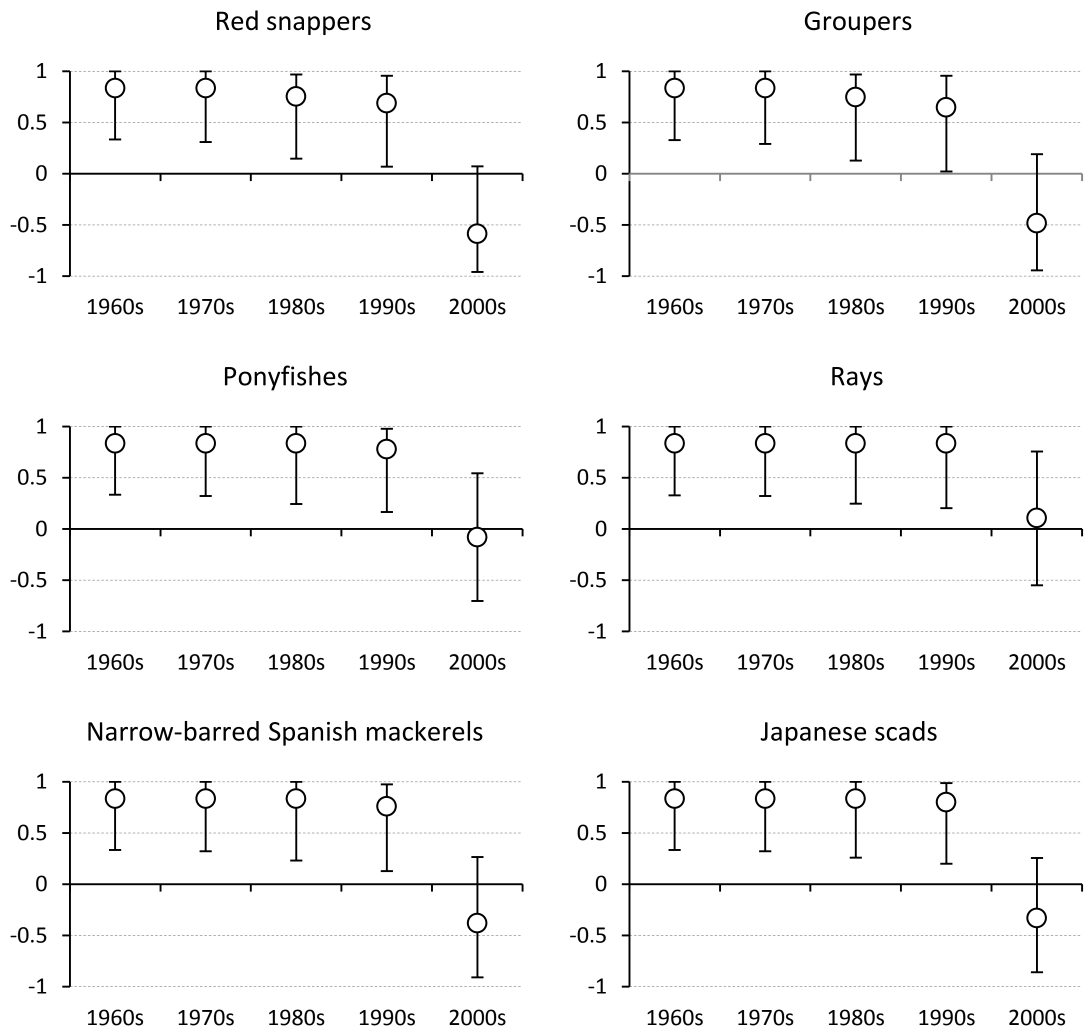

FIGURE 5.10: Relative abundance of selected stocks in Brunei over five time periods from fuzzy logic algorithm. Zero on the Y-axis corresponds to the centroid of the 'medium' abundance category in the defuzzification membership function. Error bars show weighted average based on upper/lower range of membership function, rather than centroid.

5.3.3 GIS outcomes as indicators of spatial and temporal patterns of red snapper distributions and fishers' fishing activities

The distribution of red snapper based on fishers' LEK is shown in Figure 5.12, which revealed that patches of high presence possibility were associated with areas of higher complexity, where reefs, shipwrecks and oil platforms are found. These areas are mainly present in the shallow waters of Brunei, which corresponded to Zone 2 of Brunei fishing zonation. Accordingly, these reported harvesting sites are located at depths between 1 m and 111 m, and were significantly clustered (average nearest neighbour test; nearest neighbour ratio = 0.516, *z*-score = -13.85, p-value = <0.001) throughout the study area. The majority (9.7%) of the reported red snapper harvesting locations occurred within 3 km of Lumut reefs (Figure 5.11).

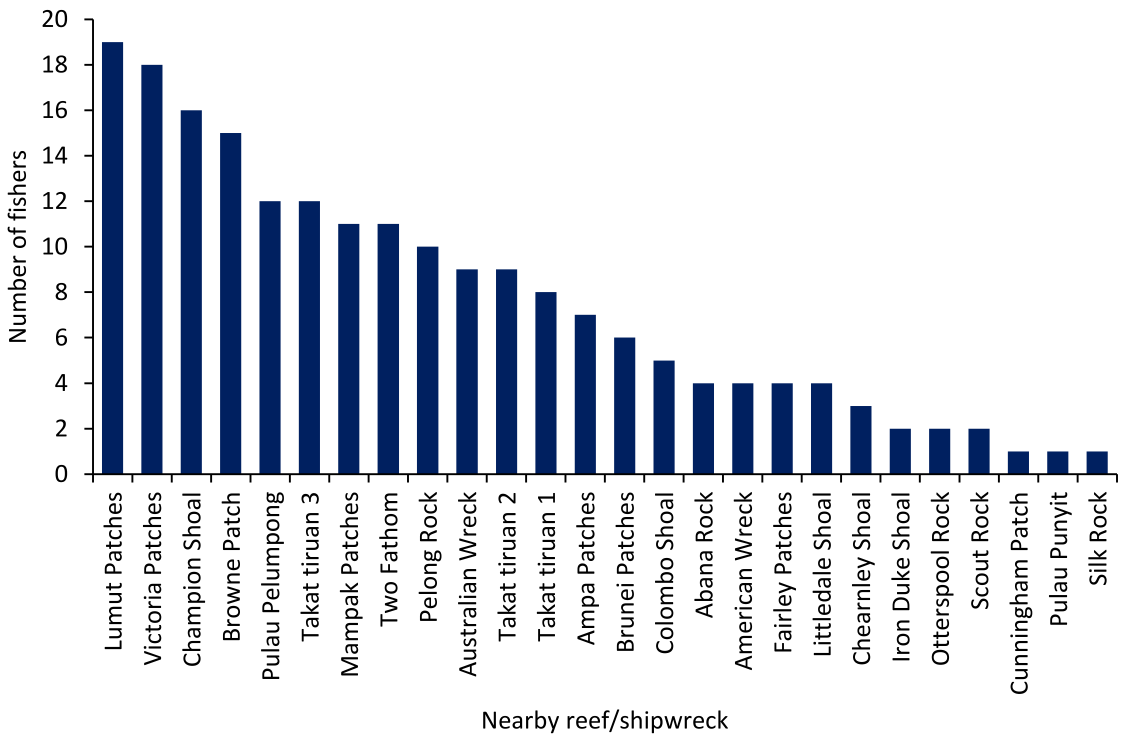

FIGURE 5.11: Nearby major natural / artificial reefs or shipwrecks associated with the reported red snapper harvesting location in Brunei waters.

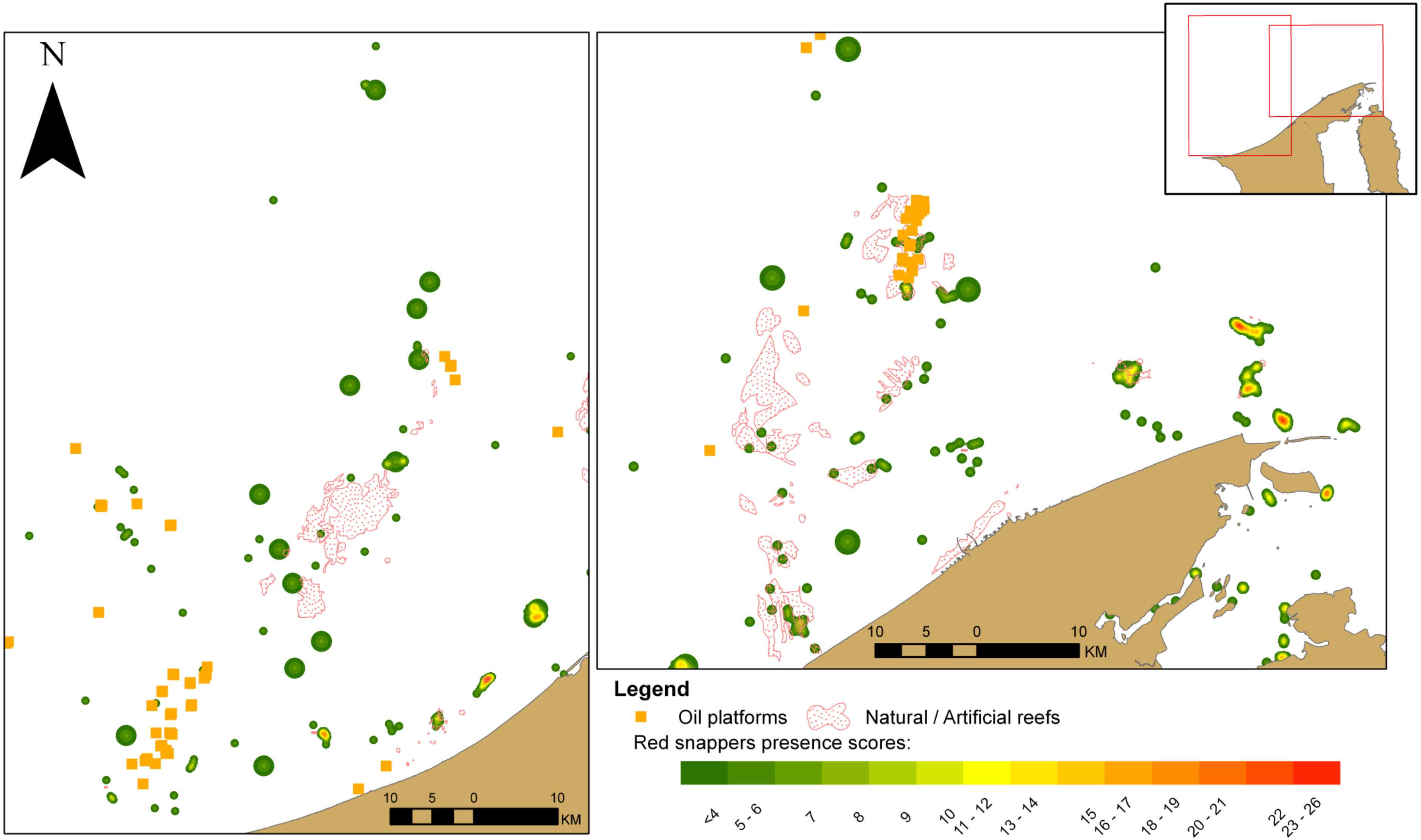

FIGURE 5.12: Mapping LEK. Distribution of red snapper presence scores based on fishers' LEK in Brunei (i.e. harvest location of best day's catch).

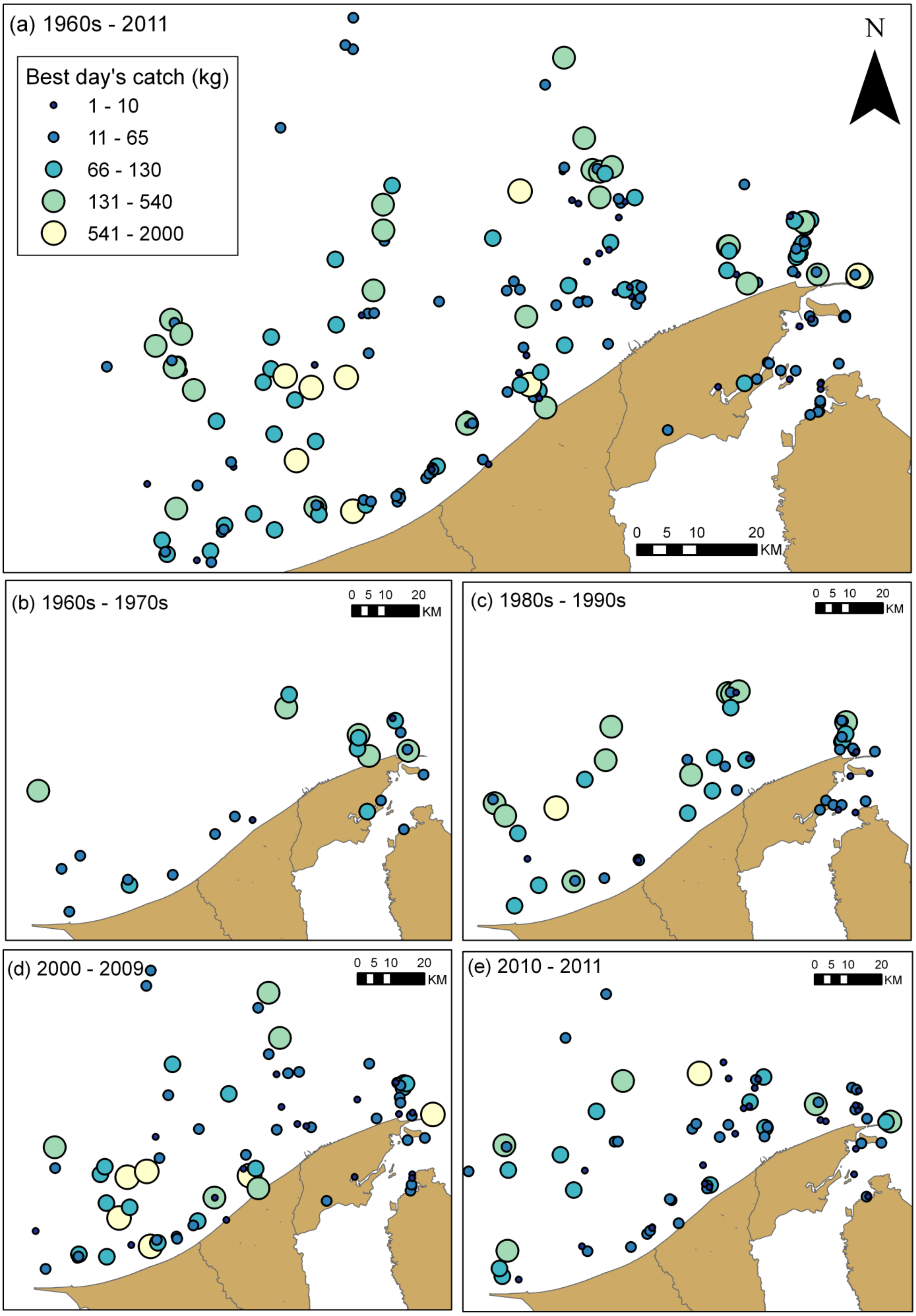

FIGURE 5.13: Spatiotemporal pattern of fishers' best day's catch in Brunei for: (a) all data combined; (b) 1960s-1970s; (c) 1980s-1990s; (d) 2000s; and (e) 2010-2011.

Red snapper distribution can be grouped into four main areas of unequal size: (1) Brunei Bay, (2) waters off Brunei-Muara district to just east of Kuala Tutong, (3) waters off Belait district as far as Kuala Tutong, and (4) deeper waters off the continental shelf (Zone 3). Mean best day's catch differed between the four main areas over the years (two-way ANOVA; $F_{8,215} = 5.915$, $p < 0.001$), with a relatively higher best day's catch occurring in waters off Belait district (Figure 5.13; post-hoc LSD test, $p < 0.05$ for Area (3) against all other areas). Eight fishers recalled catching ≥ 1000 kg of red snappers on their best day's catch – the majority (62.5%) of this occurred near reef patches found in the waters off Belait district.

Figure 5.14 shows the results of the high-pressure harvest area (HPA) analysis. Although fishers operate over a wide-ranging area, the fishery essentially focuses on the eastern side of Brunei waters. The calculated potential harvest area for fishers interviewed in this study was 4 588.5 km^2, encompassing 53.4% of Brunei's continental shelf area of 8 600 km^2 (or 11.9% of Brunei's total marine territory area of 30 000 km^2).

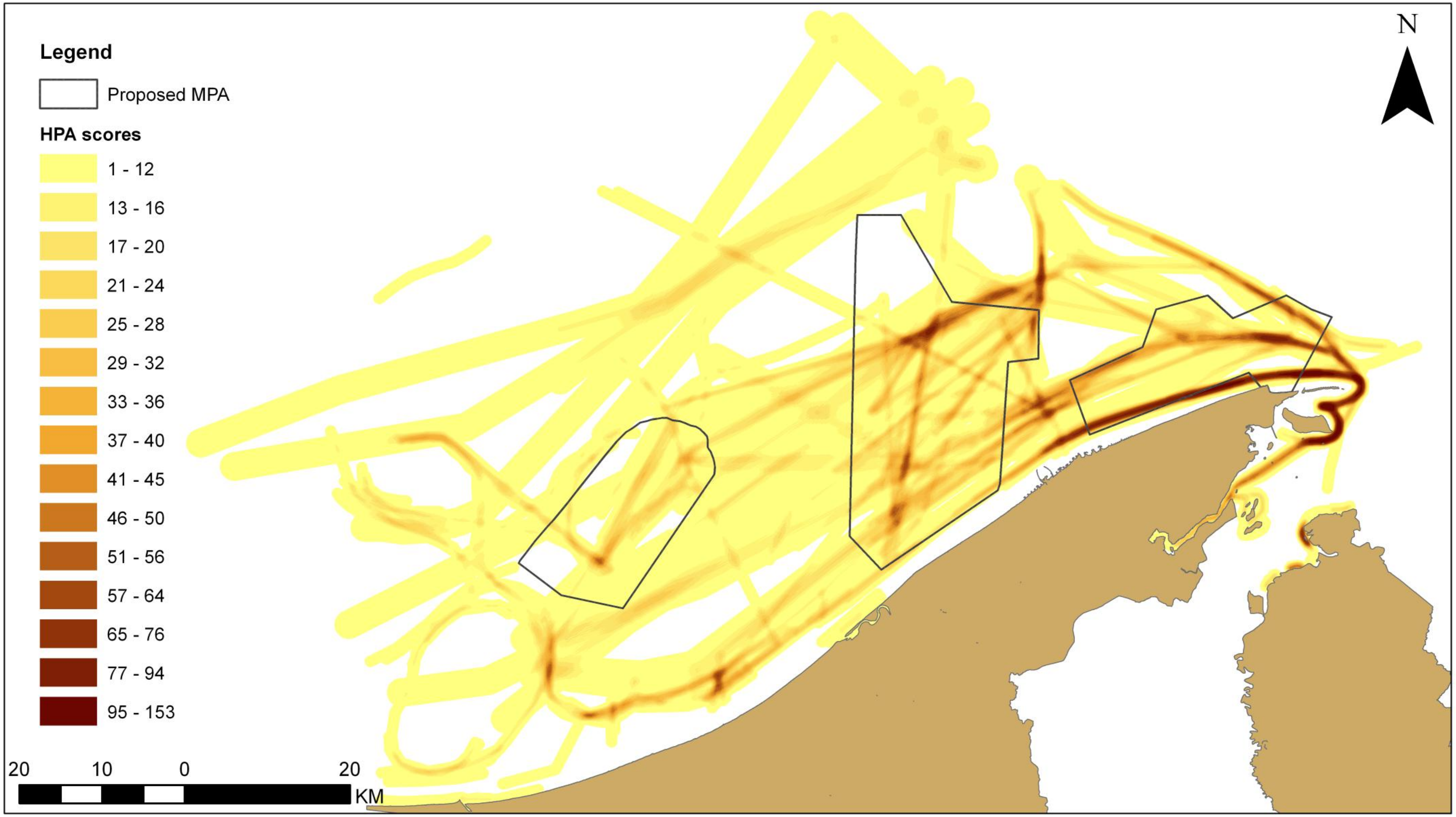

FIGURE 5.14: Distribution of high pressure harvest area (HPA) based on 236 fishers' most frequently visited sites. The proposed marine protected area (MPA) will be a 'no take' MPA, to be implemented soon.
(Note: Based on a press statement released by DOF in September 2011, the MPA would be fully operational by January 2012, although currently (April 2013) it has yet to be implemented).

Summary statistics of HPA scores are shown in Table 5.5 and Figure 5.15. The distribution is right-skewed, with more values in the lower range, suggesting a relatively dispersed pattern of fishing activity, as would be expected in a mixed fishery deploying multiple gears. If the fishery had only a very small number of locations where fishers visited frequently, then a left-skewed distribution of HPA scores would have been expected, since fishers would be visiting the same locations. Median and upper quartiles of HPA scores were used as a threshold to identify the highest-pressure harvest zones, which covered an area of 233.29 km^2 for scores >36 (HPA36) (2.7% of Brunei's continental shelf area) or 77.72 km^2 for scores >54 (HPA54) (0.01% of Brunei's continental shelf area).

69.1% (828 km^2) of the potential harvest area was found to fall within the newly proposed no-take marine protected areas (MPAs) of Brunei waters, of which 8.8% and 2.6% were HPA36 and HPA54, respectively.

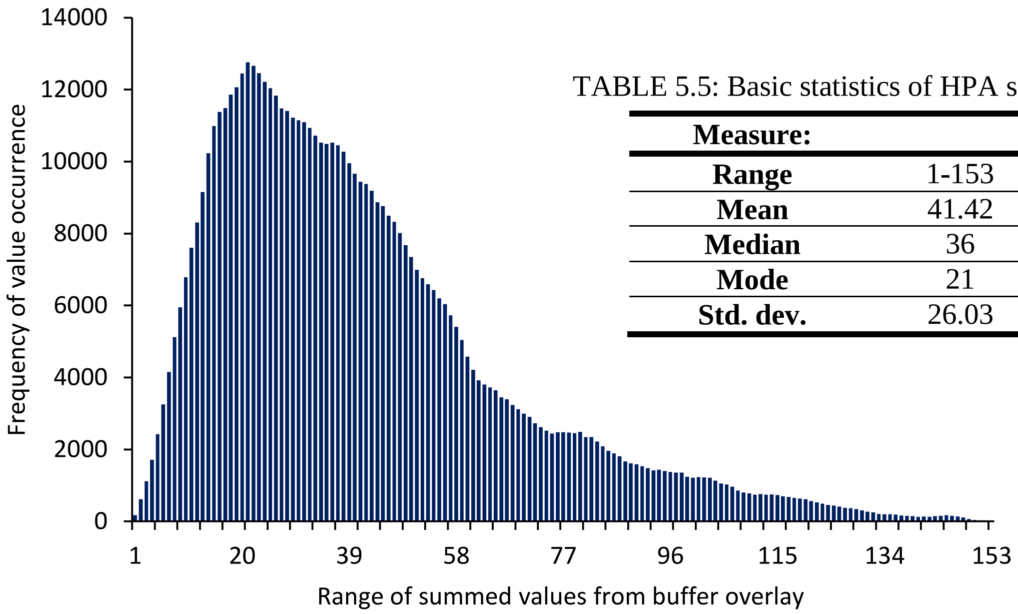

TABLE 5.5: Basic statistics of HPA scores

Measure:	
Range	1-153
Mean	41.42
Median	36
Mode	21
Std. dev.	26.03

FIGURE 5.15: Range of HPA scores generated for Brunei waters using 236 fishers' most frequently visited sites.

5.3.4 Qualitative assessment of fishers' opinions on current fishery management in Brunei

Fishers' comments on current management practices for Brunei marine resources can be divided into two main groups; approximately 20% of fishers gave either a short positive comment (e.g. "everything OK") or provided elaborate positive viewpoints (e.g. "it is good that the local authority have deployed artificial reefs in our waters"). The majority (65.6%), however, had negative comments on the local fishery authority and current management practices. Fisher comments can be further divided into eight themes, summarised in Table 5.6.

TABLE 5.6: Fishers' negative comments on the local fishery authority and current management practices in Brunei were assessed qualitatively and divided into eight themes. Note that the proportion of interviewed fishers will not add up to 100%, since a fisher may comment on more than one issue.

Themes	**Proportion of interviewed fishers (out of all 259 fishers)**
Gear conflicts	33.2%
Poor enforcement	18.1%
Lack of communication (difficulty in communicating with DOF)	14.3%
Unfair treatments (for SS fishers)	14.3%
Poorly managed artificial reefs	11.2%
Poorly maintained/Lack of landing sites	8.9%
Licensing issues	2.7%
Others: Lack of fish price control Conflicts near borders Demand subsidies	3.5%

5.4 Discussion and Conclusion

This study presents the first quantified evidence of the SBS based on fishers' perceptions in Brunei. It underlines the importance of tapping into LEK, which can make a valuable contribution to the body of scientific knowledge concerning marine stock status. The systematic collection of LEK of fishers in Brunei has generated useful guidelines for compiling such knowledge, and has also demonstrated a perceived decline in abundance of marine resources in Brunei, especially in the last decade. More importantly, this study also serves as a digital archive for an important knowledge resource which would otherwise be lost if it was never assembled (Johannes, 1998).

The sample size (259 fishers) used in the interview survey is considered to have provided a fair representation of fishers views in Brunei, representing just over 10% of the total number of recorded fishers in Brunei in 2010.

5.4.1 Extracting Brunei's local ecological knowledge on fishery

In this study, level of fishing experience (measured in years spent fishing), rather than fishers' age is used as an explanatory variable. Although both variables are highly inter-correlated, fishers' experience was considered a better indicator, especially in the context of Brunei's fishing community structure. In Brunei, the majority of young fishers are foreign labourers employed specifically to fish, while some of the older fishers are civil servant/army retirees who may have only started fishing recently, may not have a great level of fishing experience and/or fishing may not always have been their livelihood.

The Code of Conduct for Responsible Fisheries, formulated in 1995 by FAO, highlights the need to investigate and document traditional fishery knowledge and to assess its application to the sustainable conservation, management and development of fisheries (Article 12.12). Brunei has a long fishing tradition and European records as far back as the sixteenth century attest to the significance of fisheries as a socio-economic activity in Brunei (Silvestre and Matdanan, 1992). However, due partly to the favourable economic circumstances of a high GDP ever since the 1970s, the total number of young local fishers is declining due to more comfortable, land-based alternatives (Silvestre and Matdanan, 1992). In an earlier study of LEK, Pilgrim (2006) pointed out that as level of economic development increases and resource dependence of a community decreases, the rate of knowledge acquisition tends to diminish, thus resulting in a progressive loss of LEK in the younger generations. Therefore, in areas where few written records are kept, important knowledge about natural resources may die with each generation unless someone records it, since conventional biological field research is unlikely to recover this information.

One example of such knowledge is on the types and numbers of species mentioned as depleted by the fishers. Just as in Rodrigues, Mauritius, where there were some species of fish about which the younger generations in the fishery community had little or no knowledge (Bunce *et al.*, 2008), about half of all species in Brunei mentioned as depleted in this study had not been identified by the least experienced fishers. These findings, in accordance with other studies (Johannes and Yeeting, 2001; Dulvy and Polunin, 2004; Saenz-Arroyo *et al.*, 2005b), demonstrate that interviews with older or more experienced fishers can be a useful means of identifying declining species and confirming the disappearance of exploited species, potentially in time for conservation action. Also extracted from the interview surveys were traces of traditional management systems mentioned by experienced, older fishers. These fishers, all from the traditional fishing village of Kampung Setia B, commented on the disappearance of the customary practice of '*bagi makan laut*' (literally means 'letting the sea eat') usually carried out by a *sharif* (a hereditary title for Arab descendants, traditionally believed to possess great religious knowledge and hence, the expertise to perform rituals to safeguard the sea from bad omens). The time to *bagi makan laut* was usually determined by village elders who would have extraordinary traditional knowledge of biophysical and biological resource characteristics. During this period, fishers were prohibited to fish, and such rules were easily enforced, as fishers believed them to be sacred. The underlying myth was in fact based on scientific rationales, as seasonal closures are known to enhance fish stocks (Hilborn and Walters, 1992). Although the practices may not be as explicit as those observed in many oceanic island communities, such as in North Lombok, Indonesia (Arif, 2007) and in Vanuatu (Hickey, 2007), the practical outcomes of these beliefs and values may have induced an effective system for the sustainable management of marine resources. An important point, however, is that such wisdom and knowledge had been well-maintained because it was handed down through generations. However, with the loss of traditional LEK, such practices are becoming rapidly eroded, and in some places stocks have dwindled (Johannes, 1981a; Mulrennan, 2007).

Interview results from this study also highlight potential difficulties in composing suitable questions for extracting LEK by interviewing fishers. First, the interview design had to be simplified because, generally, the initial question sequence was too long to retain interest and attention of respondents. Moreover, some of the fishers were approached just as they arrived from the sea and, while it may be preferable to conduct the interviews at times that are most convenient to the fishers (e.g. at fishers' home), logistical constraints precluded more extensive survey. In any interview survey, trade-offs between number of questions asked, number of interviewees consulted and survey duration are inevitable (Bunce *et al.*, 2000; Venkatachalam *et al.*, 2010).

Secondly, a common problem when conducting interviews is that fishers may interpret questions quite differently from the way they were intended by the interviewer (Meeuwig *et al.*, 2007). In this study, fish stocks that were ecologically classified as demersals were poorly defined, so when fishers were asked about the changes in abundance of demersal fish specifically, they were referring to changes in abundance of fish in general. The results can be easily misinterpreted if care is not taken to consider the answers in the light of fishers' perceptions and experience.

Consequently, it is also important to cross-reference interview results against other sources of information. For instance, one important body of LEK, particularly in tropical waters, concerns reef fish spawning aggregations (Morris *et al.*, 2000). Although not part of the key questions, and hence not probed further during the interviews, the outcomes pertaining to fishers' harvest sites for best day's catch of red snapper in the interview had implied a spawning aggregation in the waters northeast of Southwest Ampa oilfield, where fishers reported red snappers catch of up to 2000 kg in this area (Figure 5.12). Extreme reports of high catches may have created suspicion of exaggeration by the respondents. However, when the data were presented as number of red snappers (e.g. assuming that the total weight of 2000 kg could result from 505 aggregating individual snappers at 3.96 kg (mean from this study) each), the fishers' answers fell within the range previously reported for Brunei (see Chou *et al.*, 1992). Adding to this belief may be the type of gear used when these catches were made – fishers that reported their best day's catch of ≥1000 kg all recounted using either a purse seine (*pukat lingkong*) or a ring net (*ancau*); both are 'surrounding nets' based on FAO's definition and classification, a roughly rectangular net without a distinct bag that is set vertically in water to surround the school of fish, although generally of pelagic nature. Possibly, these fishers had encountered red snapper spawning aggregation, since reef fish species such as snappers and groupers are well known to form spawning aggregation at the same location, season and moon phase each year (Arreguín-Sánchez *et al.*, 1996). Like other small, local stocks, many of these aggregations are highly vulnerable to rapid depletion, or complete elimination (Johannes *et al.*, 1999; Morris *et al.*, 2000). Considering the generally limited knowledge on fish reproduction in the scientific literature, clues from fishers concerning spawning periods and potential aggregation sites could potentially be useful for either defining periods of closed fishing activities or designing MPAs (Johannes and Neis, 2007). Further research could be undertaken in order to confirm these potential spawning sites, especially since these sites are not included in the newly proposed MPA.

In fact, research on the spatial heterogeneity of ecosystems for fishery management has typically focused on biological processes of the environment. The network of MPAs for Brunei proposed by DOF just over a year ago resulted from three comprehensive marine biodiversity assessments (DOF-pers.comm.). Meeting the challenge of place-based ecosystem management such as MPAs, however, will require an improved understanding of the human use patterns in the marine environment, by highlighting areas of intense use or areas where multiple activities are occurring (Moreno-Báez *et al.*, 2012). This study uncovers potential fishing 'hot spots', visualized in map form and this information is neither extremely difficult nor time consuming to produce, yet serves as a potentially important complement to the collection of scientific data in the area.

This study also confirms the occurrence of territorial and gear conflicts between fishers of different areas and sectors, as predicted by Beales *et al*. (1982) and identified by Silvestre and Matdanan (1992) and the national fishery authorities (Ranimah, 2008). However, of particular significance, are the potential conflicts between fishers, and scientific, or bureaucratic, perspectives on marine resources, as more than half of the total area legally established for the new no-take MPAs is used frequently by current fishers.

Although differences in perspective are common in fisheries (Gray *et al.*, 2008), the current study revealed that fishers had more optimistic perceptions of stock abundance than suggested from analysis of official scientific data. While this is not surprising considering the spatial and temporal dynamics of fishers' exploitation activities and the way these influenced their observations and related perceptions (Murray *et al.*, 2008), existence of such divergent view itself may create problems whereby fishers may not be supportive of introducing effort or catch controls, or the limited entry to the fishery. Lack of trust between fishers and the national fishery institution was certainly evident from the interview survey – one of the main themes identified from qualitative analysis of interview data was a lack of effective communication between fishers and the fisheries authority. Furthermore, fishers were more hesitant to talk to researchers, perhaps for fear of reprimand or other repercussions (Close, 2003), if they thought that the researchers were working for the fishery department, despite assurances of anonymity and confidentiality beforehand. Evidently, fishers were more willing to freely share their knowledge and voice their views when they were notified that the interviewers were independent student researchers. Just as study of fishers' knowledge of resource complexities is seen as high priority, and potential means of reducing the likelihood of conflicts, equally important is the public outreach of scientific data to allow fishers and their knowledge to become effective and integrated counterparts in fisheries science and management (Johannes and Neis, 2007). It has been shown in Newfoundland, Canada how fishers began to see how a more 'scientific' approach to record keeping could improve their own fishing performance (Murray *et al.*, 2006). Similarly, fishing-rights owners in Vanuatu had willingly sacrificed considerable short-term catch benefits by subscribing to extended moratoria of up to 15 years on fishing for certain species. They were assured that the benefits of making such a sacrifice would accrue to them directly, despite the risk linked to accepting such a long term view (Adams, 1998). Needless to say, such collaboration will depend very much on the degree of trust between fishers and fisheries authorities, including scientists who are expected to fill in the gaps in knowledge about past, present and future state of the fishery (Hilborn and Peterman, 1995).

5.4.2 Evaluating past abundance of Brunei fishery resources

One significant advantage of a fuzzy logic approach is that it provides a transparent method for interpreting linguistic descriptions of abundance as perceived by the fishers (Ainsworth *et al.*, 2008). Inevitably in this study, the fuzzy logic algorithm was only used as a method of deriving numerical trends from ordinal LEK data, despite its capacity to integrate various data streams to reconstruct a composite time series of species abundances (Ainsworth, 2011). While the trends shown are relative, at least two other studies had demonstrated that it was possible to develop absolute trends by scaling the relative outputs to match the available partial time series from scientific sampling (see Ainsworth *et al.*, 2008; Lozano-Montes *et al.*, 2008). This was not feasible in the current study, due to the lack of reliable survey information specific to the study area, as well as the lack of permission to carry out a more detailed study using unpublished data collected by the DOF.

By synthesising data contained in anecdotes and fishers' memories, this study has reaffirmed the relatively high abundance of Brunei fishery resources, at least up to 2000, in the literature. Silvestre and Garces (2004) reported that Brunei fishery resources were still lightly exploited based on the demersal trawl surveys carried out between 1989 and 1990. Using regression modelling, Christensen *et al*. (2003) has shown that the predicted fish biomass of trophic level ≥ 3.0 in Brunei in 2000 was roughly 80% of its predicted biomass in 1960. In comparison, the predicted fish biomass in the neighbouring countries in 2000 was calculated to be between 7 – 33% of its predicted biomass in 1960 (Christensen *et al.*, 2003).

Estimates of relative abundance of the different species group for the 2000s suggested that large demersal stocks (i.e. snappers and groupers) had declined the most, followed by large pelagics (narrow-barred Spanish mackerel), small pelagics (Japanese scads), small demersal (ponyfishes) and rays. These outcomes seem logical and consistent with the life history information for the different species groups in the literature. For example, the perceived decline in Japanese scads and ponyfishes are less substantial than that of large demersal stocks (i.e. red snappers and groupers), perhaps because both scads and ponyfishes are known small-bodied *r*-species which have short generation times that favour rapid adaptation (Munday *et al.*, 2012; FishBase, 2012). On the other hand, the substantial decline in snappers and groupers may reflect the fact that these *K*-species groups, which generally have restricted breeding ground, are highly vulnerable to fishing and thus could be rapidly over-exploited over a short period of time.

For red snappers, this is further supported in this study by the significant correlation of both the best day's catch and largest fish ever caught, not only with the period of fishers' experience, but also with actual years. Worryingly, the real scale of these reductions could also be much greater than reported since large catches remain possible so long as there are still unexploited or lightly fished areas (Saenz-Arroyo *et al.*, 2005a; Saenz-Arroyo *et al.*, 2005b). Remarkably, this trend seems inconsistent with the scientific outcome from official fishery statistics (Chapter 4), which do not point to any discernible resource decline. Yet, there is clear evidence of resource decline using information reported by fishers, which strongly suggests that harvests were higher in earlier decades. Invariably, and perhaps understandably, the fishery authorities rely mainly on fishery catch statistics to inform decisions about stock size and state of fishery. As this and other studies (Saenz-Arroyo *et al.*, 2005a; Venkatachalam *et al.*, 2010) have shown, however, patterns derived from short time series can be inaccurate. Fishery management decisions that augment scientific data with records drawn on long-term information, even if the only source available is reports from fishers, may still be better and more robust that decisions, actions or outcomes reliant on short-term scientific information alone.

5.4.1 State of 'shifting baseline syndrome' in Brunei

Although relatively inexpensive and easy to carry out, care must be taken in collation and use of opinion based knowledge (Venkatachalam *et al.*, 2010; Daw *et al.*, 2011). Of particular significance is the potential for recall bias, which remain a challenge when using memory-based perceptions of trends, particularly in the absence of records or repeated surveys.

Few studies on uncovering the cognitive processes of memory and recall bias currently exist in fishers' LEK literature (e.g. Saenz-Arroyo *et al.*, 2005b; Bunce *et al.*, 2008; Venkatachalam *et al.*, 2010). All these studies, although claimed to have found field evidence for Pauly's 'shifting baseline syndrome' (Pauly, 1995), had, in fact, demonstrated 'generational amnesia', a mechanism in which individuals setting their perceptions from their own experience, and failing to pass their experience on to future generations, and hence, as these observers leave the system, the population's perceptions of normality updates and past conditions are forgotten (Papworth *et al.*, 2009).

Essentially, a range of different mechanisms exist which can either mask or exaggerate perceived trends at a community or individual level. However, for SBS to occur, in addition to the presence of age- or experience-related differences in perception, biological change must be present in the system (Papworth *et al.*, 2009). In this study, fishers' perceptions of trends in the abundance of the six selected stocks had revealed three mixed results on the state of SBS for Brunei;

(1) Fishers' perceptions of the narrow-barred Spanish mackerel and ray stocks showed a classic example of SBS where the age- or experience-related perceptual change corresponded with decreasing catches from official fishery data (see Chapter 4 for ray, Appendix 5.5 for mackerel).

(2) In fishers' perceptions of Japanese scads abundance, the results suggested that declining trends may be exaggerated or incorrectly perceived, especially since the official catch data revealed that recent catches were larger (Appendix 5.5). Influential memory of extremely good catches in earlier years may have created 'memory illusion', whereby fishers would inaccurately remember past conditions and recall change where there was none, or vice versa (Papworth *et al.*, 2009). Thus, it is likely that SBS is absent in fishers' perceptions of these stocks.

(3) Fishers' perceptions of the demersal stocks (ponyfishes, red snappers and groupers) implied absence of SBS as there were no significant differences of perceived changes between fishers of various experience years.

Knowledge of SBS is important considering that the use of LEK for assessment of system state and dynamics is becoming more common. If SBS does occur, one may need to take into account the inherent bias associated with these sorts of data, especially since biases are expected to increase with the length of time over which respondents are asked to remember (Daw *et al.*, 2011). In addition, SBS can present a problem when setting conservation goals for ecosystem or fish stocks regeneration, as perceptions of past change may influence target setting, particularly when biological data are not readily available (Saenz-Arroyo *et al.*, 2005a; Venkatachalam *et al.*, 2010).

As a result, it may be interesting to note from this study that fishers' perceptions of how abundant the three demersal stocks were in the past are likely to be more accurate than may have commonly been thought. This seems contradictory to previous studies on fishers' SBS which suggested that the true magnitude of stock decline is always not well appreciated by those who rely on the resources (Saenz-Arroyo *et al.*, 2005b; Bunce *et al.*, 2008; Ainsworth *et al.*, 2008; Venkatachalam *et al.*, 2010; Ainsworth, 2011). Except for rays, all the other stocks are targeted species which fishers' depend on for their livelihood. Perhaps if fishers are more aware of the creeping disappearance of resources, such as in the case of demersal stocks, transfer of LEK across generations may be more effective. In contrast, it may be that due to the migratory nature of the pelagic stocks, the fishers are less likely to acknowledge decline if they believe that the stocks 'have just gone somewhere else, and will be back' (Johannes and Neis, 2007). Undeniably, further research is required to test this, as well as to investigate factors which could bias trend perceptions.

5.4.2 Concluding remarks

This study addresses the need for more inclusion of fishers' LEK in the management of fisheries, and represents the first attempt to process and apply LEK data to elucidate abundance trends of the six species groups in Brunei. The study also demonstrates that LEK can provide an invaluable and rapid means of highlighting issues that need further consideration and research. Although such knowledge may not equate to scientific "truth" – as it is based mainly upon perceptions – LEK may contain clues to aid fisheries management in relatively data-poor countries such as Brunei. More importantly, however, this study supports the suggestion that Brunei marine ecosystem seems to have experienced rapid significant changes in the last 10 years.

Chapter 6
General Discussion – Towards sustainable management of the demersal fisheries of Brunei Darussalam

"The world is beautiful and verdant, and verily Allah, be He exalted,
has made you His stewards in it, as He sees how you acquit yourselves."
– Prophet Muhammad (PBUH)

Chapter Summary

To ensure continuity of its demersal fishery resources, sustained effort to effectively manage the fisheries of Brunei is necessary. At present, the overall goal of Brunei's fisheries management is the "sustainable development of (coastal) capture fisheries… towards optimization of benefits to the nation". To assist in achieving this goal, the current legal framework in Brunei has covered most aspects of fisheries, including jurisdiction, management, development and delegation of responsibilities. Despite the good intention of the fisheries laws, and in light of the findings set out in this thesis, there remain issues in implementation to achieve the sustainability of fish resources. Particularly, in relation to the continued open access nature of the fisheries, as well as the inadequate capacity of the institution both in enforcing regulation and carrying out timely applied research. Improved monitoring, assessment and management approaches are required in order to move progressively towards sustainable demersal fishery development.

6.1 Introduction

With an ever increasing human population, the issue of resource scarcity has caught the attention of policy makers, academics and the general public. Due to their potential to regenerate, fishery resources have been categorized as renewable resources, similar to forest and grazing pasture. However, they cannot regenerate under all circumstances and their potential to regenerate is limited and conditional on how much of the resource is taken and how much is left in the water. It is this basic idea that underlines the need to understand the resources and factors influencing their variability, both natural and man-made.

Assessment of fisheries has evolved through different phases over time, in parallel to the changing perceptions of the resources. A century or more ago, it was widely believed that the resources of the sea are infinite and that fishing could go on indefinitely (Costanza, 1999). Now, many have acknowledged that most major stocks of the oceans are declining and exhibit serious depletion problems (Myers and Worm, 2003; FAO, 2012b). Many different fishery assessment tools have been developed and it is likely more will be developed in the future, to address specific questions, pertinent at the time of their development. However, these assessment approaches develop not solely out of the questions asked, but also depend on the resources available to accomplish the task and their applicability to the circumstances on which they are to be used. Accordingly, it is within such context that the demersal fishery resources of Brunei Darussalam were assessed in this thesis.

In this chapter, findings from the study presented in the preceding chapters are synthesised together with other information to explore possible approaches that should be taken in the management of demersal fishery resources, and their implications on the sustainability of the fisheries in Brunei. The current institutional framework and fishery management objectives are reviewed, some of the key issues are identified and several options and/or recommendations are presented.

6.2 Managing the demersal fishery resources of Brunei Darussalam

Through an objective analysis of the stock situation with regard to demersal catches from Brunei marine ecosystem, it has been shown in this thesis that significant changes have occurred to the structure of the fish community, particularly since 2000, with an underlying decreasing trend for the overall demersal stocks abundance. Although some of the issues concerning demersal stocks are not new to the fishery authorities in Brunei, they may have not been presented as comprehensively as done here, and were rather speculative in the past. To ensure continuity of the demersal fishery resources, it is essential that sustained effort is made to manage the demersal fishery of Brunei.

6.2.1 Legal and institutional framework

As briefly mentioned in Chapter 1, the Department of Fisheries (DOF) is the line agency responsible for a variety of functions which includes fisheries research, development and management. The current fisheries law which defines the authority and functions of DOF is the Fisheries Order of 2009, which recently repealed the Fisheries Act of 1972 and section 4 of the Brunei Fishery Limits Act of 1983, and amended the Fisheries Regulations of 1973.

According to the Order, the organisational structure of DOF is headed by a Director who prepares fisheries plans designed to ensure the optimum utilisation of fishery resources. The Order has also established, among others, the framework for (1) the licensing system, (2) the establishment of lobster fishing areas, marine reserves and marine parks and restrictions related to these areas, (3) the development and management of inland fisheries, and (4) the types of offences, penalties and powers of enforcement officers.

6.2.2 Objectives of fisheries management in Brunei

One of the essential requirements for effective fisheries management is the general arrangements of goals and objectives, to allow development of strategies in achieving the goals and objectives, rational allocation of human and resources, and prioritization, weighting and balancing of choices when there are conflicts (Barber and Taylor, 1990). In Brunei, the overall goal of fisheries management is the "sustainable development of (coastal) capture fisheries… towards optimization of benefits to the nation" (Silvestre and Matdanan, 1992; DOF, 2011).

Nevertheless, fisheries management objectives are usually different from more general fisheries goals, whereby they are more verifiable, specific and quantifiable. They often have a performance measure attached by which the management agency can evaluate progress and effectiveness in meeting the stated objectives (Barber and Taylor, 1990). In the 1990s, DOF had identified and adopted the following specific objectives for fishery management in Brunei (Silvestre and Matdanan, 1992):

(1) Increased production and efficient utilisation of capture fishery resources towards greater self-sufficiency.
(2) Upliftment of the socioeconomic status or well-being of participants in capture fisheries; and
(3) Provision of a stable supply of fish and fishery products at reasonable prices

However, these objectives were formulated then, based on the available assessments and studies of variable scope and reliability. More recently, while DOF still uphold the attempt to optimize productivity or efficiency of the fisheries exploitation regime as one of its management objectives (i.e. objective number 1), they have replaced the other two earlier objectives. Currently, the other two objectives of fishery management in Brunei are (DOF, 2011):

(1) To ensure that the benefits of production or improved productivity are distributed equitably, and
(2) To ensure that the productivity generated results in minimum damage to the resource base and natural environment.

One of the strategies to achieve these objectives is to improve the knowledge base of the fisheries and its resources, which this study seeks to provide with respect to the demersal stocks of Brunei.

6.2.3 Current aspects of demersal fishery management

At present, management of demersal fishery is mainly directed towards limiting fishing efforts of the LS sector (especially trawlers) although the demersal stocks are also exploited by the SS sectors (Table 4.1, Chapter 4). Some of the regulations governing the demersal fishery include:

(1) *Gear controls*: the mesh size in the cod-end of bottom trawls must not be less than 51 mm, while the use of spear gun, dynamite and chemicals for fishing is prohibited.

(2) *Fishing zone specifications*: fishing vessels from LS sectors are prohibited to operate in Zone 1 (0 – 3 nm from shoreline). In addition, fishing vessels of inboard engine > 350 horse power is not permitted to operate in Zone 2 (3 – 20 nm from shoreline).

(3) *Restrictions on entry though licensing*: moratorium on new fishing licenses for LS trawlers in Zone 2 and SS fisheries in Zone 1, have been imposed since 2000 and 2008, respectively.

Although there have been improvements, compliance with these regulations is poor. For instance, fishers operating without licenses are the norm rather than the exception in the SS sector. Banned fishing practices (i.e. use of cyanides, etc.) continue to operate freely, and LS vessels are often seen fishing in the shallow waters of Zone 1, much to the annoyance and detriment of SS fishers (Chapter 5).

6.3 Key issues

There is a wide range of issues facing Brunei's fisheries industry in general and the demersal fishery in particular. However, many of them are beyond the scope of this study. Therefore, the key issues presented below are only those of which are relevant to the findings of this study.

6.3.1 Overexploitation of the fisheries resources

Trawl surveys carried out by DOF in 2006 revealed that the exploitation rate (E) (see Silvestre and Garces, 2004) of overall demersal stocks was E = 0.50, which was approximately the same as the maximum acceptable limit (E_{max} = 0.54) although higher than the biological optimum ($E_{0.1}$ = 0.36) (DOF, 2011). Despite operating around the maximum sustainable yield, stock abundance decline is evident in the past decade. The total catches of overall demersal resources remained stagnant between 2000 and 2009, while the CPUE index of abundance revealed a decreasing trend (Chapter 4). The fishery administrators claimed that the increase in both trawl and SS effort had apparently caused stock abundance to decline (DOF, 2011), yet no significant increase in trawl effort is evident over the study period (Figure 3.3, Chapter 3). This highlights the importance of choosing the right effort indicator as supported by appropriate hypothesis tests (Chapter 4). Like most fisheries worldwide, a larger proportion of the DOF effort is spent on regulating the trawlers, which are often seen to cause more harm to the resources by being relatively well-equipped with modern electronic devices, and heavier and bigger fishing gears. However, it is obvious that while an eight-meter fibreglass fishing boat used by the SS sector is considered "small-scale", its fishing capacity may be fairly "high" with two, or even three, outboard motors, and portable electronic devices to aid fishing. Additionally, their ability to easily manoeuvre over reef patches and between oil structures mean that they can simply concentrate their effort on highly productive fishing ground which may be important nursery, spawning or feeding grounds for the fish. This non-random effort distribution was apparent from the interviews with the SS fishers, which shows clustering of high-pressure harvest area (Chapter 5).

At present, the fishery authorities are rapidly developing the aquaculture industry in Brunei, which is erroneously perceived to be able to solve some of the problems posed by declining stocks, by meeting the increasing demand for seafood. However, aquaculture sometimes aggravates the problem of fisheries decline as the feed for farmed (carnivorous) fishes comes from marine ecosystems (Pauly *et al.*, 2002). Therefore, it would be advisable for the fishery management efforts to shift its focus to the SS sector instead, especially the fleet operated (SSc) sub-sector, to regulate the latent excess fishing capacity in Brunei fisheries.

6.3.2 Inadequate information on the fisheries resources

The small fishing area and unisectorally oriented legal and institutional framework in Brunei enable relatively good quality of catch data to be collected from the LS sector. Under-reporting of catches may not be an issue, which is often faced by other LS fisheries in the region. For instance, other than to compile catch statistics, catch data are also used by district governments in Indonesia to determine the amount of tax or levy that must be paid by fishing operators or vessel owners. This relationship between the catches reported by fishers and the tax payable increases the likelihood of under-reporting of catches (Prisantoso, 2011).

In spite of this, there is generally lack of consistent time series of fisheries data that are essential for making reliable stock assessments. Perhaps one contributing factor for data and information gathering to be poorly implemented is the lack of clear mandate and understanding of responsibilities on part of the DOF. The present formal top-down system could mean that at the lower levels, nobody is clearly accountable for the accuracy of data collected.

From this study, it is evident that the existing fisheries data available at national level is designed primarily for providing production statistics and not for providing data suited to science-based stock assessments. For instance, catches of several species recorded under the 'mix' categories may include catches of juveniles with a separate category for the adult stock. Also noted was the discrepancy in the local and scientific species categories in the current catch-effort data collection system between the different gears/fleet. As an example, catches of obtuse barracuda, *Sphyraena obtusata* is recorded with a local name of '*alu-alu*' in the dataset obtained from the purse seine and long line fisheries, but the same catch is categorised under '*titir*' in the trawl fishery dataset. On the other hand, both the purse seine and long line fisheries dataset had considered the local name of yellowtail barracuda, *Syphyraena langsar* as '*titir*'.

While such confusion is common even within academia (e.g. Senou, 2001), it limits the usefulness of the catch-effort data collected. For the purpose of this study, objective reasoning led the dataset to be analysed at higher taxonomic levels. In order to improve the assessment of demersal fish resources in Brunei, the fishery authorities should attempt to improve the accuracy of existing fisheries statistics.

Refining the inconsistency within the LS catch-effort data collection system accordingly may be the first step towards improvement.

6.3.3 Open access to the fisheries resources

In general, the fishery resources in Brunei may be considered to be managed in an open access manner. The resources are open to all, only requiring one to pay for the annual fishing licence and registering the vessel being used, but even these minimum criteria for entry are seldom adhered to (e.g. many fishers operating onshore are without a fishing licence). What is particularly concerning is the common misconceptions among locals that fishing licences are only for full-time fishers operating out in the sea.

In the absence of control, open access systems, whether in fisheries or in any other free-range resources, invariably become overexploited, hence leading to declining returns for all participants. Such outcome has commonly been dubbed the "Tragedy of the Commons" (Hardin, 1968). Where there is control of overall exploitation, the resources may be protected but serious social and economic distortions commonly still arise (Christie, 2004; Sanchirico *et al.*, 2002). Open access fisheries are characterised by the race to fish, whereby all participants strive to catch as much of the resource as they can, before their competitors do so. Thus, to maintain catch in a situation where resources are declining has encouraged some fishers in Brunei to use illegal fishing techniques. From the interviews conducted in this study, few of the respondents from Kuala Tutong area claimed to have witnessed others using explosives over reef patches, while a number of respondents from Temburong district reported others who may have used fish poison such as rotenone found in roots of Derris plant (locally known as '*tuba*'), as they can sometimes smell it even after four or five months. These are typical short term measures fishers feel they are obliged to adopt even though there is widespread awareness amongst them of the damage this is inflicting on the resource base and market. In fact, measures to spread awareness such as road shows and dissemination of information through leaflets and other media have been done by the fisheries authorities (DOF-pers.comm.), but there are fishers who argued that communication between fishers and the fisheries authorities is still considerably poor (Table 5.6, Chapter 5), thus leading to a lack of legitimacy of the latter (and therefore their regulations) in the eyes of the user, and hence to poor compliance and cooperation.

At present, while regulations exist for lobster stocks and aquatic mammals in Brunei (Section 24 – 25, and Section 32 of Fisheries Order of 2009), no restrictions are being imposed on the demersal fish stocks.

6.3.4 Inadequate monitoring, control and surveillance capacity

Non-compliances are notorious in fisheries, and currently, enforcement is still beyond the capacity of the fishery authorities in Brunei. With the dispersed nature of the fisheries (i.e. numerous landing sites along the rivers and coast), huge numbers of fisheries personnel would be required to enforce regulations under the existing top down management system. Although various Government departments such as the Royal Brunei Marine Police unit and the Immigration Department often coordinate with the DOF in enforcement activities, such operations tend to focus more on patrolling Brunei waters against illegal foreign fishing vessels than enforcing regulations locally.

As a result, the second most common theme identified from the fishers' interviews in this study relates to the incompetency of DOF to implement fisheries regulations properly (Table 5.6, Chapter 5). Such dissatisfaction is particularly apparent among local SS fishers who perceived the foreign labour fishers as having no or little sense of long-term responsibility to the resources and fishery. Consequently, they felt that the lack of enforcement would weaken even the locals' moral obligation to comply. Indeed, as moral obligation and social influence are weakened, compliance tends to erode among those who would normally comply with the regulations. These were already found to be the case in a study on enforcement and compliance with fisheries regulations in Malaysia, Indonesia and the Philippines (Viswanathan *et al.*, 1997).

6.3.5 Regulatory ambiguity on recreational (sport) fishery

Presence of regulatory ambiguity may complicate fisheries management, as evident from other fisheries worldwide (e.g. Prisantoso, 2011; Njiru *et al.*, 2008). Such issue was noted during the course of this study when discrepancy was detected on the number of fishers as provided by the fishery authorities and personal observation during the interview survey.

Based on the Fisheries Order of 2009, no regulations are currently in place for recreational (sportfishing) fishers in Brunei, except for the licence they have to obtain when holding or organizing a sportfishing event or tournament (Section 23, Fisheries Order of 2009). The definition of sportfishing based on Section 2 of the Order means that it intuitively falls under the part-time SS category according to the fishery authorities, where fishing is done as a secondary activity either for family consumption, for part-time business or for pleasure (Ranimah, 2008).

Ambiguity arises from the definition of sportfishing in the Order, which is taken as "fishing for sport or pleasure only", without further clarification, on the fishing gears used for instance. Presently, part-time fishers that employ nets and/or traps are being imposed by the fishery authorities to only operate with valid licenses for their gears, while regulations on those that possess hook and line gears (especially pole and line, or '*joran*') remain unclear. In the licensing database collected by DOF, few records exist of part-time SS fishers that own hook and line gears only, leading to the assumption that these fishers may fish for reasons other than "for sport or pleasure". However, there is no guarantee that those who own hook and line gears, but do not have a valid licence, may be fishing for pleasure only, and majority would agree that their intent to fish also includes own or family consumption. Subsequently, part-time fishers who own nets and/or traps may also argue that they are "fishing for pleasure" and avoid having to pay for licenses if they are aware of the rights they may assume under the Order. In fact, recreational fishing in some countries such as Canada, Finland and Sweden, is practised with gears that were predominantly designed for commercial purposes such as gill-nets and traps (Cowx, 2002). Hence, there is vagueness in deciding on the situation where a gear licence is required or not for the part-time fishers. Such ambiguity further questions the legitimate objective of the licensing system in Brunei fisheries, whether the system being applied is used to control the number of fishers and/or fishing vessels operating in Brunei waters or used to generate revenue only. In addition, the DOF also acknowledged to using the registered licenses as their source of effort data, so any assessment procedures could potentially produce underestimated results if care is not taken.

The minimal impact on fish stocks and negligible contribution of recreational fishery to overall fisheries productivity is often used as an argument against legitimate management of this user group. However, the fishing effort exerted by recreational fishers can be massive, and can account for a significant component of the catch for the country. This has been shown in South Africa where the total contribution of recreational fishery to the total landings in the marine inshore fishery was over 30% (Cockcroft *et al.*, 2000), while in the US, Ihde *et al.* (2011) revealed that 71% of species for which harvest data were available showed an increase in the magnitude of recreational harvests relative to commercial harvest from 1981 to 2006.

6.3.6 Consideration of climate change and environmental variability

Regional warming trends for Southeast Asia are not above the global average and will more gradually manifest than in other regions such as the Middle East and Central Asia (Carius and Maas, 2009). This supports the lack of significant long-term changes in the environmental variables between 2000 and 2009 in Brunei as assessed in this study (Table 4.3, Chapter 4). However, climate variability is likely to increase and will become a major challenge due to its associated unpredictability (IPCC, 2007; Carius and Maas, 2009).

While the fishery authorities have acknowledged climate change as a contributing factor that aggravated the state of demersal stocks in Brunei (DOF, 2011), variability in climate and other environmental parameters are not being considered in the management of the Brunei fisheries in general. Perhaps because little reliable data is available on concrete impacts of climate change, even at regional level (Carius and Maas, 2009). But with better understanding on how climate influences the variability seen in the catch of commercially-important species, fisheries managers will have the opportunity to improve the sustainable harvest of fish in response to climatic conditions. In Australia, terrestrial farming systems have been managed in response to forecasts of rainfall variability for quite some time now, and results have been both reductions in financial risk and improved sustainability (Meinke and Hochman, 2000).

Impacts on the fishery as a result of anthropogenic climate change may alter the relationship between environmental parameters and demersal stock catches identified in this study. As ecosystems are altered, extreme events become more common (IPCC, 2007) and the mean state of various environmental parameters will need to be adjusted.

6.3 Monitoring, assessment and/or management recommendations

Earlier reports often highlighted how Brunei, compared to other countries in the region, is in a "favourable position", particularly in the context of development and management of coastal and marine resources which are considered to be relatively underexploited (e.g. DOF-MIPR, 1992, Silvestre and Matdanan, 1992, Silvestre and Garces, 2004). Yet, management of demersal fishery resources in Brunei still suffers from various weaknesses, as highlighted in previous section, which to some extent are related to the lack of information required for, and lack of capacity to implement, successful management. While there is no sign of systematic failure, there is indeed plenty of room for improvement. Suggestions for better monitoring, assessment and/or management approaches are summarised as follows.

6.3.1 Licensing requirement

In order to achieve the improvement of enforcement and compliance via the licensing system, the fishery authorities should impose licenses to all fishery entities without any exception, including recreational (sportfishing) fishers whether they operate inland (rivers and lakes), inshore or offshore. This can reduce IUU fishing, particularly with the ever increasing number of part-time fishers (Figure 1.5, Chapter 1). Except for the fish landing complexes (FLC) where strict monitoring is already in place, enforcement of the licensing requirement at main landing sites (especially Jerudong, Kuala Tutong and Kuala Belait) should be enhanced and plausibly linked to a reporting obligation for data collection. Involving community in the enforcement of licensing system should also be explored, where encouragement approaches, with incentives to enhance compliance and discouragement approach to reduction of non-compliance can be introduced.

6.3.2 State-of-the-art monitoring system

While tremendous efforts on monitoring, control and surveillance has been noted on illegal foreign fishing vessels in recent years, the fishery authorities should attempt to improve control over the encroachment of LS fishing vessels at sea by utilizing the fishing vessel monitoring system (VMS) technology. VMS is nowadays a standard tool of fisheries monitoring and control worldwide (FAO, 2005b), but it has yet to be implemented in Brunei fishery. Admittedly, putting VMS into practice is a costly and complex procedure that requires careful research and planning, and more importantly, acceptance by the industry. High-level fishery authorities are already aware of this, with experimental installation of VMS on two purse-seine vessels several years ago for a regional study on pelagic resources (Matzaini *et al.*, 2005).

However, the objective then was not on the practical use of VMS, and while the DOF had resolved on the possibility of using VMS as stated in a regional workshop report (FAO, 2005b), the project never took off.

6.3.3 Access rights

The biological characteristics of the fish stocks are often used as arguments against fine-scale local management, in that the restriction of access would be ineffective if the management area did not encompass the full distribution range of the stocks. However, there is a consensus of long-term site attachment in demersal species in all environments, especially reef fishes (Jones *et al.*, 2008). Therefore, restricting access can lead to specific management arrangements for individual stocks. For instance, one of the more effective cases of fisheries management in Indonesia relates to the Bali Straits' sardine stock where participation is limited to fishers from two areas only (Prisantoso, 2011).

However, a particular concern that arises in moving from a system of open access to one of limited access is determining which of the present users should be granted access and to whom it should be denied. Moreover, the social conflicts generated may be considerable, even if only for a short-term. Nevertheless, access rights may encourage a sense of ownership in the user, which should lead to a greater sense of long-term responsibility to the resources and fishery, leading to more responsible fishing (Shotton, 2000). In fact, the right to fish carries with it the obligation to conserve and manage the resources effectively, under the United Nation Convention on the Law of the Sea (UNCLOS III) and FAO International Code of Conduct for Responsible Fisheries, which Brunei had signed to adhere.

However, a policy on the possible restriction of access should only be made after consideration of relevant factors and wide public discussion. This leads to the next point which considers co-management or participatory approach in fisheries management.

6.3.4 Co-management and the participatory approach

Many have acknowledged community-based co-management as the only realistic solution for many of the problem facing global fisheries (Berkes *et al.*, 2007; Gutiérrez *et al.*, 2011). Co-management has been noted to prevent the tragedy of the commons because cooperative management by fishers, managers and scientists often results in sustainable fisheries (Gutiérrez *et al.*, 2011). However, in countries where conservation awareness has not caught on well with people, fisheries management is often seen as a governmental responsibility, and to some extent, this may be the case for Brunei, as evident from the interview survey carried out during the course of this study.

Co-management is “an approach to management in which the government share certain authority, responsibilities and functions of managing the fisheries with resources users as partners” (SEAFDEC, 2006). Co-management is seen as an important tenet in modern fisheries management with aspects that address most of the key issues pointed out earlier, such as greater sensitivity to local socioeconomic and ecological constraints, improved management through use of LEK, collective ownership by users in decision making, increased compliance with regulations through peer pressure and better monitoring, control and surveillance by fishers (Berkes *et al.*, 2007).

Currently, there is no co-management system in place for Brunei, although in June 2011 at the ASEAN-SEAFDEC Conference on Sustainable Fisheries for Food Security Towards 2020, the Brunei Government had resolved to promote co-management aimed at increasing the socio-economic benefits of the fisheries to all stakeholders. The regional guidelines for co-management in Southeast Asia (SEAFDEC, 2006) suggest the local government to work in partnership with resource user organisation at the community level for a more effective management of fisheries resources. However, such organisation is non-existent in Brunei. In fact, formation of local fishing associations in Brunei has been proposed in the report by Silvestre and Matdanan (1992), but twenty years later this idea has yet to be implemented.

Data collected from the interview survey in this study had identified few outstanding individuals and this could serve as a starting point towards the establishment of an appropriate community-level organisation, on the basis that leadership is critical for successful co-management of fisheries (Gutiérrez *et al.*, 2011). Accordingly, the presence of at least one singular individual with entrepreneurial skills, highly motivated, respected as a local leader and making a personal commitment to the co-management implementation process, was required. As a result, the authors further suggested that additional resources should be spent on efforts to identify community leaders and build social capital rather than only imposing management tactics without users' involvement (Gutiérrez *et al.*, 2011).

6.3.5 National fishery statistics

Decision-making in fisheries management is ideally based on the scientific evaluation of fish stock characteristics, but these high standards will be more difficult to achieve if the minimum requirement of an appropriate fishery data collection system is barely met. Few options to improve the quality and usability of the existing catch and effort data include:

- Improvement of current LS data collection system in terms of accuracy and reliability, by routinely collecting and updating the data from time to time, perhaps by replacing monthly log-books submission into weekly or fortnightly.
- Fisheries observers and inspectors should be on board LS vessels as often as possible.
- Logbooks should be introduced on the SSc fleet, as this could help in assessment of fishing effort exerted by this sub-sector.
- Conditions for license renewals for both LS and SSc sectors should include submission of accurate statistics of all operations.
- Appoint full-time enumerators to collect data, not only from the LS sector, but also from the SS sector.

6.4 Concluding remarks

Although the main data used in this study were acquired from the LS sector, the trends in CPUE may still reflect the trends of actual abundance level of demersal stocks entering the fisheries of Brunei within the study area due to the non-selectivity nature of the gears used by the LS sector (particularly trawlers). Most, if not all, of the SS fishers operate gears that are passive and selective, and only about 40.9% employ gears targeted at the demersal stocks (Chapter 5).

On a national level, despite the relatively small fishing area and population size of Brunei, management of its demersal fishery resources appears to be ineffective in addressing the issue of declining stocks. Hence, there is a need to improve the present capacity of the local fishery institution. Assessment of fisheries resources and their exploitation needs to be continually updated, while monitoring, control and surveillance must be strengthened to enable DOF to enforce rules and regulations.

While the national fishery statistics still require improvement, other related research efforts such as exploratory fishing and socio-economic aspect of fisheries, and in particular independent resource surveys, should be undertaken at the same time as well. Close cooperation with fishers, as well as with the industry bodies is also important in understanding overall issues in fisheries. In the context of sustainability of demersal fishery resources in Brunei, data collection from both fishery-dependent and fishery-independent sources should be given due priority, where emphasis is on the coordination and sharing of common data amongst various agencies and stakeholders.

Chapter 7
General conclusions and suggestions for future work

7.1 Conclusions

Statistically assessing the demersal fishery resources, as carried out in this study, was challenging, because of the need to deal with non-experimental and observational data in which random treatments and control groups are not present. Nonetheless, this study has shed some light on the nature and types of changes that have occurred in the marine ecosystem of Brunei. In particular, it has been shown that substantial changes occurred in recent period between 2000 and 2009.

Mean Trophic Level (MTL) of large-scale fishery catches revealed a declining trend in Brunei's marine ecosystem state, despite the short study period (2000 – 2009), at a rate of 0.08 trophic levels (TL) per decade. In order to focus on changes in relative abundance of the more threatened, higher TL finfish only, MTL was recalculated as $^{3.30}$MTL. Subsequently, food web collapses as implied from a "fishing down the marine food web" process may not have occurred yet in Brunei waters as (1) the decline in MTL has not been associated with overall declining catches, (2) no significant decline in $^{3.30}$MTL detected and (3) catches of high-TL species have been maintained. However, closer inspection of species shifts revealed that within a short time scale of 10 years, significant changes in underlying fish assemblage beyond the direct effects on target species, particularly on the demersal ecological group, had occurred. The implied poor and deteriorating state of Brunei marine coastal ecosystem is further supported by the increasing Fishing-in-Balance (FiB) index and temporal patterns of catch trophic spectra (TS), suggesting expansion of the fishery effort offshore by the end of the study period.

In-depth evaluation of the demersal finfish stocks, based on the Catch-Per-Unit-Effort (CPUE) index which was standardised for other factors not related to abundance, further corroborated the occurrence of shifts in species composition of Brunei's demersal habitat. In general, abundance of overall demersal resources had declined, even when total catches remained stationary between 2000 and 2009. Influence of climate and the environment seems relatively minimal, although additional studies to confirm this are in order, especially because potential effects of the environment may be implicit. From this study, trends in CPUE appeared to vary among the different demersal fish families. Generally, abundance of several demersal zoobenthic feeders exhibited decline, while the majority of the intermediate demersal predator stocks were shown to increase over the study period.

Considering the long fishing tradition in Brunei, this study may be open to criticism because the full influence of fishery activities may have been obscured by the short time-series of the official fishery datasets. By using fishers' local ecological knowledge (LEK), this study has reaffirmed the relatively high abundance of Brunei fishery resources up till the 2000s reported in the literature.The study also revealed the "Shifting Baseline Syndrome" (SBS) among currently active fishers in Brunei, in respect of resource decline. Of particular significance is that fishers' perception of how abundant the demersal stocks were in the past are likely to be more accurate than commonly suggested in the literature, especially with several authors having raised concerns over the potential problem of SBS in setting conservation goals or other fishery management programmes. However, with special reference to the red snappers stock, this study has also shown that patterns derived from short time series may potentially be wide of the mark, as there is strong evidence of red snapper abundance decline using fishers' LEK, which compellingly suggests that harvest were higher in earlier decades, before the onset of official fishery data.

While a number of factors have been identified as contributing to falling catch rates of some species, assessment of the resources in Brunei is still relatively insufficient for informing fishery management in a timely manner. However, fisheries scientists have become increasingly aware of the inherent unpredictability of fishery systems, the non-biological complexities of fisheries and the need for alternative complementary perspectives. Thus management needs to be adaptive in nature, guided by the precautionary approach, if sustainability of the fishery is to be ensured.

7.2 Suggestions for future work

There are a number of research gaps that have been identified during the course of this study that will require attention for a better academic understanding of exploited demersal stocks in a tropical multi-specific and multi-gear fishery, as well as more comprehensive assessment of the demersal fishery in Brunei:

- The outcomes from this study should be supplemented with information obtained from fishery-independent sources, especially to validate CPUE values as index of relative abundance. Furthermore, incorporation of LEK with both fishery-dependent and fishery-independent data using fuzzy logic should be explored further.
- This study has concentrated on changes at the community and family levels, but very little was done at species level. In addition, the analyses could be improved by using more spatially refined catch data, perhaps to the scale of

chl-a resolution (0.1° x 0.1° latitude and longitude) which falls within the lower home range of most demersal stocks.

- Inclusion of lagged environmental variables in GLMs of stocks' CPUE would facilitate extraction of environmental influence from fishing and other effects on stocks' abundance variability. It could have also benefited from a more comprehensive age-/size-structured catch data, as there are still limited understanding on the influence of multi-gear fishing and environment on stocks' life history.
- A more systematic analysis of fishers' qualitative LEK data collected in this study has not been explored. Fishers' LEK could provide an opportunity to highlight anomalies and generate hypotheses related to the fishery resources.

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APPENDICES

Appendix A-3.1 (Trophic spectra trends)

Summary statistics of trends in catch proportions (logit-transformed). Species catches were distributed by trophic class of 0.1 increments according to their trophic level and were smoothed with a three-increment weighted moving average, except for TL ≤ 2.5.

TL	Slope *b*	SE	*t*-stats	p-value
2.0	0.014	0.057	0.243	0.814
2.5	-0.030	0.014	-2.201	0.059
2.9	0.169	0.050	3.366	**0.010**
3.0	0.059	0.016	3.653	**0.006**
3.1	0.054	0.013	4.122	**0.003**
3.2	0.009	0.009	1.012	0.341
3.3	0.031	0.015	2.037	0.076
3.4	0.032	0.019	1.666	0.134
3.5	-0.053	0.024	-2.195	0.059
3.6	-0.035	0.021	-1.640	0.140
3.7	-0.054	0.029	-1.868	0.099
3.8	-0.020	0.016	-1.280	0.236
3.9	-0.015	0.012	-1.286	0.234
4.0	-0.001	0.006	-0.093	0.928
4.1	-0.030	0.016	-1.899	0.094
4.2	-0.047	0.017	-2.755	**0.025**
4.3	-0.004	0.018	-0.233	0.822
4.4	0.002	0.016	0.119	0.908
4.5	0.047	0.015	3.135	**0.014**

Appendix B-4.1 (GLM models of stocks' CPUE)

Summary statistics of most parsimonious model from GLM analyses of nominal CPUE for overall demersal resources and for each family categories.

Dependent Variable: Overall demersal resources

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	667.497[a]	73	9.144	14.784	.000	.724
Intercept	2489.284	1	2489.284	4024.871	.000	.907
YEAR	5.586	9	.621	1.004	.436	.022
MONTH	31.884	11	2.899	4.687	.000	.111
GEAR	221.754	2	110.877	179.275	.000	.466
ZONE	.095	1	.095	.153	.696	.000
MONTH * GEAR	34.741	22	1.579	2.553	.000	.120
YEAR * GEAR	49.882	17	2.934	4.744	.000	.164
GEAR * ZONE	8.073	2	4.036	6.526	.002	.031
YEAR * ZONE	13.152	9	1.461	2.363	.013	.049
Error	254.193	411	.618			
Total	6243.511	485				
Corrected Total	921.691	484				

a. R Squared = .724 (Adjusted R Squared = .675)

Dependent Variable: Ariidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	170.449[a]	21	8.117	11.919	.000	.786
Intercept	826.629	1	826.629	1213.858	.000	.947
YEAR	17.303	9	1.923	2.823	.007	.272
MONTH	43.754	11	3.978	5.841	.000	.486
ZONE	97.867	1	97.867	143.712	.000	.679
Error	46.308	68	.681			
Total	3540.327	90				
Corrected Total	216.757	89				

a. R Squared = .786 (Adjusted R Squared = .720)

Dependent Variable: Balistidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	87.260[a]	15	5.817	6.715	.000	.664
Intercept	1320.322	1	1320.322	1524.075	.000	.968
YEAR	14.297	9	1.589	1.834	.085	.244
GEAR	9.417	2	4.709	5.435	.007	.176
ZONE	1.625	1	1.625	1.876	.177	.035
YEAR * ZONE	11.294	3	3.765	4.346	.008	.204
Error	44.182	51	.866			
Total	3162.944	67				
Corrected Total	131.441	66				

a. R Squared = .664 (Adjusted R Squared = .565)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Carangidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	356.334[a]	81	4.399	5.939	.000	.717
Intercept	1568.327	1	1568.327	2117.331	.000	.918
YEAR	53.214	9	5.913	7.982	.000	.274
MONTH	22.295	11	2.027	2.736	.003	.137
GEAR	3.708	2	1.854	2.503	.085	.026
ZONE	8.632	1	8.632	11.654	.001	.058
MONTH * GEAR	40.705	20	2.035	2.748	.000	.224
YEAR * GEAR	67.823	16	4.239	5.723	.000	.325
GEAR * ZONE	8.121	2	4.060	5.482	.005	.055
MONTH * ZONE	19.134	11	1.739	2.348	.010	.120
YEAR * ZONE	38.698	9	4.300	5.805	.000	.216
Error	140.735	190	.741			
Total	10251.734	272				
Corrected Total	497.069	271				

a. R Squared = .717 (Adjusted R Squared = .596)

Dependent Variable: Drepaneidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	34.105[a]	26	1.312	1.103	.409	.555
Intercept	2.444	1	2.444	2.055	.165	.082
YEAR	20.744	9	2.305	1.938	.097	.431
MONTH	13.435	11	1.221	1.027	.455	.329
GEAR	5.166	1	5.166	4.344	.048	.159
ZONE	.766	1	.766	.644	.430	.027
SST	1.607	1	1.607	1.351	.257	.055
LN(chl-a)	.440	1	.440	.370	.549	.016
PPT	.907	1	.907	.763	.391	.032
eqSOI	2.243	1	2.243	1.886	.183	.076
MONTH * GEAR	.000	0	.	.	.	.000
YEAR * GEAR	.000	0	.	.	.	.000
GEAR * ZONE	.000	0	.	.	.	.000
MONTH * ZONE	.000	0	.	.	.	.000
YEAR * ZONE	.000	0	.	.	.	.000
Error	27.354	23	1.189			
Total	2949.334	50				
Corrected Total	61.459	49				

a. R Squared = .555 (Adjusted R Squared = .052)

Dependent Variable: Ephippidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	79.878[a]	21	3.804	11.281	.000	.937
Intercept	257.047	1	257.047	762.313	.000	.979
YEAR	24.734	9	2.748	8.150	.000	.821
MONTH	15.660	11	1.424	4.222	.005	.744
ZONE	6.860	1	6.860	20.344	.000	.560
Error	5.395	16	.337			
Total	2101.468	38				
Corrected Total	85.273	37				

a. R Squared = .937 (Adjusted R Squared = .854)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Gerreidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	95.683[a]	13	7.360	8.001	.000	.689
Intercept	5.864	1	5.864	6.374	.015	.119
MONTH	27.309	11	2.483	2.699	.009	.387
ZONE	54.953	1	54.953	59.736	.000	.560
SST	7.772	1	7.772	8.448	.006	.152
Error	43.237	47	.920			
Total	3353.658	61				
Corrected Total	138.920	60				

a. R Squared = .689 (Adjusted R Squared = .603)

Dependent Variable: Haemulidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	74.078[a]	33	2.245	4.097	.000	.617
Intercept	441.582	1	441.582	805.936	.000	.906
YEAR	22.841	9	2.538	4.632	.000	.332
MONTH	13.743	11	1.249	2.280	.017	.230
GEAR	2.925	2	1.462	2.669	.075	.060
ZONE	7.560	1	7.560	13.798	.000	.141
YEAR * GEAR	10.791	6	1.799	3.283	.006	.190
MONTH * ZONE	6.902	4	1.726	3.149	.018	.130
Error	46.025	84	.548			
Total	6523.702	118				
Corrected Total	120.103	117				

a. R Squared = .617 (Adjusted R Squared = .466)

Dependent Variable: Lactariidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	154.179[a]	22	7.008	23.931	.000	.832
Intercept	431.646	1	431.646	1473.983	.000	.933
YEAR	10.072	9	1.119	3.822	.000	.245
MONTH	66.381	11	6.035	20.607	.000	.681
GEAR	40.528	1	40.528	138.395	.000	.566
ZONE	48.922	1	48.922	167.058	.000	.612
Error	31.041	106	.293			
Total	2908.846	129				
Corrected Total	185.220	128				

a. R Squared = .832 (Adjusted R Squared = .798)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Leiognathidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	278.251[a]	46	6.049	7.304	.000	.697
Intercept	1097.617	1	1097.617	1325.447	.000	.901
YEAR	68.918	9	7.658	9.247	.000	.363
MONTH	50.799	11	4.618	5.577	.000	.296
GEAR	14.507	1	14.507	17.518	.000	.107
ZONE	17.282	1	17.282	20.869	.000	.125
MONTH * GEAR	41.104	11	3.737	4.512	.000	.254
YEAR * GEAR	51.068	7	7.295	8.810	.000	.297
GEAR * ZONE	3.382	1	3.382	4.084	.045	.027
YEAR * ZONE	41.974	5	8.395	10.137	.000	.258
Error	120.904	146	.828			
Total	5743.879	193				
Corrected Total	399.155	192				

a. R Squared = .697 (Adjusted R Squared = .602)

Dependent Variable: Lethrinidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	42.564[a]	9	4.729	7.329	.000	.647
Intercept	2106.822	1	2106.822	3265.165	.000	.989
YEAR	2.778	5	.556	.861	.517	.107
GEAR	14.683	1	14.683	22.756	.000	.387
YEAR * GEAR	10.735	3	3.578	5.546	.003	.316
Error	23.229	36	.645			
Total	2586.262	46				
Corrected Total	65.792	45				

a. R Squared = .647 (Adjusted R Squared = .559)

Dependent Variable: Lutjanidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	673.307[a]	58	11.609	23.698	.000	.814
Intercept	1090.567	1	1090.567	2226.304	.000	.876
YEAR	29.681	9	3.298	6.732	.000	.161
MONTH	13.654	11	1.241	2.534	.004	.081
GEAR	99.347	2	49.674	101.405	.000	.392
ZONE	205.376	1	205.376	419.258	.000	.571
YEAR * GEAR	32.488	10	3.249	6.632	.000	.174
YEAR * ZONE	22.068	9	2.452	5.006	.000	.125
MONTH * GEAR	28.601	14	2.043	4.171	.000	.156
GEAR * ZONE	86.468	1	86.468	176.517	.000	.359
Error	154.305	315	.490			
Total	8390.952	374				
Corrected Total	827.611	373				

a. R Squared = .814 (Adjusted R Squared = .779)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Mullidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	115.029[a]	8	14.379	19.825	.000	.836
Intercept	513.815	1	513.815	708.430	.000	.958
YEAR	13.583	7	1.940	2.675	.027	.377
ZONE	22.438	1	22.438	30.936	.000	.499
Error	22.484	31	.725			
Total	1041.390	40				
Corrected Total	137.513	39				

a. R Squared = .836 (Adjusted R Squared = .794)

Dependent Variable: Nemipteridae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	339.648[a]	18	18.869	26.812	.000	.784
Intercept	349.385	1	349.385	496.454	.000	.789
YEAR	29.869	8	3.734	5.305	.000	.242
GEAR	.002	1	.002	.003	.954	.000
ZONE	2.733	1	2.733	3.883	.051	.028
YEAR * GEAR	4.640	1	4.640	6.593	.011	.047
YEAR * ZONE	24.968	6	4.161	5.913	.000	.211
GEAR * ZONE	25.383	1	25.383	36.068	.000	.213
Error	93.600	133	.704			
Total	4241.006	152				
Corrected Total	433.248	151				

a. R Squared = .784 (Adjusted R Squared = .755)

Dependent Variable: Priacanthidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	130.372[a]	33	3.951	23.797	.000	.978
Intercept	69.339	1	69.339	417.657	.000	.959
YEAR	13.962	8	1.745	10.512	.000	.824
MONTH	5.155	11	.469	2.823	.025	.633
GEAR	2.298	1	2.298	13.843	.002	.435
ZONE	26.094	1	26.094	157.176	.000	.897
Rainfall	1.457	1	1.457	8.778	.008	.328
YEAR * ZONE	6.210	3	2.070	12.468	.000	.675
MONTH * ZONE	5.435	6	.906	5.456	.002	.645
Error	2.988	18	.166			
Total	1233.510	52				
Corrected Total	133.360	51				

a. R Squared = .978 (Adjusted R Squared = .937)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Psettodidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	176.990[a]	26	6.807	19.906	.000	.859
Intercept	1734.270	1	1734.270	5071.324	.000	.984
YEAR	102.308	9	11.368	33.241	.000	.779
MONTH	13.633	11	1.239	3.624	.000	.319
ZONE	2.994	1	2.994	8.755	.004	.093
YEAR * ZONE	11.441	5	2.288	6.691	.000	.282
Error	29.068	85	.342			
Total	4614.708	112				
Corrected Total	206.057	111				

a. R Squared = .859 (Adjusted R Squared = .816)

Dependent Variable: Sciaenidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	183.360[a]	27	6.791	6.499	.000	.621
Intercept	1210.188	1	1210.188	1158.108	.000	.915
YEAR	48.664	9	5.407	5.174	.000	.303
MONTH	61.329	11	5.575	5.335	.000	.354
ZONE	6.415	1	6.415	6.139	.015	.054
SOI	8.623	1	8.623	8.252	.005	.072
YEAR * ZONE	14.012	5	2.802	2.682	.025	.111
Error	111.812	107	1.045			
Total	4275.821	135				
Corrected Total	295.171	134				

a. R Squared = .621 (Adjusted R Squared = .526)

Dependent Variable: Serranidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	439.198[a]	32	13.725	23.600	.000	.717
Intercept	8342.168	1	8342.168	14344.196	.000	.980
YEAR	26.348	9	2.928	5.034	.000	.132
MONTH	17.031	11	1.548	2.662	.003	.089
GEAR	167.631	1	167.631	288.238	.000	.492
ZONE	8.261	1	8.261	14.204	.000	.045
YEAR * GEAR	22.381	9	2.487	4.276	.000	.114
GEAR * ZONE	54.700	1	54.700	94.056	.000	.240
Error	173.308	298	.582			
Total	11233.661	331				
Corrected Total	612.506	330				

a. R Squared = .717 (Adjusted R Squared = .687)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Siganidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	10.097[a]	3	3.366	8.244	.000	.318
Intercept	217.969	1	217.969	533.933	.000	.910
GEAR	2.861	2	1.430	3.504	.037	.117
ZONE	7.628	1	7.628	18.684	.000	.261
Error	21.636	53	.408			
Total	2428.942	57				
Corrected Total	31.733	56				

a. R Squared = .318 (Adjusted R Squared = .280)

Dependent Variable: Stromateidae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	63.054[a]	24	2.627	2.314	.010	.587
Intercept	208.680	1	208.680	183.798	.000	.825
YEAR	22.528	9	2.503	2.205	.043	.337
MONTH	22.401	11	2.036	1.794	.089	.336
GEAR	5.231	1	5.231	4.607	.038	.106
ZONE	6.778	1	6.778	5.970	.019	.133
MONTH * GEAR	7.427	2	3.713	3.271	.049	.144
Error	44.280	39	1.135			
Total	5027.584	64				
Corrected Total	107.334	63				

a. R Squared = .587 (Adjusted R Squared = .334)

Dependent Variable: Trichiuridae

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	56.300[a]	16	3.519	3.024	.000	.328
Intercept	1529.011	1	1529.011	1314.136	.000	.930
YEAR	26.736	9	2.971	2.553	.011	.188
GEAR	3.484	1	3.484	2.994	.087	.029
ZONE	11.734	1	11.734	10.085	.002	.092
YEAR * GEAR	27.782	5	5.556	4.776	.001	.194
Error	115.187	99	1.164			
Total	4643.861	116				
Corrected Total	171.488	115				

a. R Squared = .328 (Adjusted R Squared = .220)

APPENDIX B-4.1 (*Continued*)

Dependent Variable: Dasyatidae

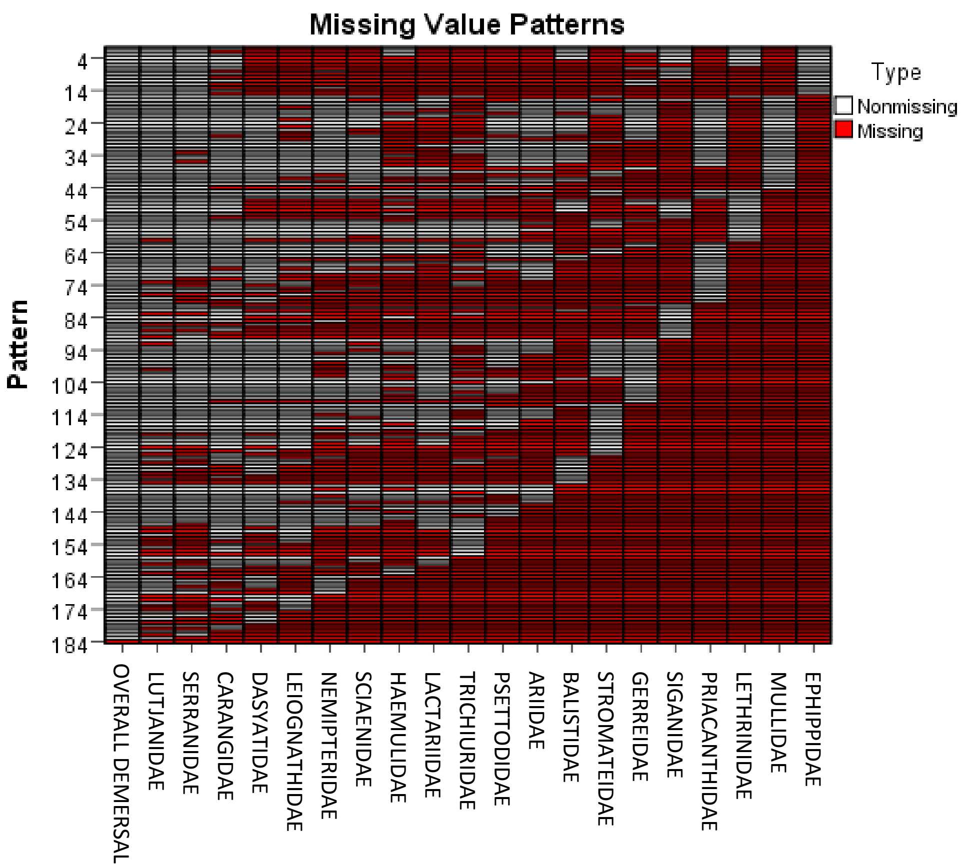
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	343.462[a]	44	7.806	22.922	.000	.841
Intercept	1339.025	1	1339.025	3932.039	.000	.954
YEAR	13.325	9	1.481	4.348	.000	.171
MONTH	19.955	11	1.814	5.327	.000	.236
GEAR	127.799	1	127.799	375.281	.000	.664
ZONE	3.438	1	3.438	10.095	.002	.050
YEAR * GEAR	4.189	4	1.047	3.075	.017	.061
YEAR * ZONE	32.364	9	3.596	10.560	.000	.333
MONTH * GEAR	17.659	9	1.962	5.762	.000	.214
Error	64.703	190	.341			
Total	4503.826	235				
Corrected Total	408.165	234				

a. R Squared = .841 (Adjusted R Squared = .805)

Appendix C-4.2 (Missing value patterns of data)

Overall summary of missing values in 21 datasets used in this study is given below:

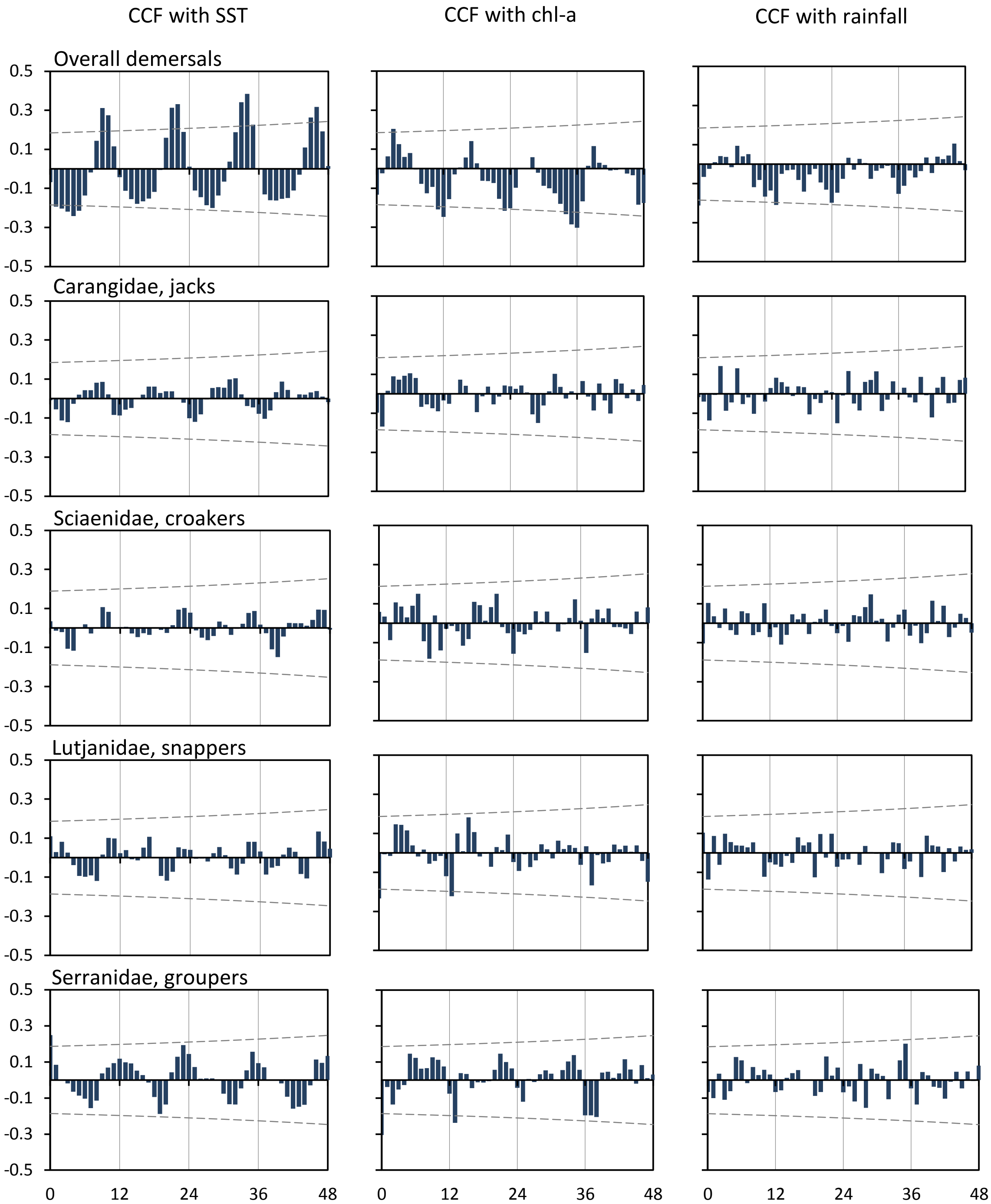
Category	Missing		Valid N
	N	Percent	
EPHIPPIDAE	682	94.7%	38
MULLIDAE	680	94.4%	40
LETHRINIDAE	674	93.6%	46
PRIACANTHIDAE	668	92.8%	52
SIGANIDAE	663	92.1%	57
GERREIDAE	659	91.5%	61
STROMATEIDAE	656	91.1%	64
BALISTIDAE	653	90.7%	67
ARIIDAE	630	87.5%	90
PSETTODIDAE	608	84.4%	112
TRICHIURIDAE	604	83.9%	116
LACTARIIDAE	602	83.6%	118
HAEMULIDAE	602	83.6%	118
SCIAENIDAE	585	81.3%	135
NEMIPTERIDAE	568	78.9%	152
LEIOGNATHIDAE	527	73.2%	193
DASYATIDAE	485	67.4%	235
CARANGIDAE	448	62.2%	272
SERRANIDAE	389	54.0%	331
LUTJANIDAE	346	48.1%	374
OVERALL DEMERSAL	235	32.6%	485



Appendix D-4.3 (Plots of CCF analyses)

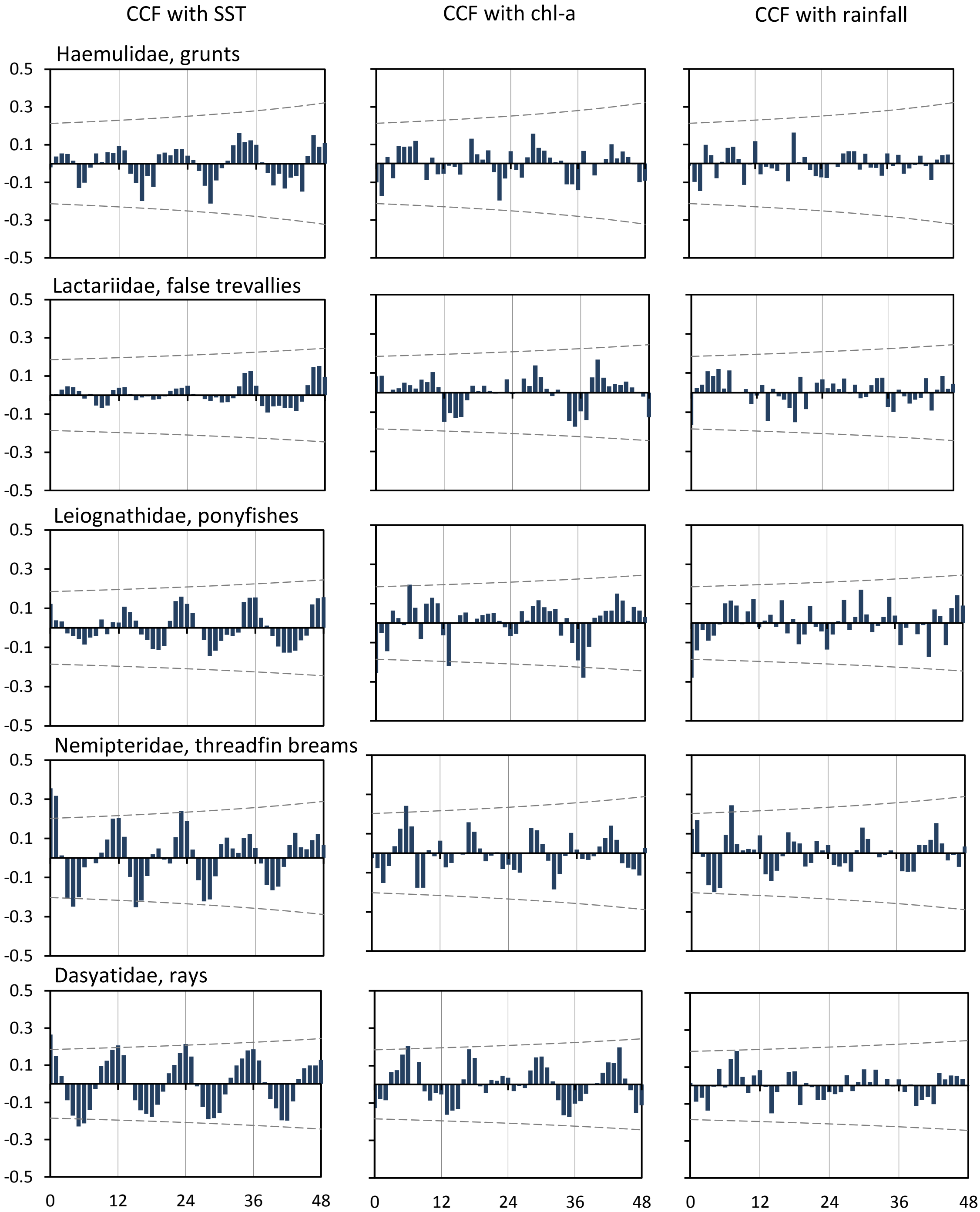
Cross-correlational functions of the three environmental variables (SST, chl-a and rainfall) as leading indicators and residuals of stocks' CPUE as lagging indicator. Dashed lines show 95% confidence intervals.

ZONE 2



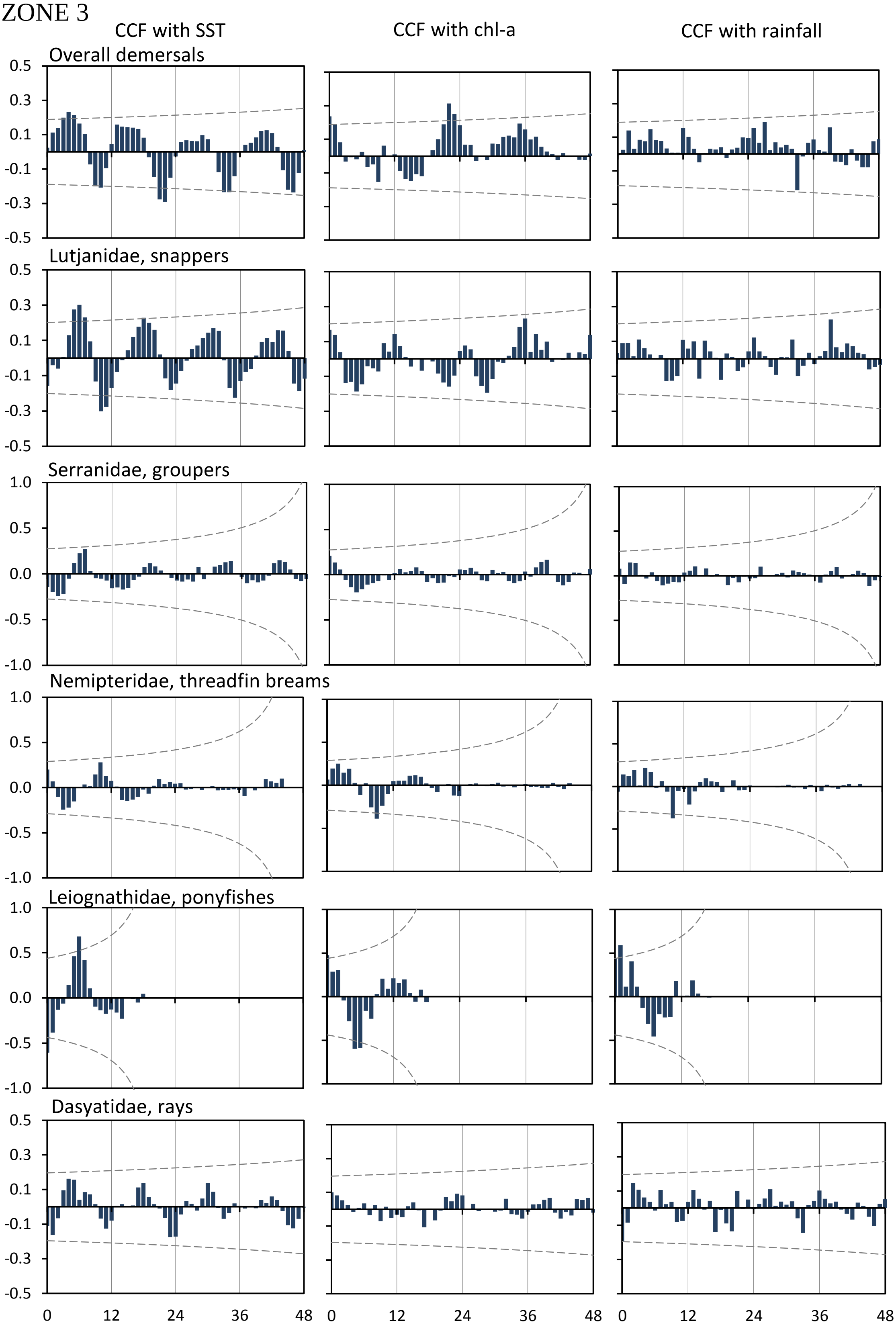
APPENDIX D-4.3 (*Continued*)

ZONE 2 (*Continued*)



APPENDIX D-4.3 (*Continued*)

ZONE 3



NOTE: CCF plots of Carangidae, Sciaenidae, Haemulidae and Lactariidae are not given due to large number of missing values. Also note the different y-axis.

Appendix E-5.1 (Interview questions)

Interview questions (translated) and map used during the survey.

Questionnaire on Capture Fishery of Brunei Darussalam 2011

REF. CODE:

Department of Fisheries, MIPR, would like to utilise the knowledge of commercial fishermen in Brunei as part of an evaluation of the marine capture fishery. This should not take more than 30 minutes, as the answers need only be estimates. All answers will be treated with confidentiality and anonymity. Thank you for your assistance.

DATE form is completed: .... Interview LOCATION:..

Section A: Fishers background

Respondent name:.. Vessel / Company name: ....

Nationality:...................... Age: .... Years fishing in Brunei waters? ....years; Full-time / Part-time

Type of gear used in fishing operations:

[ ] Trawl [ ] Purse seine [ ] Long line [ ] Outboard engine boat:..

On the map provided, (1) please circle (O) your *most frequently visited* site, and

~~(2) please cross (X) the fishing ground you believed has the *highest fish density*.~~

Section B: Perception of change

1. Name all the marine species which you believed to have been depleted by fishing.

....

Please choose whether the following has **increased, stayed the same (no change) or decreased**, since when you *first started fishing*:

	Increase	No change	Decrease
2. ~~Amount of catch for the demersal species in general~~	[ ]	[ ]	[ ]
3. Abundance of Brunei marine resources in general	[ ]	[ ]	[ ]
4. Fish size of Brunei marine resources in general	[ ]	[ ]	[ ]
5. Average fish price in Brunei market in general	[ ]	[ ]	[ ]

6. The following question is refering to the **average amount of catch** obtained for each species/groups based on the time period given: (1 – Low, 2 – Medium, 3 – High)

Species	Period	Average catch 1	2	3	Species	Period	Average catch 1	2	3
Red snapper	Pre-1970s	[ ]	[ ]	[ ]	Ponyfish	Pre-1970s	[ ]	[ ]	[ ]
	1970 – 1984	[ ]	[ ]	[ ]		1970 – 1984	[ ]	[ ]	[ ]
	1984 – 2000	[ ]	[ ]	[ ]		1984 – 2000	[ ]	[ ]	[ ]
	2000 – now	[ ]	[ ]	[ ]		2000 – now	[ ]	[ ]	[ ]
Grouper	Pre-1970s	[ ]	[ ]	[ ]	Mackarel (pelagics)	Pre-1970s	[ ]	[ ]	[ ]
	1970 – 1984	[ ]	[ ]	[ ]		1970 – 1984	[ ]	[ ]	[ ]
	1984 – 2000	[ ]	[ ]	[ ]		1984 – 2000	[ ]	[ ]	[ ]
	2000 – now	[ ]	[ ]	[ ]		2000 – now	[ ]	[ ]	[ ]
Japanese scad (pelagics)	Pre-1970s	[ ]	[ ]	[ ]	Stingray	Pre-1970s	[ ]	[ ]	[ ]
	1970 – 1984	[ ]	[ ]	[ ]		1970 – 1984	[ ]	[ ]	[ ]
	1984 – 2000	[ ]	[ ]	[ ]		1984 – 2000	[ ]	[ ]	[ ]
	2000 – now	[ ]	[ ]	[ ]		2000 – now	[ ]	[ ]	[ ]

7. Have you ever caught a red snapper (*membangan*)? YES [ ] NO [ ]

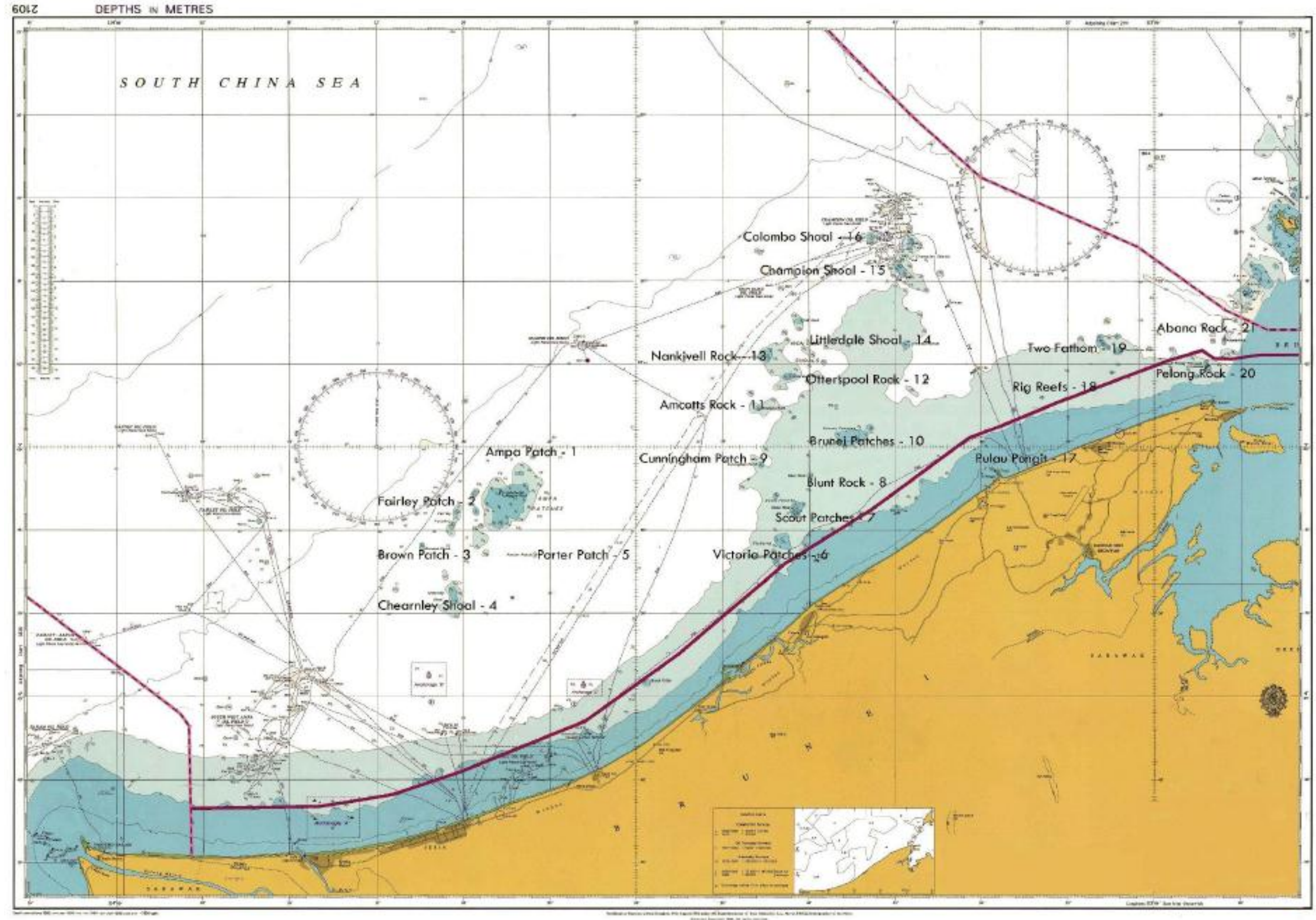
If no, please proceed to question 14.

8. If yes, what was your best ever catch of this species in one day? .... kg
9. How old were you when you caught your best catch of this species? .... years [OR Which year?]
10. Please mark with a star (★) in the map next page, where was your best catch caught?
11. What was the size of the largest fish of this species you ever caught? .... kg
12. How old were you when you caught this largest fish? .... years [OR Which year?]
13. What type of fishing gear did you use?
    [ ] Trawl [ ] Purse seine [ ] Line and hook [ ] Traps [ ] Others: ....
14. How do you feel about the way Brunei marine resources are being managed?

    ....

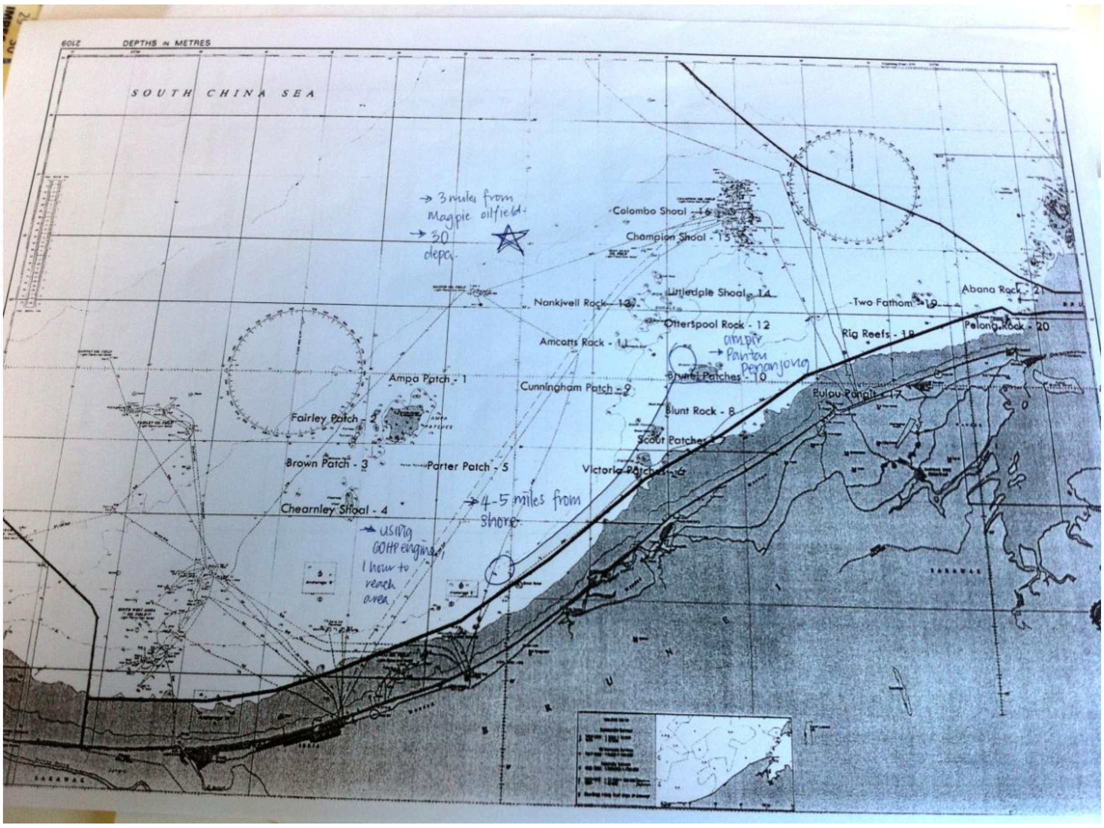
Any questions/comments should be addressed to: Miss Syazana Ebil, Tel: 8848158 (m) / 2260669 (r), Email: S.Ebil@warwick.ac.uk

Small version of the map used in the survey (A4 size).



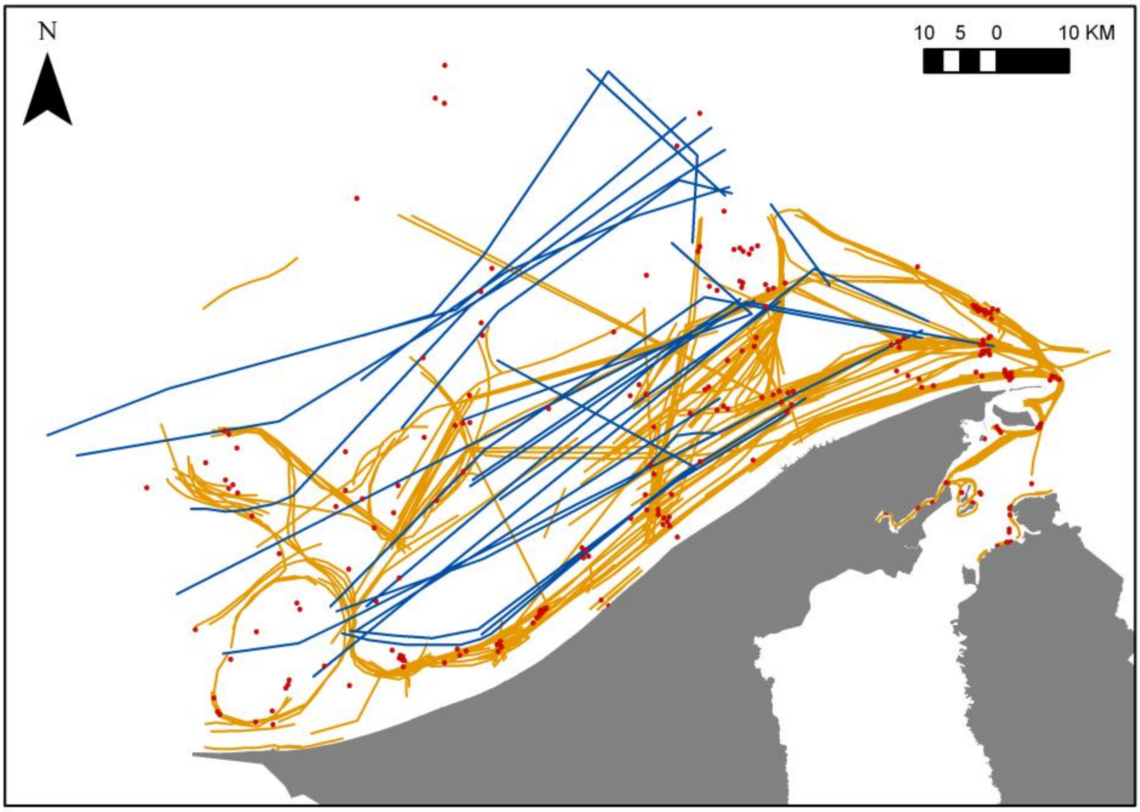
Appendix F-5.2 (Example of 'logical consistency')

Example of a fisher's response for the map-based portion of the interview survey is given below, where notes were taken on field to check for logical consistency of points/lines drawn. In this example, the fisher frequents the reef patches near Kuala Tutong, stating in general that it would take him around an hour to reach the fishing ground which is about 4-5 miles from shore. As for the location of the best day's catch of red snapper, he recalled the catch to be made about 3 miles away from Magpie oilfield, in the direction of Champion oilfield. The fisher gave an approximate depth of the area in "depa", which is a local unit of depth measurement often used by (older) fishers. The values were then converted to meters.



Appendix G-5.3 (Interview survey input data)

Illustration of fishers' raw input data for the map-based portion of the interview survey.



Appendix H-5.4 (List of depleted species from interview survey)

List of depleted species cited by fishers which they perceived had been depleted in their lifetime, with 18 species being cited by all groups.

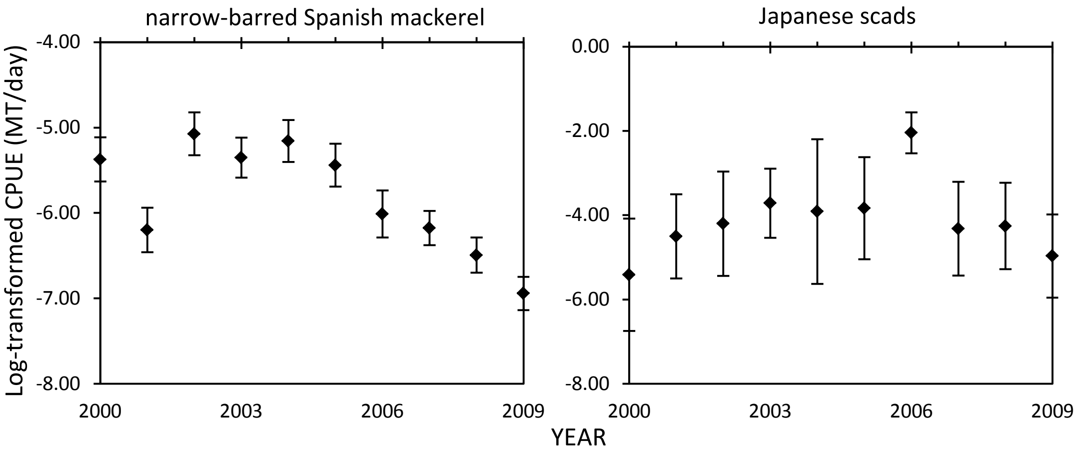
Local name	Family name	Scientific name	Common name	Number of respondents (by fishing experience years)			
				<10 years	11-39 years	>40 years	Total
Ikan merah	Lutjanidae	*Lutjanus erythropterus*	red snapper	11	17	11	39
Rumahan	Scombridae	*Rastrelliger* spp.	small mackerel	18	11	9	38
Tenggiri	Scombridae	*Scomberomorus commerson*	narrow-barred Spanish mackerel	4	11	13	28
Temanung	Carangidae	*Atule mate*	yellowtail scad	9	10	8	27
Ikan putih	Carangidae	*Caranx* spp.	jacks	8	13	5	26
Duai putih	Stromateidae	*Pampus argenteus*	silver pomfret	6	10	9	25
Beberahan	Lutjanidae	*Lutjanus johnii*	John's snapper	9	11	5	25
Kerapu	Serranidae	*Epinephelus* spp.	grouper	7	7	1	15
Udang	Penaeidae	*Penaeus* spp.	prawn	1	9	4	14
Tamban	Clupeidae	*Sardinella gibbosa*	goldstripe sardinella	1	7	5	13
Membangan	Lutjanidae	*Lutjanus malabaricus*	Malabar red snapper	2	4	2	8
Jarang gigi	Sciaenidae	*Otolithes ruber*	tiger-toothed croaker	2	5	1	8
Kelapa-kelapa	Lactariidae	*Lactarius lactarius*	false trevally	2	5	1	8
Ketumbang	Lutjanidae	*Lutjanus rivulatus*	blubberlip snapper	1	4	1	6
Kerisi	Nemipteridae	*Nemipterus* spp.	threadfin breams	2	1	2	5
Tongkol	Scombridae	*Katsuwonus pelamis*	skipjack tuna	3	1	1	5
Kerisi Bali	Lutjanidae	*Pristipomoides multidens*	goldband snapper	1	2	1	4
Bekalang	Carangidae	*Scomberoides commersonnianus*	Talang queenfish	1	1	1	3
Kembura	Mugilidae	*Chelon* spp.	mullet	0	3	6	9
Kuasi	Clupeidae	*Anodontostoma chacunda*	gizzard shad	0	2	5	7
Kurau	Polynemidae	*Leptomelanosoma indicum*	Indian threadfin	0	1	5	6
Kanai	Centrarchidae	*Micropterus* spp.	Borneo black bass	0	3	3	6
Parang	Chirocentridae	*Chirocentrus* spp.	wolf herring	0	1	3	4
Menangin	Polynemidae	*Polydactylus sextarius*	blackspot threadfin	0	0	3	3
Umpak	Haemulidae	*Pomadasys hasta*	silver grunt	0	0	3	3
Gagok	Ariidae	*Arius thalassinus*	giant catfish	0	3	2	5
Terubuk	Clupeidae	*Tenualosa macrura*	longtail shad	0	2	2	4
Ayam laut	Balistidae	*Abalistes stellaris*	starry triggerfish	0	1	2	3
Menukuk	Carangidae	*Seriola* spp.	amberjack	0	0	2	2
Pusu	Engraulidae	*Setipinna* spp.	hairpin anchovy	0	0	2	2
Puput	Clupeidae	*Ilisha elongata*	slender shad	0	2	1	3
Belanak	Mugilidae	*Moolgarda seheli*	bluespot mullet	0	1	1	2
Yu	Carcharhinidae	*Carcharhinus dussumieri*	whitecheek shark	1	0	1	2
Kerapu sambui-sambui	Serranidae	*Chromileptes altivelis*	humpback grouper	0	0	1	1
Luluk	Clariidae	*Clariidae* spp.	airbreathing catfishes	0	0	1	1
Malabua	Cyprinidae	*Osteochilus melanopleurus*	carp	0	0	1	1
Pat-pat kuning	Osphronemidae	*Osphronemus goramy*	golden guorami	0	0	1	1
Sulit gadong	Caesionidae	*Caesio cuning*	deep-bodied fussilier	0	0	1	1
Sulit hijau	Caesionidae	*Caesio caerulaurea*	scissor-tail fussilier	0	0	1	1
Sumpit-sumpit	Toxotidae	*Toxotes jaculatrix*	banded archerfish	0	0	1	1
Duai hitam	Carangidae	*Parastromateus niger*	black pomfret	0	3	0	3
Langguran	Carangidae	*Caranx tille*	Tille trevally	0	3	0	3

Rumahan bini	Scombridae	*Rastrelliger brachysoma*	short mackarel	0	3	0	3
Bakara	Palinuridae	*Panulirus ornatus*	spiny lobster	0	2	0	2
Salman	Carangidae	*Elagatis bipinnulata*	rainbow runner	0	2	0	2
Selunsong	Latidae	*Lates calcarifer*	barramundi	0	2	0	2
Bilis	Leiognathidae	*Leiognathus* spp.	ponyfish	4	1	0	5
Basong-basong	Carangidae	*Decapterus maruadsi*	Japanese scad	3	1	0	4
Layaran	Istiophoridae	*Istiophorus platypterus*	Indo-Pacific sailfish	3	1	0	4
Sulit	Caesionidae	*Caesio* spp.	fusiliers	2	1	0	3
Pulut-pulut	Leiognathidae	*Leiognathus equulus*	common ponyfish	1	1	0	2
Bakulan	Scombridae	*Euthynnus affinis*	bonito	0	1	0	1
Barracuda	Sphyraenidae	*Sphyraena* spp.	barracuda	0	1	0	1
Bubuk	Penaeidae	*Acetes* spp./*Lucifer* spp.	shrimp	0	1	0	1
Jukut	Channidae	*Channa* spp.	common snakehead	0	1	0	1
Keratang	Serranidae	*Epinephelus lanceolatus*	giant grouper	0	1	0	1
Kitang	Scatophagidae	*Scatophagus argus*	spotted scat	0	1	0	1
Lapih	Haemulidae	*Diagramma picta*	painted sweetlips	0	1	0	1
Rumahan laki	Scombridae	*Rastrelliger kanagurta*	Indian mackerel	0	1	0	1
Satak	Scyllaridae	*Thenus orientalis*	flathead lobster	0	1	0	1
Sembilang	Plotosidae	*Plotosus* spp.	eeltail catfish	0	1	0	1
Sotong	Loliginidae	*Loligo* spp.	squid	0	1	0	1
Udang galah	Palaemonidae	*Macrobrachium rosenbergii*	giant river prawn	0	1	0	1
Udang siar	Penaeidae	*Metapenaeus* spp.	prawn	0	1	0	1
Ungah	Lutjanidae	*Lutjanus argentimaculatus*	mangrove red snapper	0	1	0	1
Usus	Sillaginidae	*Sillago sihama*	silver sillago	0	1	0	1
Geronggong	Carangidae	*Megalaspis cordyla*	torpedo scad	2	0	0	2
Anunan	Rhinobatidae	*Rhynchobatus djiddensis*	giant guitarfish	1	0	0	1
Bedukang	Ariidae	*Hexanematichthys sagor*	Sagor catfish	1	0	0	1
Pisang-pisang	Lutjanidae	*Lutjanus lutjanus*	bigeye snapper	1	0	0	1
Taweh	Carangidae	*Alectis indica*	Indian threadfish	1	0	0	1
Utik	Ariidae	*Arius oetik*	catfish	1	0	0	1
Tungap				0	2	1	3
Kukut				0	0	1	1
Rantau				0	0	1	1
Pagong-pagong				0	0	1	1
Besar				0	3	0	3
Camau				0	1	0	1
Mengkarai				1	0	0	1
Sulai				1	0	0	1

* Scientific name for last 8 species could not be identified as the descriptions given by fishers were vague.

Appendix I-5.5 (Selected pelagic stocks' trend from official data)

Abundance of narrow-barred Spanish mackerel and Japanese scads between 2000 and 2009 based on standardised CPUE of official LS fishery data.



Test for linear trend in one-way ANOVA
Narrow-barred Spanish mackerel: $F_{9,289}$ = 26.264, p-value = <0.001
Japanese scad: $F_{9,164}$ = 12.230, p-value = 0.001

Appendix J (Manuscript published)

Syazana Ebil, Charles R.C. Sheppard, Ranimah Wahab, Andrew R.G. Price, James C. Bull (2013) Changes in community structure of finfish catches in Brunei Darussalam between 2000 and 2009, Ocean & Coastal Management, Volume 76, Pages 45-51

(http://www.sciencedirect.com/science/article/pii/S0964569113000537)