Recreational spearfishing: an historical, ecological and sociological perspective.

Thesis submitted by

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Statement on the contribution of others

This thesis includes collaborative work with my supervisors, Professor David Bellwood and Dr. Simon Foale. In these collaborations, I was responsible for the conception of the project, data collection, analysis and interpretation of data. My supervisors provided technical assistance, intellectual guidance, editorial advice and financial support.

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Abstract

Overfishing is a mounting threat to marine ecosystems and food security across the globe. Many of the world's fisheries are now overexploited or in decline and demand for marine resources is rising. Recreational fishing is a growing component of wild harvest fisheries and is increasingly linked to declines in fish populations. However, due to an absence of past monitoring and traditional fisheries data recreational fisheries are poorly understood, difficult to assess and pose governance challenges.

The first data chapter in this thesis (Chapter 2) aimed to establish historical evidence of fishery declines in recreational spearfishing literature and to examine spearfisher perceptions on the status of fisheries. The impact of recreational spearfishing on eastern blue groper (*Achoerodus viridis*) and grey nurse shark (*Carcharias taurus*) in Australia was analysed by assessing a chronology of spearfishing magazines (published between 1952 and 2009) for historical, ecological and social data. Reported captures of blue groper were found to decline by 90% from 1952–1967. Grey nurse shark captures also declined. Interestingly, early warnings of declines for both species emerged from the spearfishing community 17 and 19 years, respectively, before protection. While recreational fishers may have serious impacts on vulnerable fish species, they could also play a vital role in conservation and advocacy. This highlights the importance of reciprocal communication between fishers, scientists and governments for managing and detecting declines in vulnerable species.

The sustained decline in marine fisheries across the globe underscores the need to understand and monitor fisheries trends and fisher behaviour. The goal of the second data chapter (Chapter 3) was to explore broader historical trends in recreational spearfishing as documented in the chronology of spearfishing magazines. Data were extracted from reported

fish captures, advertising, and spearfisher commentary and regression models and ordination analyses were employed to assess historical change. The proportion of coastal fish captures reported declined by approximately 80%, whereas the proportion of coral reef and pelagic fish reports increased 1750% and 560%, respectively. Catch composition shifted markedly from coastal temperate or subtropical fishes during the 1950s to 1970s to coral reef and pelagic species in the 1990s to 2000s. Advertising data and commentary by spearfishers indicated that pelagic fish species became desired targets. The mean weight of trophy coral reef fishes also declined significantly over the study period (from approximately 30–8 kg). Recreational fishing presents a highly dynamic social–ecological interface and a challenge for management. The results emphasize the need for regulatory agencies to work closely with recreational fishing bodies to observe fisher behaviour, detect shifts in target species or fishing intensity, and adapt regulatory measures.

Isolation can provide marine ecosystems with a refuge from human impacts. However, information on the biodiversity, ecology and fisheries of remote regions is often sparse. The proposed Coral Sea Marine Reserve (CSMR) could create one of the world's largest and most remote marine parks, yet little information is available to inform discussions. The third data chapter in this thesis (Chapter 4) investigated the history of recreational spearfishing in the Coral Sea and the adjacent Great Barrier Reef (GBR) in light of the proposed CSMR. Fish captures from the Coral Sea and adjacent GBR were assessed from reports contained in the chronology of spearfishing publications from 1953 to 2009, and revealed, for the first time, the history of recreational spearfishing in the Coral Sea. Although the area is perceived as relatively untouched, the data indicated that spearfishers have frequented Coral Sea reefs for at least 43 years and reported captures have increased exponentially. Post-1993 trophy captures in the Coral Sea (mean 23 kg) were larger than the adjacent GBR (9 kg). Reef species characterize the GBR catch, while large pelagic species

characterize the Coral Sea catch. Provided that functionally important fishes are not targeted, the relatively small scale of recreational spearfishing and the focus on pelagic species suggests that spearfishing currently exerts limited pressure on the ecology of Coral Sea reefs.

Human population, wealth, longevity and demand for resources are rapidly increasing. Therefore, it is important to understand the drivers that influence human behaviour. The fourth data chapter (Chapter 5) utilised data sets of reported captures and print advertising in the 58-year chronology of spearfishing magazines and interviews with experienced fishers to examine the history and development of recreational spearfishing in Australia. The goal was to evaluate the role of technological, social and economic factors as potential drivers of change in this fishery. Advertising data and spearfisher accounts revealed that the basic equipment for spearfishing was established early and has undergone incremental refinements. The capacity for spearfishers to travel further increased significantly through time potentially reflecting increasing population, wealth, and boat ownership as positive drivers. However, multiple regression analysis identified satellite navigation technology as the most influential driver since the early 1990s. Recreational fishers corroborated this observation with 96% of interviewees identifying navigation technology as the most important driver of change in fishing behaviour. Navigation technology markedly improved the ability of fishers to locate fishing grounds and provided confidence to venture further afield. It probably underpinned a rise in fishing pressure at offshore locations. Through a combination of historical data and oral histories this chapter revealed the influence of satellite navigation technology on recreational fishing efficiency and highlighted the potential loss of ‘hard to find’ locations that acted as natural refuges. These findings emphasise the necessity for compensatory regulatory measures (including marine protected areas) to provide refuges for vulnerable target species.

In a world where pressure on marine resources is growing and fish populations are collapsing, it is important to understand the motivations that influence fisher behaviour to enable effective management. The fifth data chapter (Chapter 6) employed an ethnographic approach to interview and observe experienced fishers in Australia (recreational) and the Solomon Islands (subsistence/artisanal) and to provide cross-cultural insight into their behaviour, perceptions and motivations to fish. Although food and income were the most identified motivations by fishers in the Solomon Islands (100% and 93% of fishers, respectively), 75% of motivation categories paralleled those of recreational fishers. Fishers in the Solomon Islands also expressed an eagerness to actively pursue fishing despite the potential for alternative incomes, possibly reflecting the presence of a recreational mindset. The willingness to continue fishing in the absence of necessity illustrates the potential for growth of recreational fisheries where economic conditions improve. In Australia, connection to the environment was the most common motivation for recreational fishers (96% of fishers). Recreational fishers also perceived that fishing enhanced social capital, promoted respect for nature and provided health and economic benefits. Senior fishers identified young males to be most likely to engage in excessive fishing through displays of machismo, but emphasised the role of fishing in providing a safe environment for youth to vent angst and frustration. These results suggest that fishing activities may deliver fundamental benefits to individuals and societies and that in some regions fishers may be valuable advocates for conservation and social cohesion if their motivations and values are appreciated and channelled appropriately.

Recreational fishing is one of the highest participation activities across the globe and is likely to expand in regions with improved economic conditions. The potential impacts of recreational fishing may also grow through increased participation and enhanced efficiencies, mediated by advances in technology. Recreational fisheries can affect vulnerable species and

have detrimental impacts on habitats and ecosystems. However, recreational fishers can also exhibit strong environmental values and advocate for regulatory measures. This thesis highlights the importance of insight into the history and dynamics of recreational fishing and the behaviour, knowledge, values and motivations of fishers. Recreational fishing presents a dynamic social-ecological interface that requires a measured approach to engage and harness support and compliance from the recreational fishing community. Consideration and appreciation of these factors will help to secure the future of marine populations.

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Chapter 1: General introduction

1.1 A history of fishing and impacts.

Humans have exploited the world's rivers, estuaries and seas for thousands of years (Jackson *et al.* 2001, Hu *et al.* 2009). Thus, the practice of fishing and the harvesting of marine resources is deeply embedded within human society, culture and identity. Historically, ocean fisheries were perceived as vast and limitless (Roberts 2007). It was believed that no amount of fishing intensity could ever diminish the 'boundless' populations of marine species. However, growth in harvest intensity and fishing efficiency, particularly since the industrialisation of fishing, dramatically increased pressure on the world's fisheries (Roberts and Hawkins 1999, Watson & Pauly 2013). Widespread attention was drawn to the limited nature of fish stocks following the infamous demise of the Atlantic cod and orange roughy fisheries (Hutching & Myers 1994, Roberts 2007). These prominent case studies illustrated the vulnerability of fish populations to industrial scale fishing, slow or insufficient regulation, and the absence of basic life history knowledge of target species (Roberts 2007).

There are few corners of the globe that have escaped the impacts of fishing and many exploited species are now either overfished or declining (Costello *et al.* 2012, Watson & Pauly 2013). Overfishing poses a direct threat to the persistence of target and bycatch species, but it can also disrupt the healthy functioning of marine ecosystems and undermine their resilience (Jackson *et al.* 2001). The exploitation of functionally important species, in particular, can damage critical ecosystem processes and ecosystem equilibrium (McClanahan & Muthiga 1989, Myers *et al.* 2007, Bellwood *et al.* 2012). Overharvesting may also reduce the capacity of marine systems to bounce back from the effects of intensifying chronic

stresses on marine environments such as climate change and pollution (Levin *et al.* 2009, Hughes *et al.* 2015).

Overfishing also threatens food security for human populations, especially in developing nations striving to fulfil both local and global demand (Pauly *et al.* 2005, Sadovy *et al.* 2003, FAO 2014). Industrial-scale commercial fishing can also compete with local subsistence and artisanal fishers that depend on fishing for their livelihood (Pauly *et al.* 2005). Today, marine-derived protein is in high demand and contributes significantly to the diets of human populations across the globe (FAO 2014). Rising middle class wealth, globalisation, growing human populations and prestige associated with seafood consumption are likely to sustain this demand into the future (Worm *et al.* 2006, Mora & Sale 2011, Fabinyi 2012). Aquaculture absorbs some of the pressure on wild caught fisheries (FAO 2014), however the aquaculture industry also presents challenges due to the requirement for feed, the output of pollution, and the spread of disease (Naylor *et al.* 2000, Primavera 2006). Thus, the sustainability of wild fisheries remains a matter of ongoing importance (Costello *et al.* 2012).

1.2 Recreational fishing and missing data.

Profit-driven fishing has been the leading cause of harvest-related impacts in marine ecosystems (Sethi *et al.* 2010). As a consequence, most fisheries research has focussed on commercial and artisanal fisheries (Myers & Worm 2003, Berkes *et al.* 2006, Lewin *et al.* 2006, Brewer *et al.* 2012). However, there is a growing interest in the impacts and dynamics of recreational fishing across the globe (Cooke & Cowx 2004). Commercial fishing is an economic or profit driven fishing activity. Productivity and efficiency is of paramount importance and thus, commercial fishers have a history of rapidly exploiting a resource to maximum capacity before shifting fishing grounds or exploiting an alternative species

(Berkes *et al.* 2006, Roberts 2007). In contrast, recreational fishing is conducted for pleasure, interest, or to supplement food. Unlike commercial fishing, there is no direct monetary or profit factor involved and recreational fishers operate at a loss. Nevertheless, there is still a desire to catch large numbers of big fish (Shiffman *et al.* 2014).

Although recreational fishing research is limited, a number of studies have highlighted the potential for recreational fisheries to contribute to declines in vulnerable fish species (Sadovy 1999, Coll *et al.* 2004, Godoy *et al.* 2010) and impact aquatic ecosystems (Lewin *et al.* 2006). Recreational fishing is believed to contribute up to 12 percent of the global fish harvest (Cooke & Cowx 2004) and catch can exceed the commercial sector for some species and regions (McPhee *et al.* 2002). Evidence also suggests that recreational landings can disproportionately affect many of the most valued and overfished species (Coleman *et al.* 2004, Shiffman *et al.* 2014). Unlike commercial and artisanal fisheries, recreational fisheries are not subject to the same market and food security pressures. Rather, the recreational sector tends to thrive in affluent nations and presents a unique set of challenges for regulatory agencies.

Recreational fishing has one of the highest participation rates per capita in the developed world and may exceed 10 percent globally (Cooke and Cowx 2004). The economic importance of the recreational sector is also significant with billions of dollars contributed to local economies through equipment sales and fishing tourism (Borthwick 2012). The high level of community participation and economic value of recreational fishing also generates strong political influence, emphasising the importance of harnessing fisher support for regulatory measures (Helvey 2004, Sutton & Tobin 2009, Li *et al.* 2010). In some cases, recreational fishers have used their political power to stall or halt regulation or promote anti-conservation agendas (McClenachan 2013). Although the collective impacts of the

recreational fishing sector on marine populations have become increasingly apparent, they have historically been overlooked (McPhee *et al.* 2002, Cooke & Cowx 2004). Monitoring data on recreational catch and the collection of traditional fisheries data has been sparse or non-existent in recreational fisheries. Thus, the absence of this knowledge has hindered informed regulatory action (Cooke & Cowx 2004, Godoy et al. 2010).

1.3 Marine historical ecology and non-traditional data.

Scientists, managers and fishers can mistakenly reference the present conditions of a fishery or ecosystem as a baseline when knowledge of prior exploitation is absent. As subsequent generations remain unaware of earlier conditions, and impacts continue to alter the ecosystem, reference baselines can continue to change. This is known as the shifting baseline syndrome (Pauly 1995). Thus, historical sources of information have become critical for establishing past baselines and for understanding the extent of exploitation prior to modern monitoring programs (Pauly 1995, McClenachan *et al.* 2012, Kittinger *et al.* 2014). Historical research is a way of regaining lost or forgotten information that has the potential to provide a clearer picture of past and the changing perceptions of fishers (Al-Abdulrazzak *et al.* 2012, McClenachan *et al.* 2012).

When traditional fisheries or monitoring data are absent, alternative data sources are essential for reconstructing past fisheries (Jackson *et al.* 2001, McClenachan 2009, Al-Abdulrazzak *et al.* 2012). In the growing and evolving field of historical ecology, novel and non-traditional sources of historical data such as photographs, historical anecdotes, grey literature, and fishing competition data, are commonly used to unravel patterns in marine fisheries and alleviate the extent of the shifting baseline syndrome (Saenz-Arroyo *et al.* 2005, McClenachan 2009, Whatmough *et al.* 2011). Although these alternative sources of data

often lack information on fishing effort, they can provide remarkable insights into fisheries trends, the behaviours of fishers through time and can complement modern monitoring data and knowledge (Pauly 1995, Saenz-Arroyo *et al.* 2006, Lotze & McClenachan 2014). These alternative data sources can also help to detect shifts in target species, changes in gear types or fishing techniques, and assess biological metrics on reported captures (McClenachan 2009, Thurstan *et al.* 2014). It is also possible to extract past social information, institutional and legislative changes, and assess the perspectives of fishers through time. These novel data sources, therefore, provide valuable insights for future management and help establish a robust platform for considered regulatory action.

1.4 Historical overfishing in coral reef ecosystems

Historical analyses can also provide trajectories of long-term declines in marine ecosystems (Pandolfi *et al.* 2003). Numerous studies have examined the demise of the world's coral reefs and identified that the overfishing of megafauna, carnivores, and herbivorous reef fish has been a precipitating factor in their decline (Jackson 1997, Pandolfi *et al.* 2003). The sequential loss of large and herbivorous reef fish and the transition to smaller fish has led to a reduction in grazing on coral reefs and increased macroalgal growth (Pandolfi *et al.* 2005). These historical trajectories of reef degradation help to unravel global patterns of ecosystem collapse, predict future ecosystem states, and anticipate ecosystem decline through patterns of sequential loss of species and habitats (Pandolfi *et al.* 2003).

1.5 Spearfishing

Spearfishing is a highly selective recreational fishing method in which participants sight and target individual fish (Coll *et al.* 2004). Unlike line and commercial fishing, the ability for spearfishers to establish the size and identify a target fish prior to spearing avoids the

problem of incidental bycatch (Gaines & Costello 2013). Thus, with carefully considered regulation of target species, bag limits, and minimum and maximum sizes, and adequate compliance, spearfishing may be particularly responsive to effective management.

Nevertheless, spearfishing can have considerable impacts, particularly in countries where subsistence and artisanal fishers have fished down the food chain and transitioned from piscivorous fish species to lower trophic level herbivorous or planktivorous target species (Pauly *et al.* 2002, Cinner *et al.* 2009, Godoy *et al.* 2010). Spearfishing can also impact fish species that possess vulnerable life history or behavioural characteristics such as high site fidelity, low fecundity or late maturation (Sadovy 1999, Coll *et al.* 2004, Lloret *et al.* 2008). Large groupers, wrasse, some sharks, and parrotfish, among others, have all been identified as groups susceptible to spearfishing (e.g., Godoy *et al.* 2010, Lokrantz *et al.* 2010, Graham *et al.* 2013). However, research into the potential impacts of recreational spearfishing on fish populations has been limited due to the scarcity of data on landings and effort (but see Coll *et al.* 2004, Lloret *et al.* 2008).

1.6 Aims

The broad aims of this thesis were to explore the historical patterns, ecological implications and the social dynamics of spearfishing in Australia. It also aimed to investigate historical trends in exploitation and examine the behaviour, values and perceptions of fishers with the objective to improve historical knowledge of the fishery and reconstruct a picture of past marine systems. The findings of the thesis may offer insight into future patterns in recreational fishing pressure, helping to anticipate unforeseen challenges and improving the range and efficacy of management approaches.

The first three data chapters in this thesis (Chapters 2, 3 and 4) explored the historical impacts and patterns in recreational spearfishing in Australia and aimed to define *what* has

occurred historically. The subsequent data chapters (Chapters 5 and 6) investigated the potential drivers of these trends and explores *why* the observed patterns in spearfishing occurred. There are five main approaches to achieve the project's broader objectives. The first approach in **Chapter 2** was to ask: **"Is there historical evidence of fishery declines in spearfishing literature and how have spearfishers perceived declines?"** This chapter explored two historical case studies and provides insight into spearfisher perceptions. Following the detailed case studies, **Chapter 3** aimed to examine the broader historical trends and asked: **"What have been the major trends in catch and fisher behaviour throughout the history of recreational spearfishing in Australia?"** This chapter explored how the fishery has evolved and highlighted the potential vulnerability of coral reef fishes. In response to these findings, **Chapter 4** then asked: **"How has spearfishing impacted coral reef ecosystems in Australia's Coral Sea and Great Barrier Reef?"** Exploring beyond the historical insights **Chapter 5** asked: **"What is the relative role of technology and other social factors in driving offshore movement of fisheries?"** This chapter explored the history of gear development in spearfishing and identified a number of potential drivers that have improved spearfishing efficiency and driven recreation fishing activity further from shore. The aim of **Chapter 6** was to delve deeper into the motivations of fishers through a cross-cultural, ethnographic study and asked: **"What motivates fishers to fish?"**

Chapter 2: Impacts of recreational fishing in Australia: historical declines, self-regulation and evidence of an early warning system

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2.1 Introduction

The decline in wild fish populations is a pressing global concern (Roberts & Hawkins 1999, Jackson *et al.* 2001, Pauly *et al.* 2002). Marine systems are under ever increasing pressure due to rapidly growing human populations, rising wealth and higher demand for seafood (Worm *et al.* 2006, Fabinyi 2012, Hughes *et al.* 2013). Declines in commercial or artisanal fisheries (Pauly *et al.* 2002, Pinnegar & Engelhard 2008, Thurstan *et al.* 2010) and their accompanied social and ecological implications (Foale 2005, Worm *et al.* 2006, Christensen 2011) are well documented. However, the role of recreational fishing in fishery and ecosystem degradation is much less understood (Cooke & Cowx 2004, Erisman *et al.* 2011, Altieri *et al.* 2012). Yet, there are calls for increased regulation of recreational fisheries and further research into their potential impacts and management (McPhee *et al.* 2002, Cooke & Cowx 2004, 2006), as examples of declines in marine populations continue to emerge (Erisman *et al.* 2011, Cardinale *et al.* 2012).

Historical knowledge of past impacts and trends within fisheries is important for detecting fishery declines and for appropriate management (Pauly 1995, Swetnam *et al.* 1999, Jackson *et al.* 2001). The significance of learning from history is eloquently described by a Chinese proverb, ‘Past experience, if not forgotten, is a guide for the future’. However, historical assessments of recreational fisheries are often missing, largely because monitoring

data or catch records do not exist or are extremely sparse (Pauly 1995, Cooke & Cowx 2004, McClenachan 2009, Godoy *et al.* 2010). In the absence of modern monitoring data, non-traditional data sources are critically important for establishing historical knowledge, evaluating the social and ecological costs of fisheries and for informing management (Pauly 1995, Swetnam *et al.* 1999).

Often overlooked by past researchers, novel data sources such as photographs, observational reports, fishing competition results and grey literature may provide untapped opportunities for the assessment of fisheries (Coll *et al.* 2004, Saenz-Arroyo *et al.* 2005, McClenachan 2009, Godoy *et al.* 2010, Whatmough *et al.* 2011). These alternative sources of data often lack information on fishing effort, but can reveal remarkable insights into fisheries trends and the behaviours of fishers through time, complement modern monitoring data and knowledge, and help to alleviate the extent of the shifting baseline syndrome, whereby fishers, scientists and managers form altered perceptions of fisheries in the absence of historical knowledge of past impacts (Pauly 1995, Swetnam *et al.* 1999, Saenz-Arroyo *et al.* 2006). Such studies may also be useful for detecting shifts in target species, changes in gear types or fishing techniques, and for assessing biological metrics (such as length and weight) on reported captures (Saenz-Arroyo *et al.* 2005, McClenachan 2009). It is also possible to extract past social information, institutional and legislative changes, and assess the perspectives of fishers through time (Saenz-Arroyo *et al.* 2005, Whatmough *et al.* 2011). These novel data sources may provide valuable insights for future management and a platform for considered regulatory action.

Spearfishing has had substantial impacts on vulnerable and functionally important species in a number of countries, particularly where artisanal fishers have fished down the food chain and transitioned from high trophic level piscivorous fish species to lower trophic level herbivorous or planktivorous target species (Pauly *et al.* 2002, Cinner *et al.* 2009,

Godoy *et al.* 2010). However, there has been limited formal research into the potential impacts of 'recreational' spearfishing on fish populations, due to the scarcity of data on landings and effort (Coll *et al.* 2004, Lloret *et al.* 2008). In the present study, we aim to address this knowledge gap by employing a novel approach and data source. We specifically set out to examine the impact of recreational spearfishing on fish populations, explore changes in recreational spearfishing catches, gear types and techniques, and to assess fisher attitudes and reporting from a spearfishing perspective in Australia.

2.2 Methods

We examined a chronology of Australian spearfishing publications from 1952 to 2009 (see title chronology in Appendix 2.1, Table S2.1) for reports of trophy catches of two historically important coastal fish species, eastern blue groper (*Achoerodus viridis*) and grey nurse shark (*Carcharias taurus*). Four magazine issues per year (commencing in 1952 and subsequently every odd year) were sampled over the entire 58-year period (only two issues were accessible for 1987 and three issues for 1995, 1997 and 1999). Data on speared fish were extracted from trip reports, competition reports, club outing reports, and photographs within the magazines. Most reports within the magazines explicitly detailed species and size (weight or length) data of caught fish. Where these data were absent, fish identification and length estimates were made by assessing published photographs. For nine eastern blue groper specimens, length estimates were converted to weights using published length and weight values (Gillanders 1999). Reported captures that did not provide size data or photographs were excluded from any size-based analyses.

The proportion of the total catch represented per issue by eastern blue groper, and the number of grey nurse sharks (total per four issues sampled annually) were calculated over

time from 1952 to 2009. Additional data on grey nurse shark beach meshing/net captures in New South Wales (NSW) were extracted from Pollard *et al.* (1996). Data were restricted to the state of NSW for both species because this was the region subject to the most intense fishing pressure. We carefully excluded reports of the closely related, but geographically distinct species *Achoerodus gouldii* (western blue groper). Linear and polynomial regression models were fitted to the proportion, count and size data (blue groper weight and grey nurse length) over time, and analysed with the statistical package R. Data were transformed with log or log(x + 1) transformations for analyses where appropriate, and were found to meet the assumptions of homogeneity of variance and normality of distribution.

We also examined the perspectives and attitudes of the spearfishing community in relation to eastern blue groper and grey nurse shark populations, through published comments. These comments/opinions were stated by many prominent members of the spearfishing community in reports, articles, opinion pieces, letters to the editor and columns within the magazine issues examined (Appendix 2.2). The commentary provides chronologically-based insights into the changing perspectives of recreational spearfishers over the 58-year study period. Developments in gear types, shifts in spearfishing techniques, or changes in fisheries regulations were also noted.

2.3 Results

Blue groper and grey nurse sharks were prominent and prized target species for spearfishers in the 1950s and 1960s, and frequently appeared on magazine covers (Appendix 2.1, Fig. S2.1). Blue groper regularly featured in reports, competition results, and club trip reports. Grey nurse sharks appeared abruptly as trophy captures in the late 1950s, coinciding with the advent of powerheads (explosive spear tips, often made with shotgun shells) around 1962.

Dead grey nurse sharks made for impressive photographs for magazine covers and trip reports. The focus on these species by spearfishing publications clearly demonstrated their significance to the recreational spearfishing community during this period.

The impact of spearfishing on eastern blue groper (*Achoerodus viridis*)

From the first magazine issues we assessed (1952) eastern blue groper were a common target species, comprising around 40% of the reported catch (Fig. 2.1). Reports of eastern blue groper subsequently declined significantly, halving by 1960 and virtually absent (4% of reported catch) by 1967 (linear regression: $R^2 = 0.52$, $F = 27.88$, df = 1, 26, $p < 0.001$). This decline occurred prior to the protection of blue groper in New South Wales (NSW) in 1969.

The size of speared eastern blue groper declined steadily between 1952 and 1969 from 12 to 8 kg on average ($R^2 = 0.18$, $F = 24.32$, df = 1, 110, $p < 0.001$; Fig. 2.2). No fish larger than 15 kg were reported after 1961. The majority of blue groper killed by spearfishers were large and old, in excess 8.4 kg and probably over 30 years of age. These fish were also likely to be male, as the protogynous eastern blue groper change sex from female to male between 10–20 years of age.

The impact of spearfishing and beach netting on grey nurse shark (*Carcharias taurus*)

Grey nurse shark captures also declined precipitously from 1950 to 1990 (Fig. 2.3; 3rd order polynomial regression: $R^2 = 0.78$, $F = 44.66$, df = 3, 37, $p < 0.001$). Beach mesh/net capture data reveal that grey nurse populations were dropping from the early 1950s, before the impact of spearfishing. Between 1956 and 1974 the annual mesh/net captures of grey nurse sharks steadied at less than half the 1950 level. Although grey nurse sharks represented a small proportion of the fish species reported in the magazines, the annual number reported by

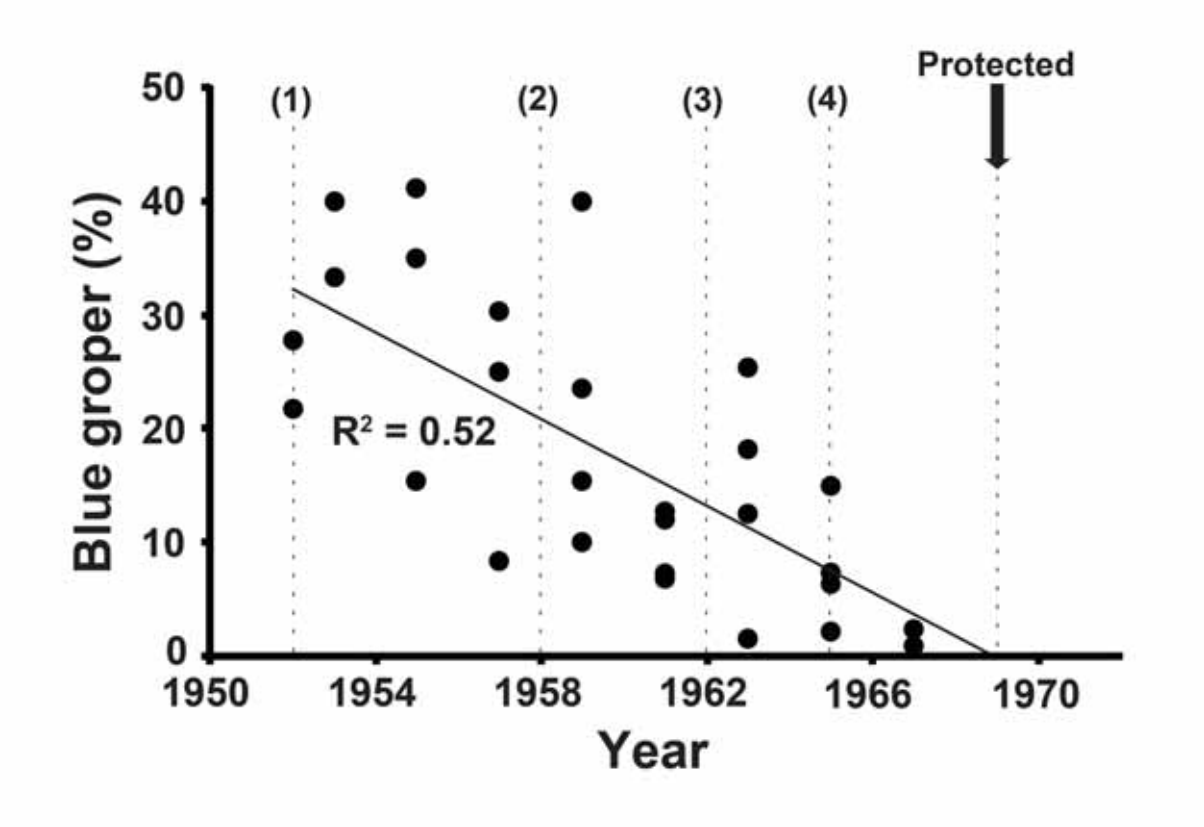

Figure 2.1 Eastern blue groper (*Achoerodus viridis*) as a proportion of total fish reported in spearfishing publications through time. Each point denotes a sample issue. Numerals above dashed lines indicate a selection of key early warnings voiced by prominent members of the spearfishing community. (1) Plea to spearfishers to only take enough blue groper for their needs and allow others to breed, and first suggestion of imposing a bag limit as a means of self-regulation. (2) Concerned spearfishing groups approach the NSW government and request a bag limit on the capture of blue groper. (3) Due to further declines in groper and concern for ecological implications, spearfishers suggest a one fish bag limit. (4) The demise of eastern blue groper is considered symbolic of the folly of spearfishing, and alternative activities to reduce spearfishing pressure are discussed (also Appendix 2.2, Table S2.2).

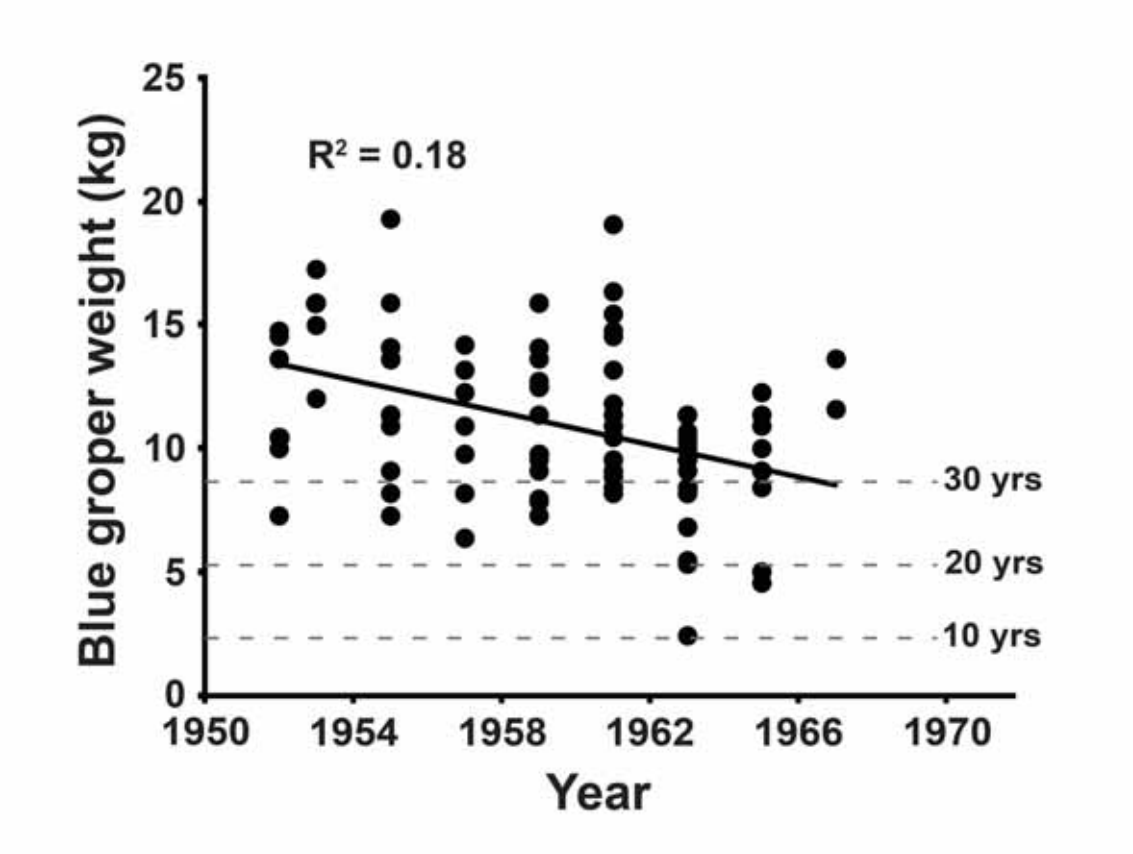

Figure 2.2 Weight (kg) of speared eastern blue groper (*Achoerodus viridis*) through time. Also indicated are approximate ages at weight (Gillanders 1999).

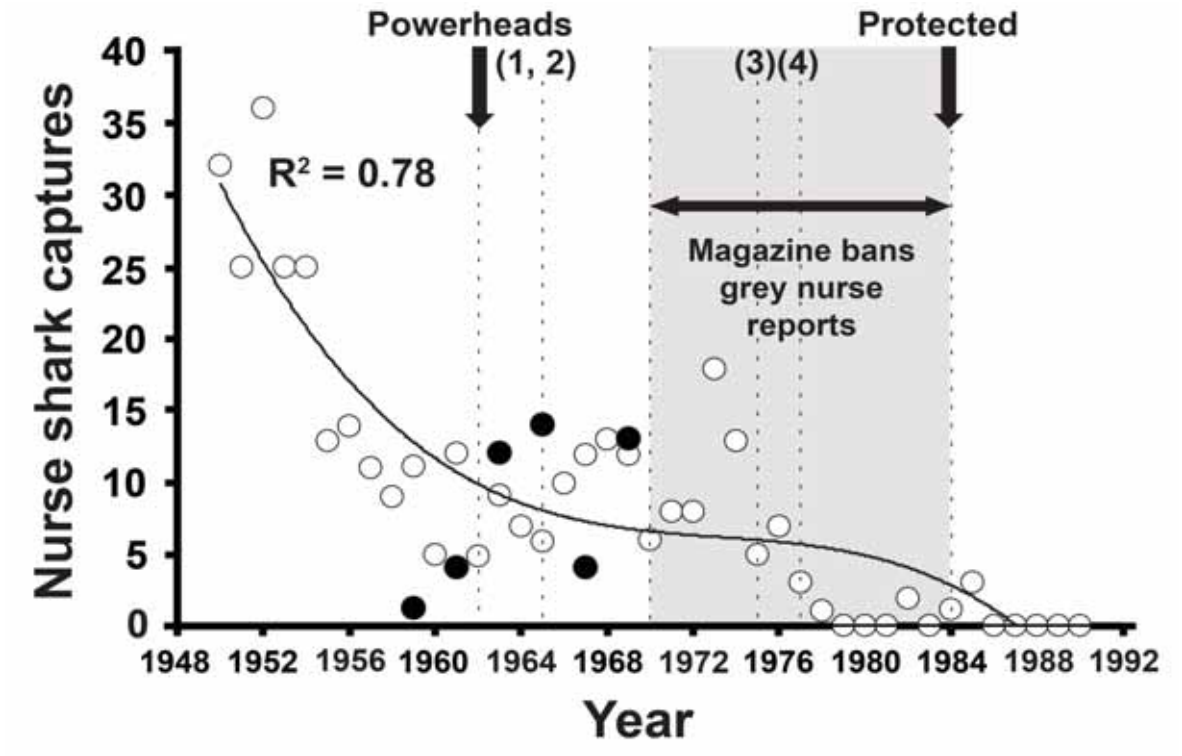

Figure 2.3 The number of grey nurse sharks (*Carcharias taurus*) reported in spearfishing publications through time (closed symbols). Each count represents a total of the four magazine issues sampled per year. Annual counts of grey nurse sharks captured in the New South Wales beach meshing programme (open symbols). Numerals above dashed lines indicate a selection of key early warnings voiced by prominent members of the spearfishing community. (1) Author highlights that grey nurse sharks are not man eaters and their populations are at risk of extinction. (2) It is acknowledged that the killing of grey nurse sharks is quickly wiping out the species and that neither the public nor fisheries department are interested in shark conservation. (3) The misconceptions about sharks and media sensationalism (coinciding with the release of the movie *Jaws*) are highlighted as major setbacks for any potential shark conservation measures. (4) The devastating impact of powerheads on shark populations is discussed (Appendix 2.2, Table S2.3). Grey shading from 1970 indicates the period prior to protection that *Skindiving in Australia* magazine voluntarily supported a ban on divers killing grey nurse sharks and refrained from publishing reports on their capture.

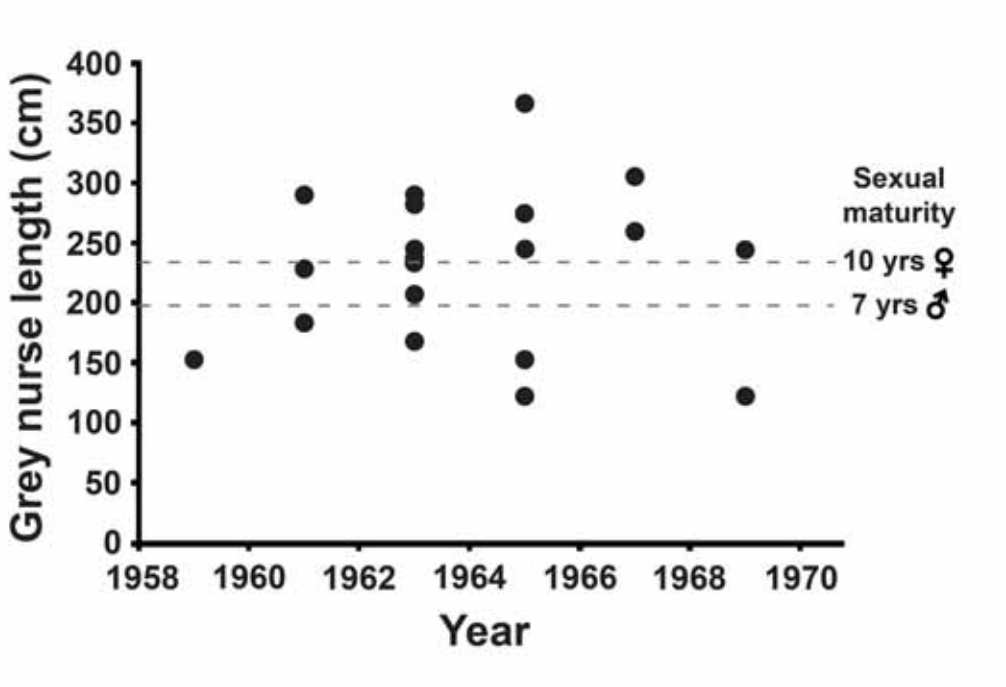

Figure 2.4 Length (cm) of speared grey nurse sharks through time. Dashed lines indicate average length at age for reproductively mature sharks (Goldman *et al.* 2006).

spearfishers generally increased after the introduction of explosive spear tips or powerheads (c. 1962). Following this, beach mesh/net captures continued to decline.

The length of grey nurse sharks taken by spearfishers ranged from 120 to 370 cm (Fig. 2.4). Nearly 50% of the grey nurse sharks killed were below the age of sexual maturity for females, at approximately 9–10 years of age or a length of 235 cm.

Blue groper and grey nurse sharks: the perspective of spearfishers

As reports of both eastern blue groper and grey nurse shark captures declined, our analysis of published comments within spearfishing publications revealed a simultaneous response of increasing concern from members of the recreational spearfishing community (Figs. 2.1, 2.3; Appendix 2.2). In both cases, prominent spearfishers repeatedly published warnings about declining fish populations, suggested regulatory measures, and lobbied government for action. Despite the early warnings and action by spearfishers, legislation for the protection of eastern blue groper and grey nurse shark took 17 and 19 years, respectively, to be enacted.

2.4 Discussion

We used popular literature to assess historical trends, ecological data and social information on recreational fisheries. Our results reveal that recreational spearfishing may contribute to dramatic declines in vulnerable target species (Fig. 2.1, 2.3). Thus, careful monitoring and regulation is imperative in countries where recreational fisheries exist. However, in the present case studies, early concerns regarding declining fisheries actually emerged from within the spearfishing community (Appendix 2.2). Unfortunately, by the time governments responded to the warnings, the populations had already declined to extremely low levels

(Pollard *et al.* 2003, Choat & Pollard 2010). Leaders among the spearfishing community presented a valuable but underused early warning system of fish declines.

Our results suggest that targeted spearfishing was a significant factor in the declines of these two focal species, although other drivers such as incidental commercial/recreational line fishing and netting may have contributed further pressures (Pollard *et al.* 1996, 2003, Choat & Pollard 2010). Additionally, in many other fisheries worldwide the impact of spearfishing may be non-existent or negligible in comparison to commercial and/or line fishing (Pauly *et al.* 2002, Thurstan *et al.* 2010).

The demise of eastern blue groper (*Achoerodus viridis*)

The loss of eastern blue groper may have had major impacts on the ecology of coastal temperate reefs. Our analyses reveal that most reported blue groper were over 10 to 20 years old (Fig. 2.2), an age range in which most of the individuals in this protogynous species would have changed sex from female to male (Gillanders 1995a, Bax 2011). Thus, exploitation by spearfishing may have contributed to a scarcity of males and the skewed sex distributions observed in the 1990s (Gillanders 1995a). Notably, the first scientific research on the biology and ecology of eastern blue groper did not commence until the early 1990s,more than 20 years after their populations had already declined. From a sample of 173 eastern blue groper collected between 1991 and 1993, the largest fish recorded was only 65 cm, or approximately 8 kg (Gillanders 1995b). Thus, the eastern blue groper populations examined by scientists in the 1990s were markedly different to those of the 1950s in terms of numbers, size and sex ratios, and thus presented a false baseline. Given the old ages of blue groper removed by spearfishing, and an estimated generation length of 12–15 years (Choat & Pollard 2010), population recovery to pre-1950s levels could take many decades.

As large eastern blue groper disappeared, sea urchin abundance appears to have increased by 3–4 fold (Appendix 2.2, Table S2.2), highlighting the potential importance of blue groper as predators in regulating sea urchin densities (Bax 2011). Sea urchins occur in the gut content of 20% of small (< 30 cm) eastern blue groper and in 70% of large (> 30 cm) individuals (Gillanders 1995b). Given all blue groper reported in the present study exceeded 30 cm in length, the capacity for blue groper to prey on sea urchins was likely to be depleted (Young & Bellwood 2012). The relationship between the loss of fish predators of sea urchins, urchin population increases, decline in macroalgae and the expansion of urchin barrens is well established (McClanahan & Muthiga 1989, Tegner & Dayton 2000).

The demise of grey nurse shark (*Carcharias taurus*)

Beach meshing programmes commenced at numerous locations in NSW during the 1930s to protect swimmers from sharks. However, the nets were highly effective at removing harmless grey nurse sharks from the netted localities (Pollard *et al.* 1996; Fig. 2.3). By the 1980s, grey nurse sharks had all but disappeared from the annual net catch. Spearfishing for sharks was popularized by media productions (films, books and magazines) that advocated their killing (Pollard *et al.* 1996, Otway & Parker 2000) and, from 1959, contributed to the decline in grey nurse (Fig. 2.3; Appendix 2.2, Table S2.3). While the netting programme captured roving sharks, spearfishers sought grey nurse habitat and promptly decimated newly discovered populations (Appendix 2.2, Table S2.3). Prominent spearfisher and later conservationist, Valerie Taylor, attributed the decline in grey nurse populations to spearfishing and the invention of the powerhead (Pollard *et al.* 1996).

Grey nurse sharks faced serious declines, yet there had been little public pressure or political will to protect them due to the misconception that grey nurse sharks were

'maneaters' (Appendix 2.2; Pollard *et al.* 1996). Confounding the situation was the lack of scientific information on grey nurse shark behaviour (Otway & Parker 2000), media sensationalism about the threat of sharks (including the release of the movie Jaws in 1975), and an irrational fear among the public (Whatmough *et al.* 2011, Neff 2012). In fact, the public had hailed spearfishers as heroes for removing the perceived threat of sharks (Appendix 2.2, Table S2.3). Ironically, calls for protection came from the spearfishers and divers themselves (Pollard *et al.* 1996).

Both grey nurse sharks and eastern blue groper display characteristics typical of vulnerable species (Dulvy *et al.* 2003). Long lifespan, slow growth, restricted range, inquisitive behaviour and an instinct to retreat into caves when threatened, contributed to the demise of eastern blue groper (Bax 2011; Appendix 2.2, Table S2.2). Likewise, long lifespan, late maturity, low fecundity (1–2 pups biannually), long gestational period, aggregating behaviour and a passive nature made grey nurse sharks susceptible (Pollard *et al.* 1996, Otway & Parker 2000, Ahonen & Stow 2009). Almost half of the speared grey nurse in our sample were below the reproductive age for females (Fig. 2.4; Goldman *et al.* 2006). Both coastal species were also readily accessible targets from shorelines or small boats due to their close proximity to shore and their high degree of site fidelity.

Evidence for potential self-regulation and an early warning system for management

Recreational fishers are often depicted and perceived to possess an anti-conservation agenda (Sutton & Tobin 2009), yet here we present evidence of a recreational spearfishing community raising the alarm in response to declining fish populations well before management realised the need for protection (Appendix 2.2). Not only did spearfishers publish early warnings, they were also proactive, informing management authorities of their concerns, encouraging self-regulatory restrictions (such as bag limits) and requesting official

regulation (Appendix 2.2, Tables S2.2 and S2.3). In fact, concern for the survival of grey nurse populations became so great among spearfishers that from 1970 the editor of Skindiving in Australia magazine refrained from publishing any further catch reports (Fig. 2.3; Appendix 2.2, Table S2.3). These early warnings from the spearfishing community emerged at a time when declines in both fish populations may have been prevented, illustrating the conundrum of management lag and the burden of proving fishery declines solely with traditional monitoring data (Pauly 1995).

Spearfishers spend much of their time in the water, which enables them to observe and monitor changes in marine populations. Therefore, witnessing declines in their valued resource first-hand may have prompted action (Lin 2009). Seeing is perhaps, believing. This pattern of self-imposed regulation has occurred in other fisheries around the world, including beche de mer (Skewes 1990) and the ornamental aquarium trade (Donnelly 2009). Thus, the two present case studies of recreational fishers raising their concerns with management is reflective of a broader global phenomenon, whereby stakeholders may take proactive steps to protect their resource. Although attempts at self-regulation in the present case studies were not sufficient to stem declines, it would be in the interest of management authorities to embrace, assess with caution and act upon stakeholder concerns, observations and actions at the earliest possible stage.

Other evidence also suggests recreational fishers can demonstrate strong support for regulatory measures (Sutton & Tobin 2009). Following the 2004 rezoning of the Great Barrier Reef Marine Park (GBRMP), 68% of fishers believed that the rezoning was a good idea and 57% expressed support for it. However, recreational fishers also felt that management, scientific and government authorities inadequately consulted them on major decisions (Sutton & Tobin 2009) or felt too ill-informed to make valuable contributions (Li *et al.* 2010). Few fishers (25%) believed that the consultation process was adequate for the 2004

GBRMP rezoning and this was largely attributed to issues in communication (Sutton & Tobin 2009).

Public opposition resulting from insufficient or ineffective engagement and communication of the science behind management decisions (Lin 2009, Sutton & Tobin 2009, Li *et al.* 2010) can delay the development and implementation of conservation policies (Helvey 2004). Thus, in cases where representative recreational bodies raise conservation and sustainability concerns, we suggest that management authorities immediately heed these warnings, closely monitor the fisheries and enhance channels of communication. Too much valuable time can be lost in conflict and disagreement, when 'the protection and propagation of fish' (to quote the primary agenda of the Australian Underwater Skindivers and Fishermen's Association) is ironically the common goal of recreational fishers, fisheries management, scientists and conservationists.

2.5 Conclusion

This study demonstrates that recreational fisheries may have serious impacts on vulnerable fish species and marine ecosystems. However, it also reveals that recreational fishers could play a vital role in conservation and advocacy. Members of the groups responsible for depleting these populations of vulnerable species recognized the problem early on and attempted to stop it. Had the government listened and acted on their concerns they may have stopped the damage much sooner. With growing impetus for stronger management of recreational fisheries worldwide, our results highlight the importance of multi-directional channels of communication between fishers, managers and scientists, for the sharing of information, the minimization of conflict and in providing an early warning system for declines in targeted species. Since protection, evidence for the recovery of eastern blue

groper and grey nurse shark populations is limited, with blue groper populations described as steady (Choat & Pollard 2010) and grey nurse shark populations listed on the IUCN red list as critically endangered and declining (Pollard *et al.* 2003). Too little, too late?

Chapter 3: Dynamic catch trends in the history of recreational spearfishing in Australia

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3.1 Introduction

Marine fisheries provide a major source of food and livelihood for hundreds of millions of people across the globe (Pauly *et al.* 2002, Costello *et al.* 2012). Thus, overfishing can have profound ecological, economic, and social implications (Pikitch 2012). Many regions of the world's oceans are now considered fully exploited (Roberts 2007, Watson & Pauly 2013), and fish stocks continue to decline (Costello *et al.* 2012). Human population growth, rising wealth, habitat degradation, and increasing demand for seafood are a few of the drivers that place immense pressure on fish populations, marine ecosystems, and food security (Worm *et al.* 2006, Fabinyi 2012, Hughes *et al.* 2013).

Profit-driven fishing is the leading cause of harvest related impacts in marine ecosystems (Sethi *et al.* 2010). Naturally, most research has focused on commercial fisheries (Jackson *et al.* 2001, Myers & Worm 2003, Berkes *et al.* 2006), although artisanal fisheries are also well researched (Foale 2005, Christensen 2011, Brewer *et al.* 2012). In contrast, research on recreational fisheries is limited, yet they are increasingly recognized for their potential to contribute to declines in vulnerable fish species (Cooke & Cowx 2004, Erisman *et al.* 2011, Young *et al.* 2014). Recreational landings may even exceed commercial landings in some regions (McPhee *et al.* 2002). Recreational fisheries are also unique in that they usually occur in developed regions and are largely free from the market or food security pressures that influence commercial and artisanal fisheries (Brewer *et al.* 2012, Hunt *et al.*

2013). Instead, recreational fisheries are subject to drivers such as interest or relaxation (Knopf *et al.* 1973) and thus present a different set of challenges for regulatory agencies. In Australia recreational fishing ranks among the most popular sports and activities (approximately one-fifth of the population participates) and annually contributes up to AU$10 billion to the economy (Borthwick 2012). Thus, it is extremely important from social, ecological, and economic perspectives.

Spearfishing is a branch of recreational fishing known to have considerable impacts on fish species with vulnerable life history or behavioural characteristics (Lloret *et al.* 2008, Young *et al.* 2014). Spearfishers typically target large individuals and may exert pressure on the reproductive potential of numerous fish species (Coll *et al.* 2004, Lloret *et al.* 2008). Large groupers, wrasse, some sharks, and parrotfish, among others, have all been identified as groups susceptible to spearfishing (e.g., Godoy *et al.* 2010, Lokrantz *et al.* 2010, Graham *et al.* 2013). However, spearfishing is also a highly selective fishing method; participants sight and target individual fish (Coll *et al.* 2004). This permits spearfishers to identify and gauge the size of target fish prior to spearing and avoids the problem of bycatch, which is associated with commercial and line fisheries (Gaines & Costello 2013). Thus, with carefully considered regulation of target species, bag limits, and minimum and maximum sizes and with adequate compliance, recreational spearfishing catch may be well suited for effective co-management.

Fisheries declines can progress unrecognized until a critical point when severe regulatory measures or entire fishery shutdowns are required to prevent collapse (e.g., Roberts 2007, Erisman *et al.* 2011, Gaines & Costello 2013). In many instances the response by regulatory agencies is too late (Berkes *et al.* 2006, Young *et al.* 2014). Fishers can also adapt or shift to alternative fisheries or localities in response to stock declines, leaving regulatory agencies behind and in a perpetual state of catch-up (e.g., Berkes *et al.* 2006,

Andersen *et al.* 2011, Cardinale *et al.* 2011). Early detection of fisheries declines and shifts in fisher behaviour and prompt and appropriate regulatory actions require an intimate knowledge of fisheries trends and close communication with fishers (Armitage *et al.* 2009, Young *et al.* 2014).

For successful fisheries management, it is also important to move beyond documenting the impacts of fishing on fish populations to consider the drivers of fishing activities (Sethi *et al.* 2010). Processes affecting the behaviour of both fish and fishers, and the subsequent management responses to population declines, can all impact the degree of resilience of fisheries and the risk of their collapse (Arlinghaus *et al.* 2013, Post 2013). Therefore, it is critical to recognize, understand, and monitor trends in both fish populations and the behaviour of fishers. Such knowledge will help regulatory agencies anticipate changes in potential drivers of fishery declines and formulate or adapt marine policy (e.g., Armitage *et al.* 2009, Hunt *et al.* 2013, Wilde & Pope 2013).

To identify fisheries of concern, establish historical trends, and improve understanding of contemporary fisheries, it is valuable to build a comprehensive picture of the past. However, historical data sets that are suitable for traditional fisheries analyses are often scarce, limited or non-existent, especially for recreational fisheries (Cooke & Cowx 2004). Thus, researchers are increasingly recognizing the importance of nontraditional sources of historical information (Pauly 1995, Swetnam *et al.* 1999) to unravel patterns in marine fisheries (Saenz-Arroyo *et al.* 2005, McClenachan 2009, Young *et al.* 2014). Our objective was to document trends in recreational spearfishing in Australia from 1952 to 2009 by using a chronology of spearfishing magazines. By assessing reported fish captures, advertising data, and historical commentary in these publications, we aimed to identify shifts in fisher behaviour, catch composition, and the size of target species to provide a historical trajectory of spearfishing trends.

3.2 Methods

To examine the historical capture trends of a recreational fishery where traditional fisheries data are absent, we extracted data on fish captures as reported in a chronology of spearfishing publications from 1952 to 2009 (Appendix 2.1, Table S2.1). This chronology of magazines was the most consistent and stable sequence available. Although the titles changed for marketing purposes, only 2 publishers were responsible for the publications over the 58-year period, which offered some consistency in management and editorial approach. The Underwater Skindivers and Fishermen's Association (USFA) published magazines from 1952 to 1970 and Mountain, Ocean and Travel Publications from 1970 to 2009. Upon commencement of the latter publication, the editor noted that the magazine was created to replace the USFA publication that had ceased to exist. This magazine was also published during a period when growth in scuba and underwater photography activities contributed to a decline in spearfishing participation (hereafter, conservation era). Although some spearfishing undoubtedly continued, reports of fish captures in the magazine ceased (Appendix 3.1, Table S3.1; also see Whatmough *et al.* [2011] and Byron [1998]). We omitted these years (1975–1993) for which there were no catch records. Due to the quantity of magazines and our labour intensive sampling approach, we sampled only odd years. Odd years were selected because they provided the most consistent number of available magazines from the archives (more even-year issues were missing). We included 1952 in the analyses because this was the earliest year available. In each sampled year, we examined 4 issues (only 2 issues were accessible from the archives for 1987 and 3 issues for 1995, 1997, and 1999). In most years the magazines were quarterlies; thus, we had complete coverage. In years with more issues, we randomly sampled 4 issues.

Data on speared fishes were extracted from multiple sources within the magazines to provide a comprehensive coverage of the catch. These sources included trip reports, competition reports, club outing reports, reader catch reports, and photographs. Most reports explicitly detailed species and size (weight or length) data. Alternatively, the identification of fish and estimations of length were made by assessing published photographs. Length estimates were then converted to weights with the length–weight relationships published on Fishbase (Froese & Pauly 2013). In cases where published relationships were not available, the length-weight relationship of a closely related species was substituted. Where no suitable substitute for conversion was available, those species were excluded from size-based analyses. If reported captures did not include size data or photographs, those captures were also excluded.

Recorded fish were identified to the lowest practical taxonomic grouping. In most cases, identification to species level was possible, but for some captures identification was limited by spearfisher identifications (i.e., parrotfish, coral trout = *Plectropomus* spp.). These species or groupings were also classified into the most appropriate habitat type for the species (coastal, coral reef, or pelagic). In cases where there was overlap in habitat type, we selected the habitat where spearfishers most commonly encountered the group. For example, *Lutjanus argentimaculatus* could be classified in both coastal and coral reef categories, but spearfishing reports of this species predominantly arose from coral reef localities. Proportions of the total catch represented per year for each species group and by each habitat type were then calculated. The mean estimated weight of trophy fish that were reported from each of these habitats was also calculated for each year. Years with sample sizes of <10 were excluded from analyses.

We also examined advertising within the issues of spearfishing publications to assess spearfishing industry trends and to gain insight into the fish groups that have been popular

through time. We specifically sampled for photographic advertisements that depicted speared fish, and we recorded the species, size, and habitat category for each featured fish. We then calculated the number of advertisements per page for coastal, coral reef, and pelagic fish in each year.

Regression models were fitted to the proportion, size, and advertising data over time and analysed with the statistical package R. Data met the assumptions of homogeneity of variance and normality of distribution. The composition of captured species in each sample year was then used to create a Bray-Curtis dissimilarity matrix and analysed using multidimensional scaling analysis (MDS) in XLSTAT. We plotted the cases (years) and significant vectors in 2-dimensional diagrams.

Relevant comments by the spearfishing community were also extracted from reports, articles, opinion pieces, letters to the editor, and columns within the issues examined. These comments provided chronologically based insights into the changing perspectives of recreational spearfishers over the study period and helped ground-truth observed patterns.

3.3 Results

Recreational spearfishing coverage in print media commenced around the early 1950s, when the sport began to gather a strong following in post-war Australia (Appendix 3.1, Table S3.1). Spearfishing grew in popularity until the early 1970s, but virtually disappeared from skin diving and underwater magazines by the mid-1970s (Appendix 3.1, Table S3.1). This decline in spearfishing coverage and popularity coincided with the emergence and development of scuba, increased accessibility to diving equipment, advances in underwater photography, and rapid growth in environmental awareness among the general public (Appendix 3.1, Fig. S3.1). During the conservation era, spearfishing participation declined

and reports on captures became scarce (Fig. 3.1 & Appendix 3.1, Table S3.1). The publisher of the magazine during this period noted that the magazine commenced in 1970 as a spearfishing publication but transitioned to an exclusively scuba oriented magazine by the mid-1970s (Appendix 3.1, Table S3.1). The shift in interest from spearfishing to scuba is well documented in the commentary of spearfishers (Appendix 3.1, Table S3.1). By the mid-1990s spearfishing in Australia had gained a renewed following, and publishers of underwater sports magazines once again saw the potential for dedicated spearfishing coverage.

In the early 1950s, approximately 90% of the catch reported by spearfishers was of coastal fish (Fig. 3.1a). At this time, coral reef fishes and pelagic species comprised approximately 2% and 8% of the reported catch, respectively. From 1952 to 2009 the reported catch of coastal species declined significantly ($R^2 = 0.88$, $F_{1,18} = 135.5$, $p < 0.001$). By the late 2000s, coastal species formed about 20% of the reported catch. Over the same 58-year period, reports of captured coral reef fish increased significantly ($R^2 = 0.79$, $F_{1,18} = 68.79$, $p < 0.001$) to approximately 35% of total reported catch (Fig. 3.1b). Likewise, reports of pelagic fish captures also increased significantly ($R^2 = 0.78$, $F_{1,18} = 64.05$, $p < 0.001$) to about 45% (Fig. 3.1c). Relative to 1952 values, reported captures of coastal fish declined by approximately 80%, whereas reports of coral reef and pelagic species increased by 1750% and 560%, respectively.

The mean estimated weight of speared coastal fish declined steeply from approximately 14 to 6 kg from 1952 to 1973 (Fig. 3.2a). Following the resurgence of spearfishing, the mean weight of reported fish increased to 10 kg ($R^2 = 0.41$, $F_{3,16} = 3.701$, $p = 0.034$). The mean weight of reported coral reef fish decreased exponentially over the study period ($R^2 = 0.85$, $F_{1,11} = 61.67$, $p < 0.001$) from approximately 30 kg in the

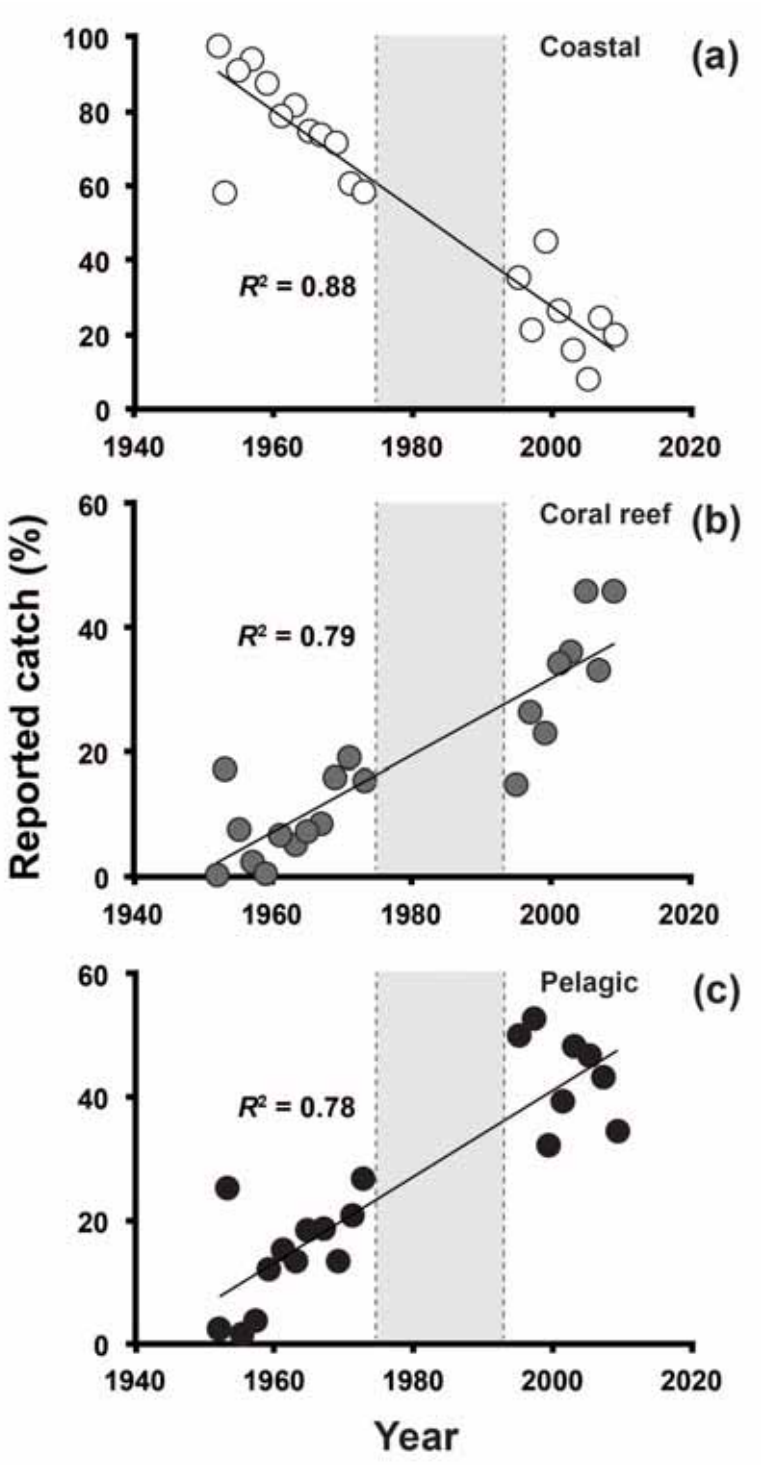

Figure 3.1 Percentage of total reported catches in spearfishing magazines by year and habitat of fish species: (a) coastal, (b) coral reef, and (c) pelagic (shaded region, time when spearfishing reports became scarce).

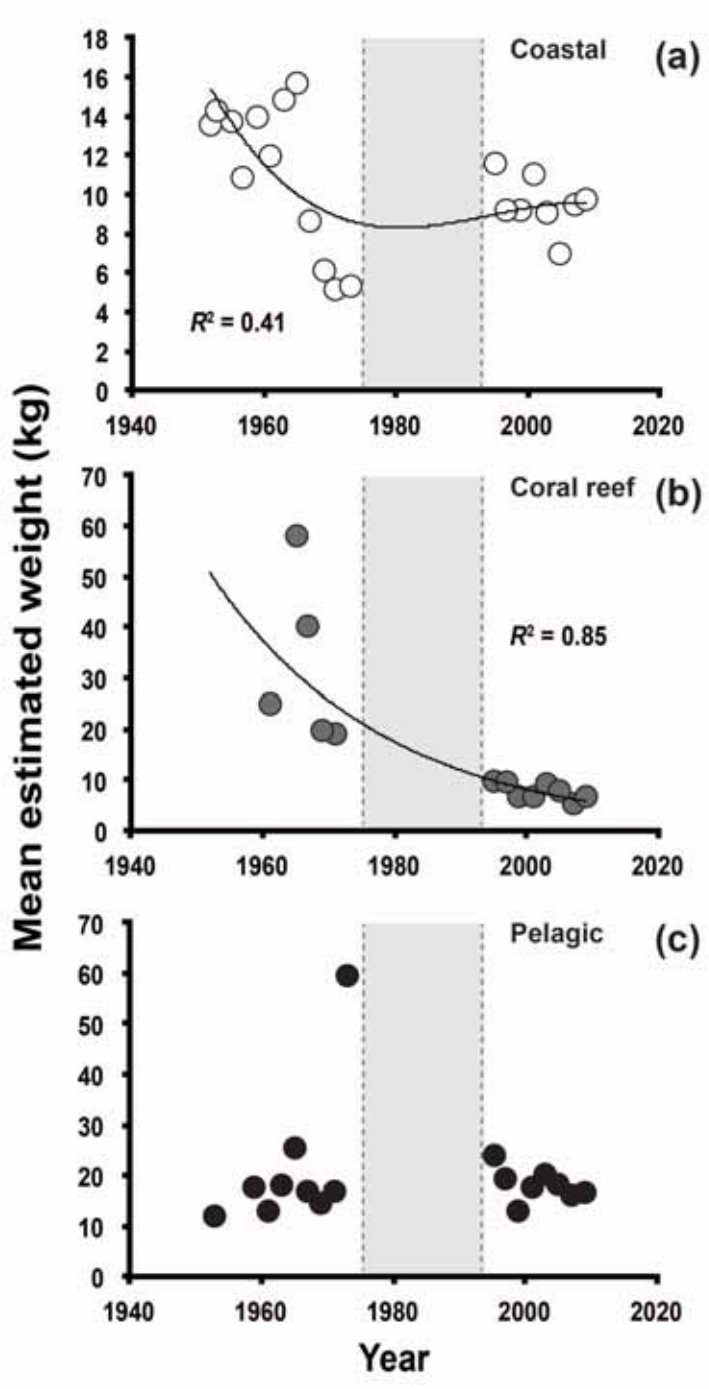

Figure 3.2 Mean estimated weight of reported catches in spearfishing magazines by year and habitat of fish species: (a) coastal, (b) coral reef, and (c) pelagic (shaded region, time when spearfishing reports became scarce). The 1973 outlier is the result of numerous reports of large whaler sharks (*Carcharhinus* spp.) being speared.

1960s to around 8 kg in the 2000s (Fig. 3.2b). The high mean weights in 1965 and 1967 were due to the reported capture of numerous large *Epinephelus lanceolatus* (Queensland groper) and *Cheilinus undulatus* (Maori wrasse). In marked contrast, there was no significant change in the mean weight of pelagic fish reported throughout the 58-year sample period (Fig. 3.2c).

Photographic advertisements, depicting images of speared fishes, began to appear in magazines during the mid-1960s (Fig. 3.3). Coastal and coral reef fish species rarely featured in spearfishing advertisements from 1967 to 2009 (Figs. 3.3a & 3.3b). However, advertisements featuring pelagic target species increased significantly over the same period ($R^2 = 0.87$, $F_{1,9} = 60.55$, $p < 0.001$; Fig. 3.3c). Advertisements depicting speared pelagic fishes increased to approximately 0.35 advertisements per magazine page (about 1 advertisement for every 3 pages) in the 2000s.

MDS of the species composition data revealed a distinct transition from the 1950s to the 2000s (Fig. 3.4a). The distribution along dimension one was primarily explained by time (Appendix 3.2, Fig. S3.2). The 1950s to 1970s and the 1990s and 2000s also showed some separation on dimension 2. The 1950s to 1970s were strongly characterized by the capture of coastal species (Fig. 3.4b). The 1950s and 1960s were characterized by temperate coastal species that included *Achoerodus viridis* (blue groper), *Kyphosus sydneyanus* (silver drummer), and *Girella tricuspidata* (luderick). *Epinephelus daemelii* (black cod), *Aplodactylus spp* (marblefishes), *Dinolestes lewini* (longfin pike), and *Nemodactylus douglasii* (morwong) characterized the 1960s and 1970s. The period following the resurgence of spearfishing in the 1990s was almost exclusively characterized by the capture of coral reef and pelagic species. Characteristic pelagic species during the 1990s and 2000s included *Scomberomorus commerson* (Spanish mackerel), *Gymnosarda unicolor* (dogtooth tuna), and *Acanthocybium solandri* (wahoo). Coral reef associated species that characterized the 1990s

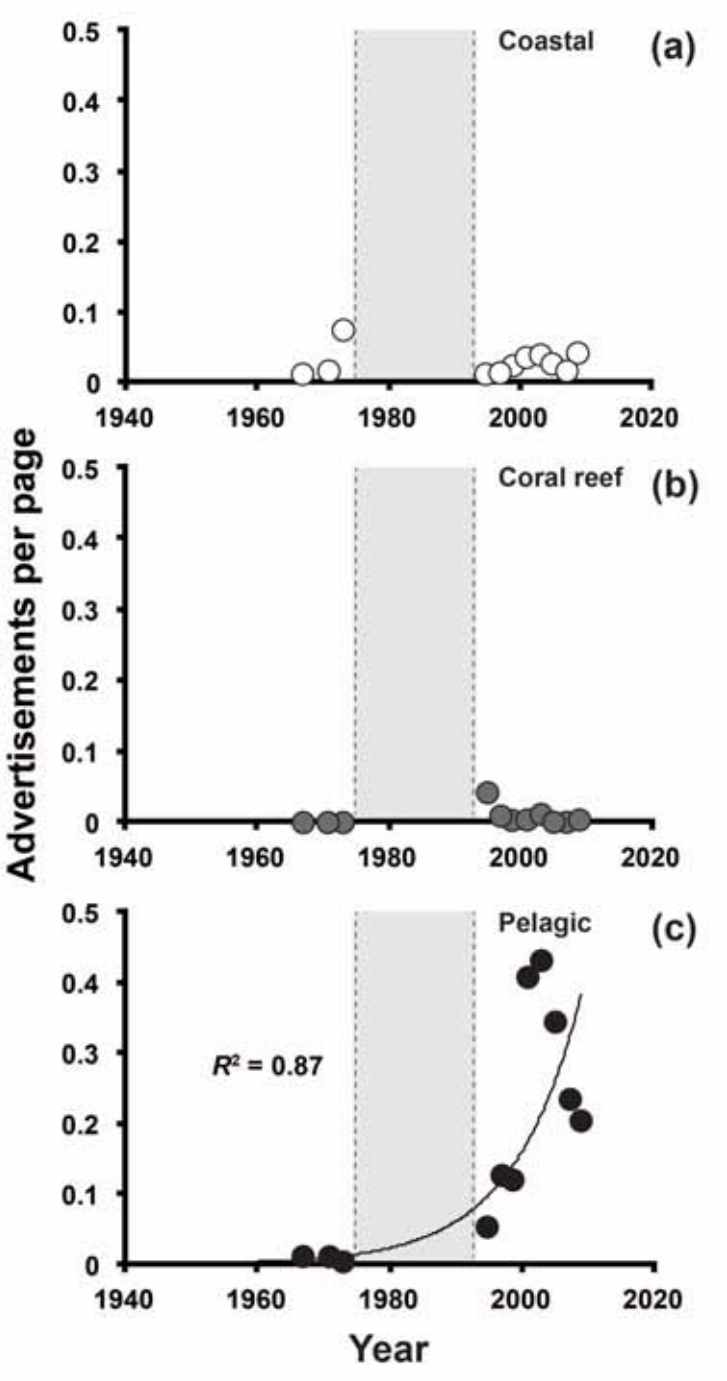

Figure 3.3 Number of advertisements with photographs of speared fish per page by year and habitat of fish species: (a) coastal, (b) coral reef, and (c) pelagic (shaded region, time when spearfishing reports became scarce).

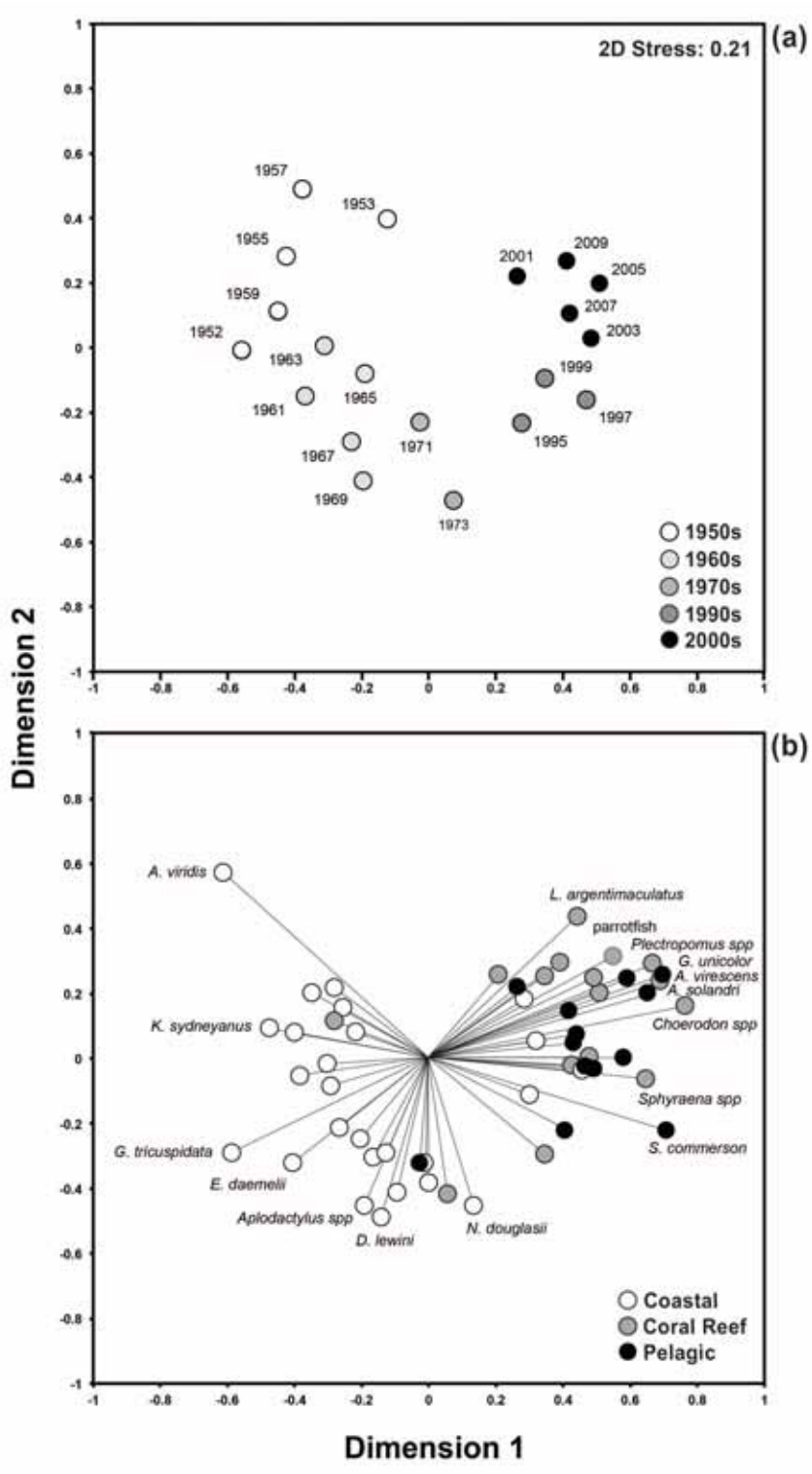

Figure 3.4 Results of a multidimensional scaling analysis of (a) spearfishing catch composition over time and (b) significant fish species or groups.

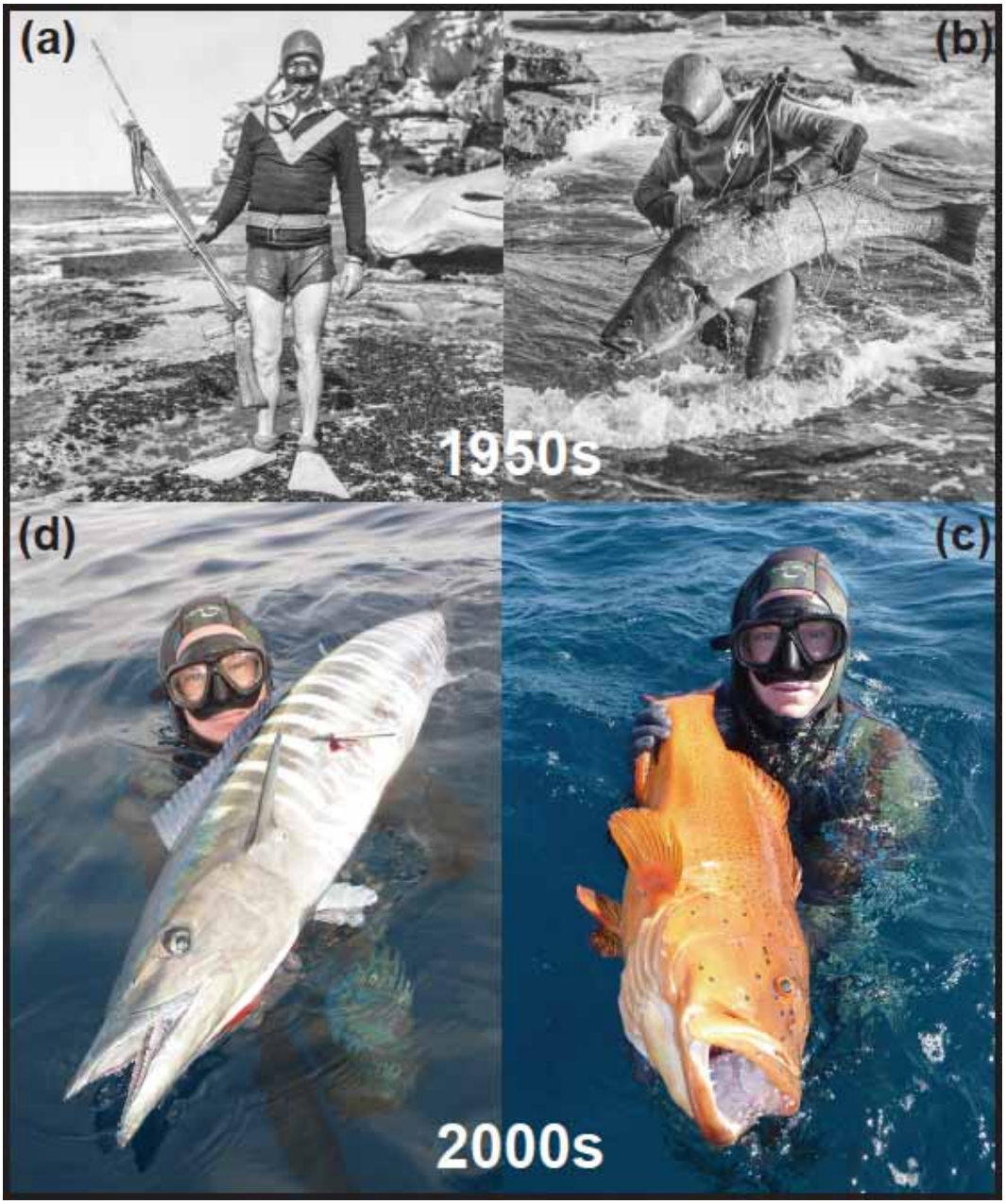

Figure 3.5 Images of recreational spearfishers from the 1950s to the 2000s: (a) coastal spearfisher wearing mostly homemade equipment (photo by Jeff Carter, nla.pic-vn4189320), (b) coastal spearfisher with a mulloway (*Argyrosomus japonicus*) on the New South Wales Central Coast 1952 (photo by Jeff Carter, nla.pic-vn3106057), (c) contemporary spearfisher holding a coral trout (*Plectropomus maculatus*) (photo by Dale Brisbane), and (d) a contemporary bluewater spearfisher displaying a wahoo (*Acanthocybium solandri*) (photo by Dale Brisbane).

and 2000s included *Sphyraena* spp. (barracuda), parrotfish, *Plectropomus* spp. (coral trout), *Choerodon* spp. (tuskfish), and *Aprion virescens* (jobfish).

The transition from coastal target species to coral reef and pelagic species was also evident in the photographic record (Fig. 3.5). In the early years of spearfishing, most spearfishers accessed fishing grounds from rocky coastal areas armed with rudimentary equipment. In latter years, coral reef and pelagic species were accessed from boats and targeted with advanced equipment (Fig. 3.5).

3.4 Discussion

Benefits and limitations of a non-traditional data source

Magazine reports are often influenced by exceptional catches. These fish, deemed worthy of reporting, are thus referred to as trophy fish (McClenachan 2009). Smaller, less significant catches are likely to be underreported. However, shifts in trophy fish may highlight changes in the most vulnerable individuals in a population, and they may provide a sensitive measure of changes in fish populations (McClenachan 2009). Although shifts in editorial interest could potentially influence reports, by sampling data from a variety of sources such as competition reports, club outing reports, reader catches, and self-reported articles, one may be able to gather a broader overview of the interests and activity of the spearfishing community at large. These data cannot replace catch per unit effort or stock assessments, but they do provide an alternate perspective on changes in the nature of noteworthy catches. We found a marked shift from coastal to coral reef or pelagic fish reports over a 58-year period. The trajectories were consistent over a relatively long period and across different sectors of the spearfishing community. Most importantly, the observed trends were supported by the comprehensive documentation of spearfisher commentary over the same period.

The conservation era

The emergence of environmental consciousness contributed to the suppression of spearfishing participation from the mid-1970s to mid-1990s (Byron 1998, Whatmough *et al.* 2011). Increased awareness of human impacts on marine ecosystems aroused anti-spearfishing sentiment among the public and this shift in mood coincided with reports of declining coastal fish populations, dwindling catches, and growing concern from within the spearfishing community (Appendix 3.1, Table S3.1) (Young *et al.* 2014). Scuba and underwater photographic equipment also became widely available and presented a timely alternative for disillusioned spearfishers. Many put down their spears and became underwater observers (Whatmough *et al.* 2011 & Appendix 3.1, Table S3.1). It has also been suggested that retail outlets favoured promoting scuba and photographic equipment over spearfishing equipment due to higher sales returns (Appendix 3.1, Table S3.1).

The influence of the conservation era also compelled spearfishing competition organizers to evolve and incorporate underwater photography (of live fish) as an integral component of competitions (Appendix 3.1, Table S3.1). This provided a competitive outlet for those who no longer wished to spear fish and was an attempt to improve relations with an increasingly hostile public. Nevertheless, spearfishing competitions, participation, and club memberships reportedly declined (Appendix 3.1, Table S3.1). A combination of declining catch, growing environmental awareness, public pressure, and the option of scuba and underwater photography combined to send spearfishing into what has been described as the dark ages of spearfishing (Appendix 3.1, Table S3.1). Comments by international spearfishers suggest that the movement away from spearfishing was not restricted to Australia and may have been part of a broader global pattern (Appendix 3.1, Table S3.1).

Catch trends and consequences

As reports of coastal fish captures declined from 1952 to 2009, the proportion of coral reef and pelagic fish reports simultaneously increased, signalling a transition in the behaviour of spearfishers and the areas in which they spearfished (Fig. 3.1). This dramatic transition through time was characterized by a distinct shift in target species (Fig. 3.4). Commercial and artisanal fisheries have historically switched target species and localities, largely in response to market forces, boom-and-bust cycles, or food security concerns (e.g., Berkes *et al.* 2006, Anderson *et al.* 2011, Cardinale *et al.* 2011). We identified a clear and sustained shift in target species in a recreational fishery that is largely free from market and food security drivers. Although coastal spearfishing may be underestimated in the spearfishing publications, the increased focus on coral reef and pelagic fishes is pronounced. Commentary from the spearfishing community (Appendix 3.1, Table S3.1) and the observed decline in mean weight of coastal fish (Fig. 3.2a) suggest that deteriorating coastal catch may have contributed to the shift in focus to coral reef and pelagic fish. However, in recreational fisheries, other drivers such as new technologies, increased disposable income, and population growth may also be important (Berkes *et al.* 2006, Bellwood *et al.* 2012). Advances in equipment and technology such as wetsuits, spear guns, and masks and access to boats undoubtedly increased the potential for spearfishers to spend more time in the water or reach locations farther from shore (Fig. 3.5). The development of large powerful spear guns and the addition of reels and floats to spear guns also increased the capacity of spearfishers to target and capture pelagic fish that were previously unmanageable. These findings highlight the dynamic and complex nature of recreational fisheries.

The trends in recreational fisheries can also reveal ecological insights. The initial decline in mean weight of coastal catch is likely to coincide with a decline in large coastal fish species (such as *Achoerodus* spp. and *Epinephelus* spp.) (Figs. 3.2a & 3.4). Similarly,

early estimates of mean coral reef fish weights are buoyed by the initial capture of conspicuous reef fish (i.e., *C. undulatus* and *E. lanceolatus*). Large, sedentary fish species commonly possess vulnerable characteristics (i.e., long lived, slow growing, low reproductive potential), occur at comparatively shallow depths, and are often inquisitive and easy to target (Lloret *et al.* 2008, Young *et al.* 2014). These species are usually among the first to disappear due to fishing pressure (e.g., Myers & Worm 2003, Lloret *et al.* 2008, Bellwood *et al.* 2012).

Although the proportion of reported catches of both coral reef and pelagic fishes increased similarly from 1952 to 2009 (Fig. 3.1b & 3.1c), only coral reef fishes experienced a significant decline in mean weight (Fig. 3.2b). It is possible that fish species found on coral and rocky reefs are more susceptible to fishing pressure than transient pelagic species (Russ 1993, Gunderson *et al.* 2008). Perhaps the relatively sedentary nature, higher levels of site fidelity, and smaller home ranges of reef fish increases their vulnerability (Russ 1993, Coll *et al.* 2004, Gunderson *et al.* 2008). Thus, persistent and systematic removal of the largest fish at a reef would likely result in a decline in mean weight through time (Lokrantz *et al.* 2010). In contrast, the highly mobile nature of pelagic species would limit the ability of spearfishers to specifically target and remove the largest individuals of a population.

Tracking popular trends through advertising

Photo advertisements featuring speared fish began to appear in spearfishing publications in the mid-1960s. Coastal and coral reef fish species rarely appeared in photo advertisements: however, images of pelagic species grew exponentially (Fig. 3.3). The dominance of pelagic fish in advertising and their simultaneous rise in proportion of reported catch suggest that pelagic fish fast became the desired spearfishing trophy fish. In contrast, the lack of coral reef fish in advertisements may imply that they were less desirable targets than pelagic species, yet coral reef fish actually comprised a comparable proportion of the reported catch.

Commentary from the spearfishing community indicates that pelagic species are often preferred targets but that coral reef fish may offer an alternative option when pelagic species are scarce, when weather conditions are adverse for targeting pelagic fishes, or when a more reliable source of food fish is sought (Appendix 3.2, Table 3.2). Additionally, although reports of both pelagic and coral reef fish captures increased similarly, only coral reef fish declined significantly in mean weight, highlighting their potential vulnerability.

The patterns of declines in weight and reported captures we found may not be attributable solely to spearfishing, but they are likely reflective of the broader condition of the fisheries. Recreational and commercial line fishing was conducted simultaneously throughout the study period. Some large reef fish may have been less frequently caught by spearfishers in the latter years of the study period, potentially due to overfishing, increased regulatory measures, or as a result of proactive conservation measures by spearfishers (Young *et al.* 2014). Spearfishing is only one component of global harvest fisheries, and for many species (especially pelagic species) the impacts of recreational spearfishing may be negligible relative to other fishing methods (Young *et al.* 2014).

Historical knowledge and its implications for conservation

Recreational fisheries present a challenge for conservation due to the chronic lack of information on historical trends and impacts (Coll *et al.* 2004, Lloret *et al.* 2008). It is difficult to anticipate fishery trends and manage them without knowledge of past fisher behaviour and actions (Pauly 1995). Thus, it is critical that recreational fisheries be understood from both a historical and contemporary perspective in order to anticipate future challenges and consider proactive action. Combined with adequate consultation and communication among fishers, managers, and scientists, this knowledge may provide a more collaborative and informed approach to future conservation efforts.

Our results indicate a clear shift in interest from coastal fishes to coral reef and pelagic species over time. Whether this reflects an actual shift in effort remains to be established. Nevertheless, the increased interest in pelagic species is likely to be of less concern to management agencies given the life histories of mobile pelagic fishes and the relatively low potential for recreational spearfishers to substantially impact pelagic fish populations. However, the growth in interest in coral reef fish species is potentially of greater concern because of the vulnerability of many sedentary and functionally important coral reef species. Thus, our findings provide opportunities for recreational spearfishers, management agencies, and conservation bodies to combine their efforts toward ensuring that spearfishing activities continue without endangering vulnerable or functionally important species.

Recreational fisheries are not simple static systems that can be managed with a broad-brush approach. Rather, they are highly dynamic and strongly influenced by the life histories of fishes, fisher behaviour, management responses, and advances in technology (Post 2013). The highly dynamic social–ecological interface of recreational fisheries presents challenges for management (Hunt *et al.* 2013), yet recreational spearfishers may offer a valuable and timely source of information for fisheries management (Young *et al.* 2014). Recreational fishing is incredibly important in Australia, and spearfishing is a small but highly contentious component. However, the ability of spearfishers to see and respond responsibly to perceived declines identifies it as a promising fishery for effective co-management. Our results emphasize the importance for regulatory agencies to work closely and cooperatively with recreational fishing bodies to monitor, detect, and adapt to change.

Chapter 4: The last marine wilderness: spearfishing for trophy fishes in the Coral Sea

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4.1 Introduction

Few marine systems have evaded the marks of human activity (Jackson *et al.* 2001, Roberts 2007). Globally, most wild fisheries are now considered fully exploited or overfished (Watson & Pauly 2013). Increasing human populations and ongoing environmental degradation are likely to further impact any relatively intact marine wilderness (Costello *et al.* 2012). The Coral Sea is one example of an isolated marine system removed from coastal impacts (Pandolfi *et al.* 2003, Wilkinson & South 2008). It is believed to be one of the few remaining places on earth where fish populations have not been severely depleted, and one of the last tropical oceanic coral reef areas with high biodiversity and an ecosystem that is relatively untouched (Wilkinson & South 2008, Young *et al.* 2012).

Situated east of Australia, the Coral Sea is bound by Papua New Guinea to the north, the Tasman Front to the south, and the Solomon Islands, Vanuatu and New Caledonia to the east. A proposed Coral Sea Marine Reserve (CSMR) has recently been the subject of much discussion (Hunt 2013). Extending eastwards from the outer boundary of the Great Barrier Reef Marine Park (GBRMP) to the limit of Australia's exclusive economic zone, the CSMR would cover 0.99 million km^2 (Fig. 4.1). Together, the GBRMP and CSMR would encompass an area of 1.3 million km^2 and form one of the largest marine protected areas in the world (Hunt 2013).

Primary literature on the ecology of the Coral Sea and the impacts of fishing in the region are sparse, therefore there has been little information for recent CSMR discussions (Wilkinson & South 2008, Hunt 2013). Only four of the 36 mapped reefs have been the subject of community level scientific study (Ceccarelli 2012) and most research comprises new species descriptions or geophysical studies (see Borsa *et al.* 2013, Kessler & Cravatte 2013). Thus, in implementing and managing a CSMR an understanding of human impacts, and fishing activity in particular, would be invaluable. Obtaining this information remains a challenge, as there are few monitored fishers.

The Coral Sea Fishery (CSF), the Eastern Tuna and Billfish Fishery (ETBF) and the recreational and charter fishing industries exploit fish populations within the Coral Sea. Commercial landings and by-catch data for the CSF and ETBF are described as limited at best (Ceccarelli 2011, Hunt 2013). Recreational and charter fishing within the Coral Sea is even less well understood, with almost no data on catch history, trends or composition (Zethoven 2008, Ceccarelli 2011). Recreational game fishing also occurs within the Coral Sea, but data from the long-term Game Fish Tagging Program indicates that only 0.8% of captures are within the Coral Sea (Ceccarelli 2011).

Recreational fishing is a growing component of global harvest fisheries (Cooke & Cowx 2004, Post 2013). However, monitoring data on recreational fisheries is typically sparse or non-existent, thus restricting scientific knowledge of past trends in exploitation (Cooke & Cowx 2004). The lack of data on fisheries of the Coral Sea, in particular recreational fishing, highlights the importance of alternative non-traditional sources of data in providing insights into current and historical extractive practices (Pauly 1995). Non-traditional data can provide valuable knowledge of historical trends and help to address the 'shifting-baseline syndrome' (Pauly 1995, McClenachan 2009). Here we present the first study to investigate recreational spearfishing in the Coral Sea. We examine historical catch

data from a chronology of spearfishing magazines to uncover trends in reported captures, including the size of fish captured and the species composition. These data are compared to records from the adjacent Great Barrier Reef (GBR). Our aim is to provide information on the history and trends in recreational spearfishing within the Coral Sea.

4.2 Methods

We extracted a broad spectrum of data from trip reports, competition reports, club outing reports, reader reports and photographs published in a chronology of spearfishing magazines from 1953 to 2009 (see Appendix 2.1). This extensive coverage of data from various sources within the magazines provides valuable insights into historical catches. We examined four magazine issues in each odd year (due to the high volume of data). In most years only four issues were published and thus our sampling provided complete annual coverage. In years with more published issues, we randomly sampled four for consistency, although only three issues were available in the National Library of Australia archives for 1995, 1997 and 1999. Data on trophy fish species (namely fish worthy of being reported in magazines), their size (weight or length), the trip type (charter or private) and location of capture were extracted from the reports. Fish were identified to the lowest practical taxonomic level, usually to species. Length estimates were converted to weights using length-weight relationships published on Fishbase (Froese & Pauly 2013). In cases where published relationships were not available, the length-weight relationship of a closely related, similarly sized species was substituted. Reported captures that did not include size data or photographs were not included in weight analyses.

Of the total Australian fish captures reported in sample magazines, we calculated the annual percentages from the Coral Sea and GBR for all odd years from 1953–1975 and

1993–2009. Between 1975 and 1993 the growing popularity of scuba and rising environmental awareness led to a decrease in spearfishing participation. During this 'conservation era' (described in Young *et al.* 2015), reports on fish captures virtually disappeared and data from these years were not suitable for analyses. To examine trends in historical catch composition, we calculated the percentage of the total annual reported catch comprised by the various taxonomic groups within each region. Where specific sites within the Coral Sea could be identified, we also examined the percentage of the total catch from each of these sites, to identify the locations most visited by spearfishers. The mean estimated weights of fishes were also calculated for each taxonomic group, with data combined for each region and period to provide a regional and temporal comparison between pre-1975 and post-1993 years on the GBR.

Simple least-squares regression models were fitted to the percentage of reported captures from the GBR and Coral Sea through time, using the statistical package R. Weight data were analysed with a Kruskal-Wallis test (in XLSTAT) and homogeneous subsets identified with a Dunn's two-tailed test. Spatial variation and temporal changes in the taxonomic composition of catches were visualized using a non-metric multidimensional scaling (MDS) ordination based on a Gower's distance matrix calculated from square-root transformed data. Species correlations and an ordination biplot were constructed using multiple partial correlations in PRIMER 6 (Anderson *et al.* 2008). Correlations were examined and a cut-off of 0.2 was applied to identify the species to be included in the biplot. Differences between the Coral Sea and the two GBR periods were tested using a one-way analysis of similarities (ANOSIM) in PRIMER 6.

4.3 Results

Historical catch reports

The percentage of Australian spearfishing captures reported from the GBR increased significantly between 1953 and 2009 (linear regression: $R^2 = 0.55$, $F_{1,14} = 17.21$, $p < 0.001$; Fig. 4.2). A single early report from the Coral Sea emerged in 1971 (Fig. 4.2). However, it was not until after 1995 that the percentage of reported captures from the Coral Sea exhibited rapid growth (exponential regression: $R^2 = 0.86$, $F_{1,7} = 43.08$, $p < 0.001$). By 2009, reports from the Coral Sea had increased to approximately 50% of those reported from the GBR (Fig. 4.2). At least 92% of all reported fish captures from the Coral Sea were taken on recreational charter trips. Private vessels contributed 2% of reported captures; 6% were of unknown origin.

Significant differences in mean trophy fish weight between periods and regions were also detected (Kruskal-Wallis: $K = 156.634$, $p < 0.0001$; Appendix 4.1, Fig. S4.1). Pre-1975 GBR weights (23.67 kg ± 4.62 SE) and post-1993 Coral Sea weights (22.93 kg ± 1.14 SE) were remarkably similar. However, post-1993 GBR weights (8.76 kg ± 0.4 SE) were markedly lower than the pre-1975 GBR or post-1993 Coral Sea values. The post-1993 GBR records are less than half the weights previously recorded from the GBR or still recorded from the Coral Sea.

Fish captures from within the Coral Sea and Australian EEZ boundary were reported from eight locations (Fig. 4.1). Wreck, Saumarez, Frederick and Kenn reefs, located in close proximity toward the southern extent of the Coral Sea region, comprised 52% of all reported captures from the Coral Sea. Marion Reef comprised 21% of reports, while just 4% were reported from the Diamond Islets and 2% from Bougainville and Holmes Reefs. A further 21% of reports emerged from unspecified regions of the Coral Sea.

Catch composition

Although the Coral Sea and GBR both represent tropical coral reef habitats, the catches from the two regions are clearly separated in the MDS ordination (Fig. 4.3a). Dimension one separated, in sequence, the Coral Sea, GBR pre-1975 and GBR post-1993. The pre-1975 years for the GBR also separate from the post-1993 Coral Sea on Dimension 2.

Coral Sea catch was primarily characterized by reports of large semi-pelagic species, wahoo (*Acanthocybium solandri*; mean weight 25 kg ± 1.64 SE), dogtooth tuna (*Gymnosarda unicolor*; 33.4 kg ± 2.18 SE) and giant trevally (*Caranx ignobilis*; 28.71 kg ± 2.58 SE) (Fig. 4.3b; Appendix 4.1, Figs S4.2 and S4.3). The GBR was characterized by the capture of reef fish, snappers (*Lutjanus sebae*; mean weight 6.02 kg ± 0.58 SE, *Lutjanus argentimaculatus*; 4.86 kg ± 0.36 SE), wrasses (*Choerodon* spp; 7.89 kg ± 0.78 SE) and emperors (*Lethrinus nebulosus*; 4.49 kg ± 0.61 SE), as well as two inshore pelagic species, the Spanish mackerel (*Scomberomorus commerson*; 10.47 kg ± 0.85 SE) and shark mackerel (*Grammatorcynus bicarinatus*; 8.23 kg ± 1.04 SE) (Fig. 4.3b and Appendix 4.1, Fig. S4.2). The pre-1975 years on the GBR and the early years of spearfishing in the Coral Sea were also characterized by the capture of Maori wrasse (*Cheilinus undulatus*; mean weight 42.43 kg ± 5.57 SE GBR, 35.33 kg ± 4.94 Coral Sea).

ANOSIM analysis of regional and period groupings demonstrated strong separation (ANOSIM global $R = 0.882$, $p = 0.001$). Pairwise tests found that both the Coral Sea (global $R = 0.973$, $p = 0.002$) and GBR pre-1975 (global $R = 0.903$, $p = 0.002$) were well separated from the GBR post-1993. Although the Coral Sea and GBR pre-1975 exhibit some overlap the groupings are significantly different (global $R = 0.746$, $p = 0.002$).

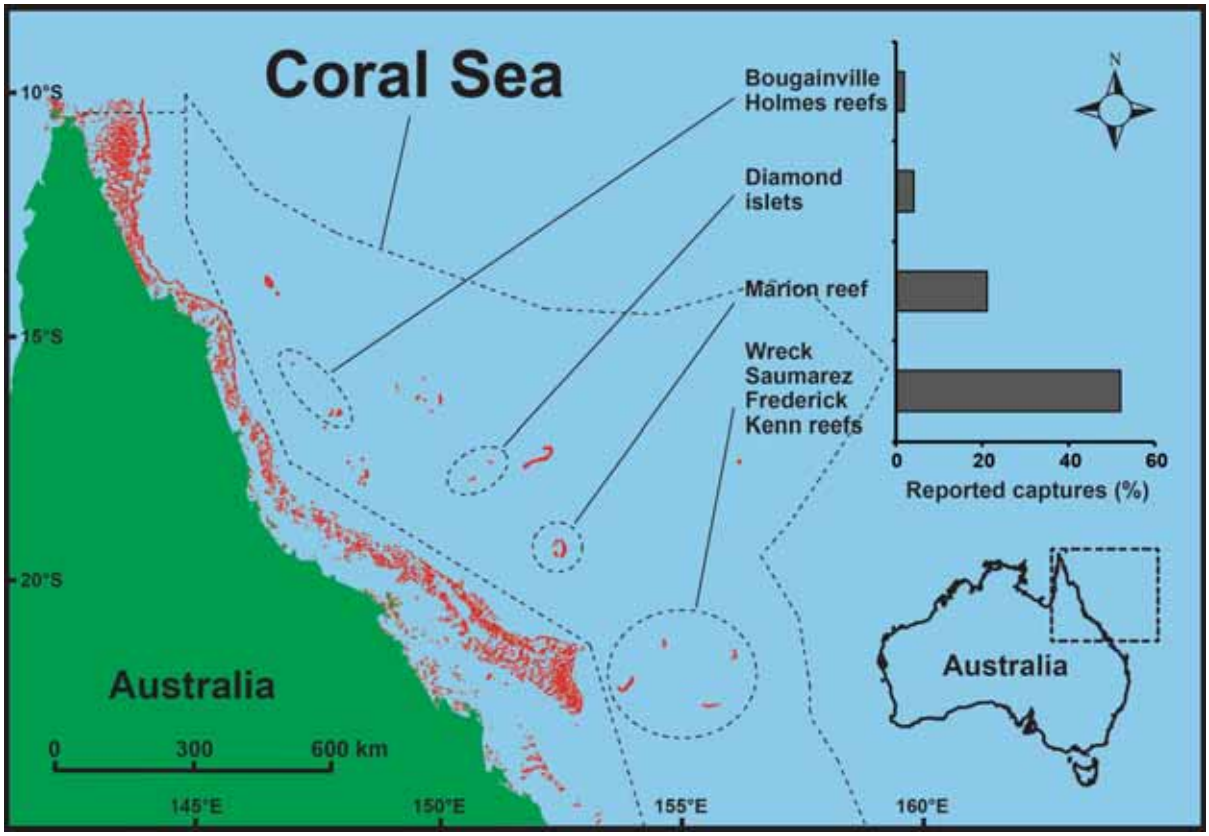

Figure 4.1 Map of the Coral Sea reef network within Australia's Exclusive Economic Zone (EEZ). The dashed line delineates the outer boundary of the EEZ and the inner boundary along the Great Barrier Reef Marine Park. The inset graph shows the percentage of total reported spearfishing captures at known locations within the Coral Sea.

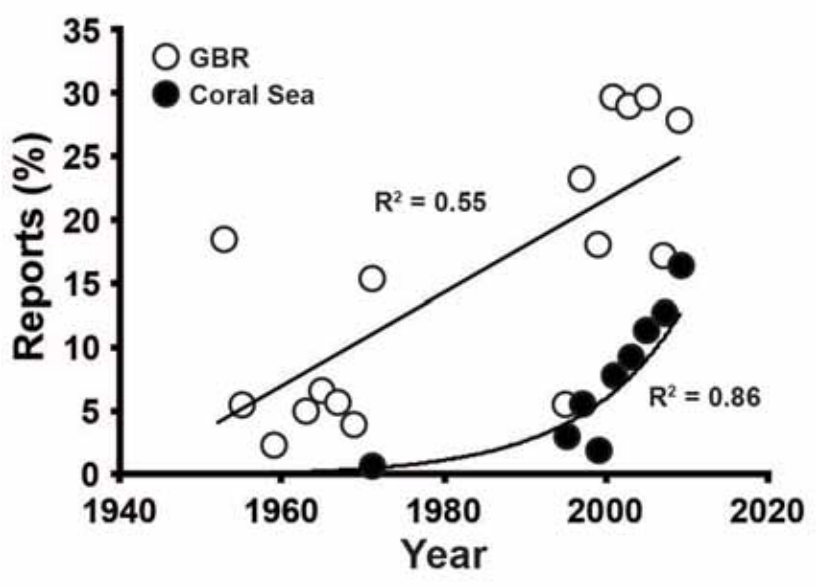

Figure 4.2 The percentage of total annual fish captures reported in spearfishing magazines from 1953 to 2009. Open symbols represent reports from the GBR, closed symbols from the Coral Sea.

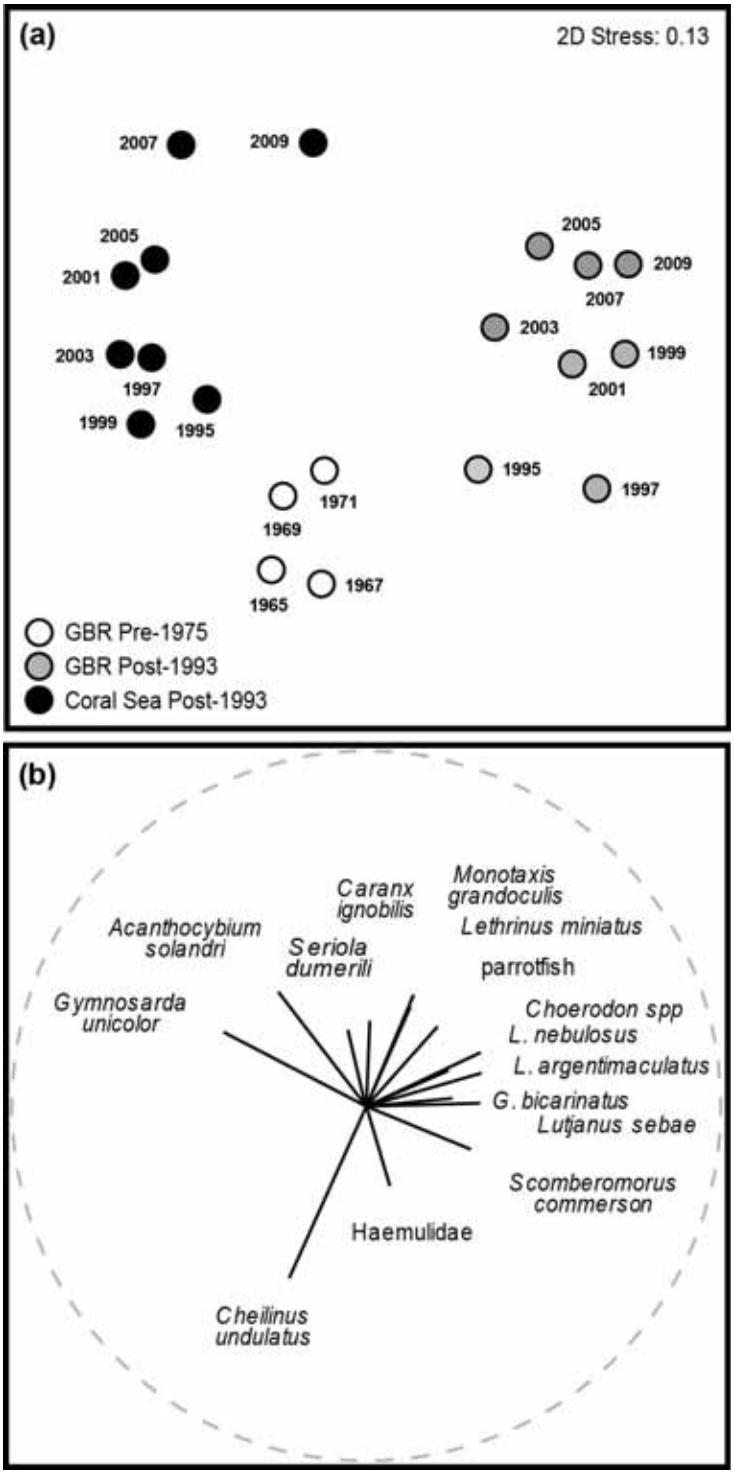

Figure 4.3 Multidimensional scaling analysis (MDS) of (a) spearfishing catch composition through time on the GBR and in the Coral Sea, and (b) biplot vectors of the main taxonomic groups; the circle indicates a correlation coefficient of 1.

4.4 Discussion

The Coral Sea is widely perceived to be relatively untouched (Wilkinson & South 2008, Young *et al.* 2012), yet our evidence suggests the region has been subjected to recreational spearfishing for at least 43 years, and reports from the region are growing. However, like commercial fishing, most spearfishing activity has occurred in the more accessible southern extent of the proposed CSMR (Ceccarelli 2011, Hunt 2013). Recreational fishing is acknowledged to be strongly limited in both extent and intensity by distance and cost (Zethoven 2008, Hunt 2013). However, as in other fisheries, technological advances and the proven ability of fishers to push further afield (Berkes *et al.* 2006, Watson & Pauly 2013), may change future patterns of exploitation.

In the Coral Sea, 36 mapped reefs and shoals, and 14 seamounts account for just 1.3% of the surface area (Harris *et al.* 2003, Ceccarelli 2012), and hard corals are not particularly abundant or diverse (DEWHA [Department of the Environment, Water, Heritage and the Arts] 2009). Thus, it is interesting that recreational spearfishers travel vast distances, and at great expense to these comparatively few and isolated reefs. With large reef fish possibly less available to fishers on the GBR, potentially due to overfishing, self-regulation (namely a conservation ethic), and/or government regulation, the Coral Sea may have provided an opportunity to target a new suite of trophy fish. At the same time, technology has improved access to more distant locations and advances in spearfishing equipment may have provided spearfishers with the ability to effectively target large pelagic species (such as *G. unicolor* and *A. solandri*) that were previously difficult to capture or less available on the GBR (Appendix 4.1, Fig. S4.3).

Although pelagic species dominate the reported catch from the Coral Sea, reef fish species were also recorded (Appendix 4.1, Fig. S4.2). Maori wrasse, for example, partially

characterize the early 1990s in the Coral Sea. This is noteworthy because large reef fish species are potentially more vulnerable to population declines than pelagic species when subjected to targeted fishing (see for example Russ 1993, Lloret *et al.* 2008). Many of these conspicuous species are slow growing, long-lived, inquisitive, and relatively scarce (Young *et al.* 2014). Due to these characteristics, they are often among the first species to be removed by fishing and are unlikely to be replenished quickly (Jennings *et al.* 1998, Coll *et al.* 2004). In terrestrial habitats, trophy hunting has had undesirable evolutionary consequences by decreasing the average size and lifespan of animals (Coltman *et al.* 2003). In the marine environment, the selective hunting of large sedentary fish could lead to similar consequences (Young *et al.* 2014). However, the high mobility of most pelagic fish and the physical limitations of spearfishing would make the selective targeting of the largest pelagic individuals difficult (Young *et al.* 2015). A selection of large-bodied reef fish taxa (such as *Epinephelus lanceolatus* and *C. undulatus*) have been protected since 2003 in Queensland waters due to concerns over potential population declines (IUCN [International Union for Conservation of Nature] 2014). Careful regulation of the harvesting of functionally important reef species would also be a sensible measure to limit the potential ecological impacts of future changes in fishing activity (Bellwood *et al.* 2012). Current regulation in Australia offers little or no protection for many of these species (Bellwood *et al.* 2004).

While recreational spearfishing has the capacity to cause declines in vulnerable species (Lloret *et al.* 2008, Godoy *et al.* 2010, Young *et al.* 2014), the extractive power of recreational spearfishing on pelagic fish species should be assessed in context. Relative to commercial fishing in the Coral Sea (Ceccarelli 2011), the intensity of recreational spearfishing is likely to be low. However, due to gaps in knowledge on the life histories of many pelagic species and the potential importance of the Coral Sea for spawning aggregations (Ceccarelli 2011), some caution is needed. Dogtooth tuna, for example, may be

more vulnerable to targeted fishing than previously thought (Bentley *et al.* 2014). Fortunately, spearfishers are likely to be among the first to observe, report and respond to potential declines in target species (Young *et al.* 2014). Thus, communication between fishers and regulatory authorities remains key to managing this fishery.

If impacts on vulnerable and functionally important fishes are minimized, the available evidence suggests that spearfishers currently exert limited pressure on the ecology of Coral Sea reefs.

Chapter 5: Gear technology and the drivers of change in a recreational fishery

5.1 Introduction

In a rapidly changing world where growing human population, longer lifespan and rising wealth place mounting pressure on global resources (Jackson *et al.* 2001, Hughes *et al.* 2013), it is critical to understand the mechanisms and drivers that influence the behaviour of humans and their impacts on the planet (Hughes *et al.* 2015, Link *et al.* 2010). Drivers of change can manifest in many forms, but are typically of demographic, economic, social or technological origin (Ehrlich & Holdren 1971, Link *et al.* 2010, Hughes *et al.* 2015). New technologies, for example, can profoundly alter the way humans interact with their surroundings. Many of these advances benefit society through increased productivity, greater efficiency, better health and safety, improved practice and raising quality of life (Walsh *et al.* 2002, Kurzweil 2012). However, technological progress is a double-edged sword that can also present unforeseen challenges and wicked problems that adversely impact humans and ecosystems (Jentoft & Chuenpagdee 2009, Levin *et al.* 2009, Marx 2012).

The development of coal-fired power is a stark example of the potential pitfalls of technological development. Coal technology provided society and industry with a potent source of energy (Termuehlen & Emsperger 2003), yet the impact of burning coal and the accompanied carbon dioxide emissions are now having far-reaching and potentially catastrophic consequences for the planet (Levin *et al.* 2009, Hughes *et al.* 2015). In a fisheries context, the development of powerful industrial trawling fleets equipped with

refrigeration, radar, navigation, and sonar technologies led to spatial expansion and greatly improved harvest efficiency of the Atlantic northwest cod fishery (Hutchings & Myers 1994, Roberts 2007). In a globally competitive environment, these developments resulted in the well-documented and rapid collapse of cod populations (Hutchings & Myers 1994, Roberts 2007). Historical case studies repeatedly illustrate our failure to recognise and implement appropriate measures to combat developing threats to the environment (Roberts 2007, Watson & Pauly 2013, Young *et al.* 2014). The expectation that technology will advance at a considerably faster rate over the next century than the last (Kurzweil 2012) emphasises the critical importance of robust monitoring for emerging issues and trends.

Technology often interacts simultaneously with economic and social drivers. The live reef fish trade is a recent example of an industry fostered by modern transport technology, lucrative global markets, rising middle class wealth, cultural factors linked to seafood consumption and fishers aspirations for improved quality of life (Fabinyi 2012, 2013, Fabinyi & Liu 2014a). The industry has a large and expanding global footprint and as supply nations across the Asia-Pacific strive to meet demand, depletion of local marine resources is on the rise (Sadovy *et al.* 2003, Fabinyi 2013). Competition for resources, habitat destruction and pollution may also confound the problem by inducing negative feedbacks that exacerbate and hasten the demise of marine populations (Sadovy *et al.* 2003, Nystrom *et al.* 2012). Thus, technology, economic, and social drivers can operate synergistically and exacerbate environmental and social damage.

The historical impact of technology, economic and social drivers on commercial fisheries is well studied (Hutchings & Myers 1994, Walsh *et al.* 2002, Roberts 2007). However, primary literature on the relationships between these potential drivers and recreational fisheries is lacking. Recreational fisheries are typically prevalent in wealthy developed nations and participants primarily engage in the activity for pleasure or interest.

Nevertheless, an increasing body of evidence highlights the potentially growing impact of the recreational sector on fish populations (McPhee *et al.* 2002, Cooke & Cowx 2004, Thurstan *et al.* 2014). Recreational fishing can cause declines in vulnerable fish populations and the total catch may even exceed the commercial sector for particular species and regions (McPhee *et al.* 2002, McClenachan 2013). Recreational fisheries are also subject to dynamic shifts in fisher behaviour and catch trends (Young *et al.* 2015), yet little is known about the factors that influence these shifts. Thus, insight into the potential drivers of change in recreational fishing would be particularly valuable.

We examine the history and development of spearfishing technology in Australia and investigate potential technological, social and economic drivers of change. Utilising data sets of catch reports and print advertising published in a 58-year chronology of spearfishing magazines, we assessed the relationship between these potential drivers and a proxy for change (mean annual distance travelled). We also conducted semi-structured interviews with experienced recreational fishers to harness historical knowledge of the fishery, to gain insight into advances in fishing technology, and to corroborate observed patterns within the published records. This study aims to explore the relative role of technology and other social factors in driving offshore movement of fisheries. It may also offer a broader insight into the mechanisms that influence recreational fisheries and provide direction for future monitoring efforts.

5.2 Methods

Mapping historical shifts through capture reports and advertising

We extracted data on reported fish captures and advertising from a chronology of spearfishing publications dating from 1952 to 2009 (see Appendix 2.1, Table S2.1 for title

chronology and Chapter 3 for detailed sampling methodology). We sampled the years 1952 and every odd year thereafter due to the high volume of data. Four magazine issues were sampled in each year, although only three issues were available in the National Library of Australia archives for 1995, 1997 and 1999. The products featured in advertisements were recorded to reconstruct a timeline for gear development. For each reported fish capture, the Google Earth distance tool was used to estimate the distance from a disclosed location of capture to the nearest departure port or access point on mainland Australia. Reports on fish captures during the period from 1975 to 1993 were scarce due a lack of spearfishing coverage (discussed in Young *et al.* 2015) and values for these years are unavailable. Sites that were accessed via the shore were assigned a default value of 0.5 km. The annual mean distance travelled per reported capture was then calculated to provide an indication of the capacity for spearfishers to travel further afield and thus provide a historical proxy of change.

Recreational fisher interviews

We conducted semi-structured interviews with 25 experienced recreational fishers to harness their perceptions on developments in fishing technology and to provide independent evidence of changing patterns and potential drivers. Following interviews with initial contacts, we used a snowball method to identify suitable candidates along the east coast of Australia (Bernard 2006). Interviews typically took one hour and were conducted in person or over the phone. We focussed efforts on fishers with extensive experience to extract more detailed and chronologically broad-based insights. Fishers were asked to identify the most significant advances in fishing-related technology that they had observed. They were given time to consider and openly discuss various gear/equipment technologies and were invited to elaborate on any technological advances they deemed to be important. Response data were tallied and graphed to illustrate the percentage of interviewees that identified particular

technologies of importance. Their observations also provided insights into the historical development of spearfishing equipment in Australia and their knowledge was utilised in conjunction with the advertising data to reconstruct historical gear developments.

Potential drivers of change

We collated a series of potential driver (predictor) variables that may have influenced or facilitated historical change in recreational spearfishing activity. Data on the Queensland population from 1952 to 2009 was accessed via the Australian Bureau of Statistics (ABS) as a measure of potential growth in spearfishing demand. Queensland population was chosen to better reflect the growth in human population potentially accessing the adjacent Great Barrier Reef and Coral Sea (ABS 2014). Data on Australian household expenditure (consumption) from 1960 to 2009 was also used as a measure of wealth (ABS 2013). We also accessed data on the annual number of Queensland recreational boat registrations from 1991 to 2009 to provide a potential measure of the number of boats accessing the Queensland coast (Hughes *et al.* 2015). To provide a measure of the global penetration of satellite navigation devices we accessed historical data on Global Navigation Satellite Systems (GNSS) global market size. GNSS encompasses a number of global satellite navigation systems including Global Positioning System (GPS). Herein we refer to GNSS technologies as satellite navigation. This data was available for years 1993 to 2000 (OECD 2000), but was estimated for three years (2003, 2006, 2009) by fitting a trendline through the 2000 data estimate and a 2013 market size estimation (OECD 2014). Data were converted to US dollars using the appropriate currency conversion calculators. We then utilised the annual mean distance travelled per reported catch as a response variable and a proxy for change in recreational spearfishing activity. The distance data through time reflects a spatial and temporal component of historical shifts in the behaviour and interests of spearfishers.

Analyses

Regression and multiple regression analyses were used to model the distance travelled by spearfishers through time (in the statistical package R). Where possible, we focused on Queensland-specific data because much of the shift in distance travelled from shore had occurred throughout this state. Queensland population, Australian household expenditure, Queensland recreational vessel registrations (boats) and GNSS global market size were used as potential predictor variables. We explored two time periods because potential predictor variables commenced at different historical points. The first period encompassed a longer trajectory from 1960 to 2009, with potential predictors of population and expenditure. The second period covered the years 1995 to 2009 for which all four potential predictor variables were present. We used the stepAIC function in the MASS package R-library to perform stepwise model selection for both time periods.

5.3 Results

Reconstructing gear developments through advertising and fisher knowledge

Spearguns

Advertisements for commercially produced spearguns first appeared in 1952, at the start of the magazine chronology sampled (Fig. 5.1a, 5.2). However, spearfishers confirmed that the first Australian speargun was patented in 1942 and that they were first commercially produced around 1949. Prior to commercial production, spearguns were almost exclusively homemade and crafted from improvised materials. Several speargun variations emerged over the years with CO_2 and pneumatic guns in the early 1950s, followed by rail and roller guns.

Speargun designs were gradually refined to lighter and more durable materials (i.e. carbon fibre) with increased power. Spears evolved from basic tips with barbs to those incorporating specialised slip-tip and flopper locking mechanisms (first advertised in 1953) to help secure fish and reduce escape. Powerheads also emerged around 1962 and experienced a short burst of popularity.

Fins, masks and snorkels

Fin, mask and snorkel advertisements were also present in sample magazines from 1952 (Fig. 5.1a, 5.2). According to historical accounts by spearfishers the first swim fins were patented by a French inventor in 1937, however, they remained virtually unknown in Australia until the late 1940s. The first basic rubber models manufactured were expensive and at the time a set of fins and a mask could cost close to one weeks wage. Prior to the advent of fins, spearfishers had worn sandshoes or sneakers to protect their feet and due to the lack of propulsion participants were restricted to shallow coastal and estuarine waters that were easy to access from the shore. Fins greatly enhanced the ability of spearfishers to swim further and deeper and to target fish that were previously beyond reach. Refinement over the years led to longer, lighter and more powerful designs. According to spearfishers, commercially produced masks emerged in the late 1940s and gradually progressed to low volume models with increased comfort (Fig. 5.1e,g). Snorkels also evolved to incorporate mechanisms such as purge valves.

Wetsuits

The first advertisements for rudimentary multi-piece rubber wetsuits appeared in 1953 (Fig. 5.1b, 2). Neoprene wetsuit advertisements followed in 1961 (Fig. 5.1e). Accounts from experienced spearfishers corroborated these observations. Spearfishers also noted that much

of the early spearfishing activity took place in the temperate coastal waters of New South Wales (NSW) and that limited insulation (woollen jumpers or football jerseys) combined with cold water constrained the time participants spent immersed. Thus, the advent of wetsuits significantly enhanced the capacity of spearfishers to remain in the water and to target fish. Over the years neoprene wetsuits became more comfortable and durable, with improved insulation capacity and even camouflage properties. Most of the wetsuit, fin, mask and snorkel developments emerged in conjunction with the booming scuba diving industry during the 1950s and 1960s (Fig. 5.1e).

Boating and travel

The first watercraft advertisement to appear in sample magazines was for a small catamaran style raft called a row float in 1957 (Fig. 5.1c). However, oral accounts suggest these were available as early as 1955. Row floats, powered by paddles and later small outboard motors, provided a means of transport to explore beyond the typical shore-accessed haunts. Small powerboats (aluminium punts and outboard motors) were first advertised and targeted toward the spearfishing community in 1961 (Fig. 5.1f). Spearfishers corroborated this observation and confirmed that powerboat mobility provided unprecedented access to locations further afield. Powerboats continued to progress over the years to incorporate v-hulls and larger models capable of handling a variety of weather conditions. The advent of four stroke motors delivered better fuel efficiency and increased reliability. These developments improved the capacity of boats to safely travel further. Organised commercial travel targeting spearfishers (often in conjunction with dive expeditions) also commenced in the late 1950s with advertisements for travel to the Great Barrier Reef first appearing in 1959 (Fig. 5.1d, 5.2). Advertisements for spearfishing charters to the Coral Sea and numerous other exotic tropical locations were first recorded in 1993 (Fig. 5.1g, 5.2).

Figure 5.1 Historical advertisements illustrating the development of spearfishing equipment. (a) Mask and spear advertisement. (b) Rubber wetsuit advertisement. (c) Row float advertisement. (d) Travel advertisement for Heron Island on the Great Barrier Reef. (e) Advertisement for neoprene wetsuits and dive equipment. (f) Powerboat advertisement. (g) Travel advertisement for charter trips to the Coral Sea.

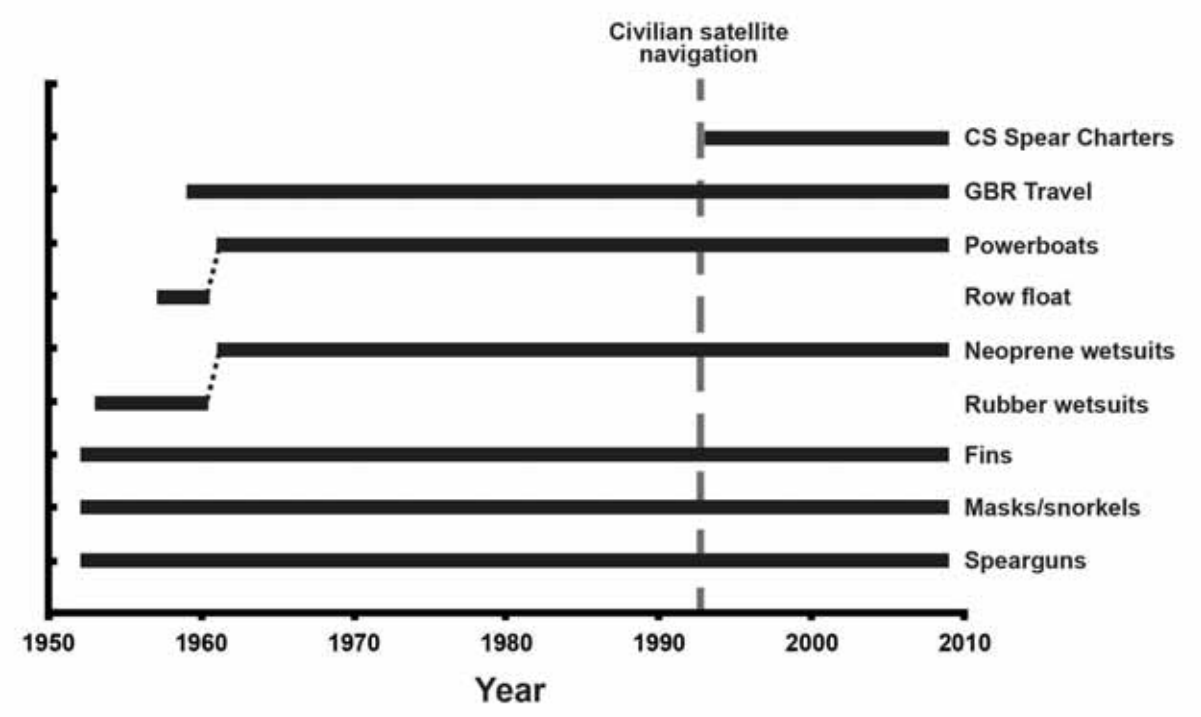

Figure 5.2 Historical timeline depicting the approximate periods that various spearfishing technologies were advertised.

Fisher perceptions on fishing technology

Satellite navigation technology was identified by 96% of fishers as, by far, the most important advance in fishing related technology (Fig. 5.3). The second most discussed advance by interviewees was sonar/sounder technology (60%), followed by braided lines (32%) and advances in fins (28%). The remainder of technologies were only mentioned by 4-16% of fishers.

When fishers elaborated on the advantages of these technologies many emphatically described satellite navigation technology as the single most significant development in fishing. They explained that the technology had markedly enhanced the ability of fishers to accurately locate and revisit fishing grounds. It provided reliability, security and confidence to fishers, especially when travelling further offshore. Prior to satellite navigation technology, fishers used landmarks, compass headings and approximate distance as a rough guide to locate reefs, wrecks and underwater structure. Many interviewees described this older method as unreliable and emphasised the skill required to be successful. Interestingly, a number of experienced fishers stated that the old hit-and-miss approach was preferable because it reduced fishing pressure and acted as a natural buffer to overexploitation. Several even voiced strong opposition to the mere existence and use of satellite navigation technology in fishing. These fishers felt that the skill required to locate productive fishing grounds had diminished and that even the least experienced fishers could now reliably target fish.

"With satellite navigation and sounder technology, fish have nowhere to hide"

Fishers also pointed out that fishing location knowledge was previously shared selectively. Now coordinates could readily be shared amongst groups of fishers and strangers and they had less control over who acquired the knowledge and intellectual property. Most

alarmingly, one interviewee described how a collection of coordinates were stolen from a computer and shared widely. He noticed a subsequent decline in catch at many of these locations. Many of the fishers interviewed expressed a perception that pressure on offshore fish populations had increased since the uptake of satellite navigation technology.

Advances in sonar technology were often mentioned alongside navigation technology. Many fishers stated that sounders were critical for pinpointing underwater structures and for locating schools of baitfish and target species. Once hotspots were identified they could then save the coordinates for that spot. Fishers spoke of the remarkable resolution of modern sounder technology, especially side imaging, 360° and forward scanning developments. Accuracy and resolution had increased so dramatically that individual fish could now be identified and targeted. Fishers also identified other gear improvements including carbon fibre fins and braided lines, although many also acknowledged that earlier technologies (i.e., rubber fins and monofilament lines) would still catch fish. Such comments reinforced the incremental nature of many gear developments.

Spatial expansion in spearfishing and the potential drivers

We extracted distance data for 3638 reported captures that disclosed the location of capture from 1952 to 2009. We found that the annual mean distance travelled by spearfishers per catch increased exponentially over this period ($R^2 = 0.73$, $F_{1,18} = 47.67$, $p < 0.001$; Fig. 5.4). This trend reflects the growing interest in locations further from the Australian mainland (i.e., GBR and the Coral Sea) and the capacity for spearfishers to reach them.

Queensland population and Australian household expenditure were both identified by stepwise AIC as significant predictor variables for the response variable (distance) over the longer-term trajectory from 1960 to 2009 (ANOVA, $F_{2,12} = 45.61$, $R^2 = 0.88$, $p < 0.001$; Table 5.1; Fig. 5.4). Beyond 1991, data on recreational boat registrations and GNSS market

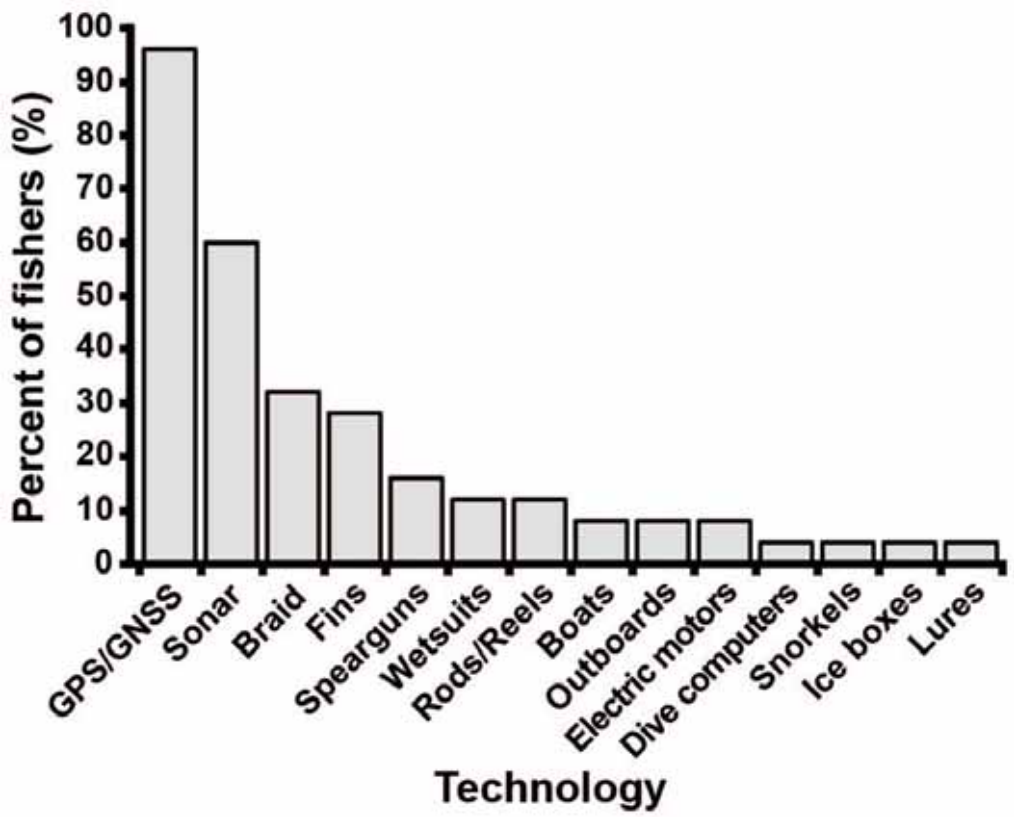

Figure 5.3 Percentage of fishers that identified important developments in fishing-related technology during interviews.

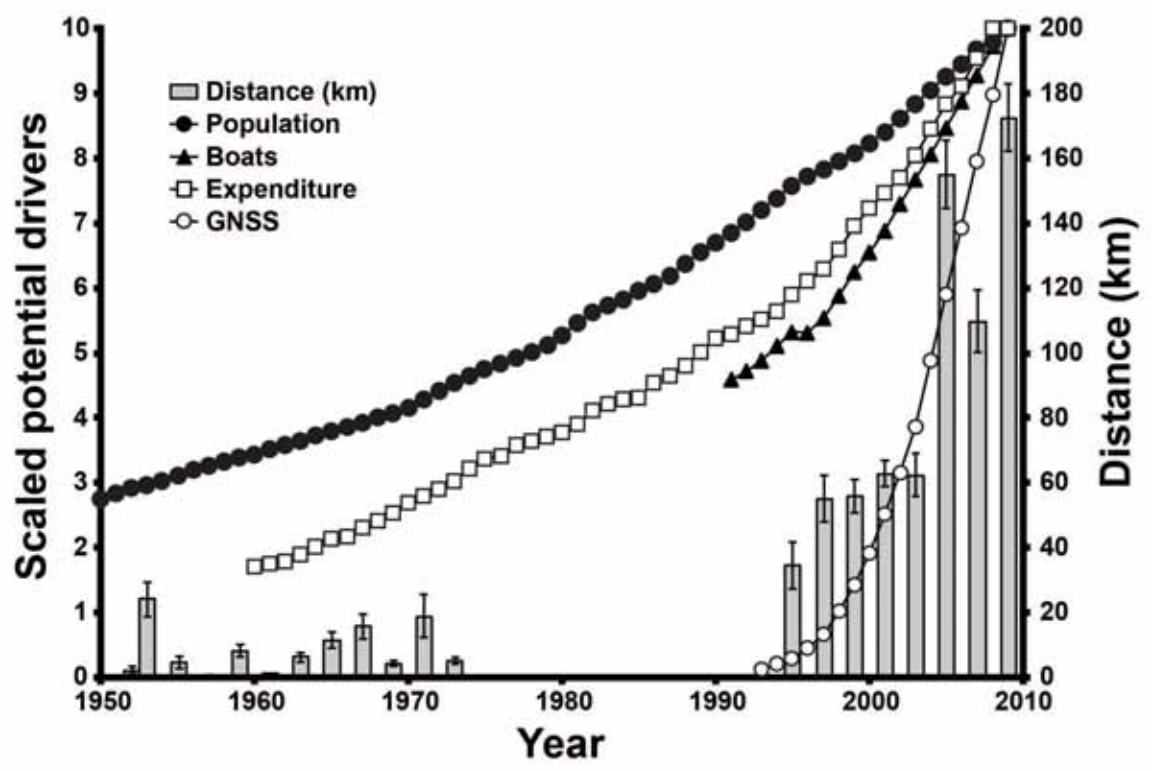

Figure 5.4 Mean annual distance travelled by spearfishers per catch ± standard error and potential drivers of change (1952 - 2009). Potential drivers are scaled relative to their highest record for illustrative purposes.

Table 5.1 Results of the multiple regression analyses of the influence of potential drivers on the distance travelled by spearfishers based on the best models identified by stepAIC. The analyses cover two historical periods.

	Estimate	***t*-value**	***P***
1960-2009			
Intercept	84.83	1.892	0.083
Population	-0.0001272	-2.733	<0.05
Expenditure	0.000842	3.677	<0.01
1995-2009			
Intercept	35.591	2.659	<0.05
GNSS	3.046	5.102	<0.01

size could also be considered as potential predictor variables. However, a stepwise AIC approach clearly identified GNSS as the best explanatory variable for the increase in distance travelled from 1995 to 2009 (ANOVA, $F_{1,6} = 26.03$, $R^2 = 0.81$, $p < 0.01$; Table 5.1; Fig. 5.4).

5.4 Discussion

Historical developments in spearfishing

Spearfishing (non-Indigenous) was first introduced into Australia in 1917 (Byron 1998). At that time Australian society was largely fearful of the sea and its inhabitants and few people dared to enter the water (Young *et al.* 2014). It was not until veterans returned home from WWII posts in the Pacific with a newly discovered passion for the sea, that spearfishing began to gain traction (Byron 1998). Many of these veterans had gleaned spearfishing knowledge from Pacific Islanders and were eager to utilise these skills in Australian waters. In the mid 1940s spearfishing equipment comprised of rudimentary homemade gear, crafted from improvised materials. Pioneer spearfishers in Australia wore sandshoes, woollen jumpers, and masks constructed from car tyre inner tubes and mirror glass. Homemade spearguns were assembled from wood, aluminium, steel and rubber (Byron 1998).

Spearfishing progressed rapidly in the 1950s and 1960s in Australia and all of the fundamental equipment, albeit rudimentary in design, became commercially available during this period. Since then, gears such as spearguns, wetsuits, masks, snorkels and fins have undergone incremental improvements, yet the general functionality remains much the same as their historical predecessors. These progressive gear refinements have gradually improved the efficiency of spearfishers. Although equipment such as floats, floatlines and reels were not detected in the advertising or interview data, they too may have enhanced the ability of spearfishers to subdue large pelagic fishes, particularly as bluewater spearfishing increased in

popularity throughout the 1990s (Young *et al.* 2015, 2016a). In addition to the gear enhancements, a host of other potential drivers are likely to have worked in concert to increase the capacity of fishers to travel and fish further afield. Human population growth, for example, has led to greater demand for marine resources, increased boat ownership and more recreational fishers. Rising wealth facilitated the means to purchase boats, pay for fuel and to embark on specialised charters to more remote regions (Young *et al.* 2016a). Wealth in Australia has been on the increase since WWII with a steady rise in disposable income and household expenditure (ABS 2013). Thus, increased population (demand), greater wealth (means) and improved gear technology (efficiency) are all likely to have contributed to historical changes in recreational spearfishing. The spatial shift in capacity to fish further from shore may also be reflected through a growing interest in coral reef and pelagic fishes (Young *et al.* 2015).

Satellite navigation and the rapid rise in fishing efficiency

Originally developed by the United States Government for military applications, satellite navigation utilises a network of satellites to triangulate a position on Earth. Coordinates are calculated to provide an accurate position without the requirement for any landmarks or visual reference points. Once these coordinates are recorded, the same position can be revisited with a high degree of accuracy. Satellite navigation first became accessible to civilians across the globe in 1993 (OECD 2000). For national security reasons, public signals were intentionally degraded (limited to 100 metres accuracy) on the initial release via Selective Availability (SA). In 2000, the United States government discontinued the use of SA and civilian satellite navigation accuracy improved tenfold (GPS.GOV 2014). This provided consumers with much greater reliability and appears to be reflected by the distance data in the present study.

Despite changes in almost every aspect of spearfishing activity, satellite navigation technology emerged as the most influential technology development via our analyses and in the opinion of recreational fishers. Interestingly, satellite navigation was not detected in the advertising data. Thus, this externally developed technology, not specifically intended for spearfishing, dramatically changed the behaviour and efficiency of spearfishers. It provided unprecedented accuracy and reliability for locating fishing grounds and gave fishers confidence to embark on potentially costly excursions further afield.

The impact of technology on fisheries has been extensively discussed (Pauly *et al.* 2002, Roberts 2007, Watson & Pauly 2013), yet there is little primary literature that directly examines the impact of satellite navigation technology on fisheries (particularly recreational). Nevertheless, the commercial fishing industry was quick to adopt and implement satellite navigation technology to their advantage and recent studies suggest the widespread use of 'smart FADs' by purse seine operations may be severely damaging pelagic fish populations (Davies *et al.* 2014). Australia's northern prawn fishery (NPF) also quickly embraced satellite navigation and plotter units and the fishing power of NPF fleets increased by 12% (Robins *et al.* 1998). Skippers stated that satellite navigation and plotter technology had a major impact on their fishing efficiency, and particularly so for fishers with less experience (Robins *et al.* 1998). Skippers operating in the demersal scalefish fishery in Western Australia also attributed increased catches and improved efficiency to the adoption of satellite navigation and sonar technologies (Marriott *et al.* 2011). These conclusions exhibit strong parallels with the present findings in a recreational fishery.

Potential drivers of recreational fishing pressure

Potential drivers such as population growth or rising wealth may impart steady and persistent change on fisheries or ecosystems over time (chronic drivers). However rapid technological

advances or new practices (acute drivers) can trigger abrupt impacts on fisheries and ecosystems. Acute drivers potentially pose the greatest threat because they may be more difficult to anticipate and could remain undetected until significant damage is already underway. Acute drivers may also hasten the demise of systems already under the strain of chronic pressures. Alternatively, some drivers may not always place increasing pressure on fisheries and ecosystems, and can act to relieve pressure. Economic downturn or global upheaval (i.e. war, recession, high oil/fuel prices) may lead to reduced fishing pressure or even the recovery of fish populations (Roberts 2007, Holm 2012). During WWII many fishing boats and crew were assigned military roles or refrained from fishing (Holm 2012). The reduced fishing pressure allowed fish stocks in the Atlantic Ocean to recover temporarily (Holm 2012). Fishing pressure may also be limited by financial constraints. For example, the profit margins of many commercial fishers are highly susceptible to fluctuations in fuel costs (Davies *et al.* 2014). Given that recreational fishing is closely tied to wealth, it is likely that recreational fishing pressure will track economic patterns within countries. Although it must be noted that spearfishing can persist regardless of per capita incomes (Bellwood *et al.* 2012).

Recreational fishing and technology in a global context

Although our case study examines recreational spearfishing in Australia, it is likely that parallels exist within recreational marine fisheries across the globe. Recreational spear and line fishing are extremely popular activities worldwide, particularly in developed countries (Cooke & Cowx 2004, Coll *et al.* 2004, Morales-Nin *et al.* 2005, Lloret *et al.* 2008). Recent research suggests that recreational fisheries and their impacts are growing, potentially a result of economic development and increased affluence (McPhee *et al.* 2002, Morales-Nin *et al.* 2005). In a global environment where middle class wealth is rising in many nations (Fabinyi 2012, Hughes *et al.* 2013), the expansion of recreational fisheries is likely to continue.

Spearfishing typically comprises a small fraction of the recreational sector, however its efficiency at targeting and removing fish may be relatively profound. In a Hawaiian study, spearfishing only accounted for 25% of the recreational fishing activity, yet the mean biomass captured through spearfishing was 28 times higher than that for line fishing (Meyer 2007). Likewise, spearfishing catch per unit effort (CPUE) in the Mediterranean was found to be more than 13 times higher than line fishing (Lloret *et al.* 2008). Spearfishing has also been implicated in the decline of coral and rocky reef-dwelling species in Australia (Young *et al.* 2014), the Mediterranean (Coll *et al.* 2004, Lloret *et al.* 2008), and the Americas (Sadovy 1999, Godoy *et al.* 2010). These studies highlight the vulnerability of fish species that exhibit higher levels of site fidelity or aggregating behaviour. Therefore, technologies that enhance the capacity of fishers to accurately locate and visualise underwater structure and habitat (i.e. satellite navigation and sonar) potentially pose a greater threat to these vulnerable sedentary species (Post *et al.* 2002, Marriott *et al.* 2011).

The historical emergence of recreational spearfishing around the early 1950s has also been observed globally (Godoy *et al.* 2010, Pita & Freire 2014). Likewise, studies have also noted the effectiveness of speargun and wetsuit developments (Coll *et al.* 2004, Godoy *et al.* 2010), while acknowledging limited historical change in spearfishing technique (Coll *et al.* 2004). These general observations closely reflect results in the present study. No previous research has explicitly addressed the role of satellite navigation technology on recreational fisheries. However, a number of studies on recreational fisheries have illustrated a high volume of boat use (Morales-Nin *et al.* 2005, Diogo & Pereira 2013) and a trend to travel further afield for improved catches (Post *et al.* 2002). Considering the inherent links between boating, satellite navigation and sonar, it seems probable that these technologies would have played an influential role in the development of recreational fisheries across the globe.

Technology, spatial expansion and the implications for conservation and management

With modern technology, recreational fishers can travel further and safer than ever before. The advent and rapid growth of GNSS-enabled smart phones exemplifies the extent to which much of the global population now has the ability to mark and revisit coordinates at their fingertips (GSA 2015). Spatial expansion is a well established metric for the decline in fisheries (Berkes *et al.* 2006). As one marine source is depleted, fishers display a tendency to move further afield in search of a better return (Kirby 2004, Berkes *et al.* 2006, Anderson *et al.* 2010). This pattern is particularly evident in commercial fisheries that are driven by economic factors and profitability (Kirby 2004, Berkes *et al.* 2006, Anderson *et al.* 2010). However, we present the first data that suggests these patterns of spatial expansion also operate within recreational fisheries.

Advances in sonar technologies also enable fishers to find, visualise and identify underwater structure and fish with greater accuracy and resolution. Fishers can now locate and potentially remove individual fish that would have otherwise escaped detection. It is likely that natural reserves for fish populations have been lost or depleted as a result of satellite navigation and sounder developments. There is almost nowhere left to hide, thus creating a conundrum for conservation and management. It remains to be seen whether current regulations are sufficient to protect vulnerable fish populations in light of these growing pressures. Observations by some fishers suggest declines in catch have occurred at locations frequented by satellite navigation users and numerous fishers have voiced opposition to the technology. The high potential for future increases in fishing efficiency and effort creep (Kennelly & Broadhurst 2002) emphasise the necessity for an array of compensatory management tools (including marine protected areas) to provide a buffer for fish populations

(Jentoft & Chuenpagdee 2009, Sale 2013, Hughes *et al.* 2016) and to maintain viable fish stocks.

5.5 Conclusions

Technological, economic and social advances may not always translate to increased pressure on marine environments. However, it is clear that cumulative advances over the past 60 years, in particular the advent of satellite navigation and sonar technologies, have greatly increased the capacity of recreational fishers to interact with marine populations both locally and further afield. It also potentially marks the loss of 'hard to find' underwater habitats that may have acted as natural refuges for fish populations. Future technologies are likely to emerge more rapidly than ever before and further improve fishing efficiency. Therefore, fishers, scientists and managers must remain alert for unforeseen challenges and maintain channels of communication. This will provide guidance for appropriate regulation, improved fishing practice and is essential to manage fishing pressure as fishers traverse new fishing frontiers.

Chapter 6: Why do fishers fish? A cross-cultural examination of the motivations for fishing

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6.1 Introduction

Humans have fished the earth's waterways for at least 40,000 years (Hu *et al.* 2009). Indeed, the earliest evidence for fishing implements (harpoons) is from Africa 90,000 years ago (Pauly *et al.* 2005). For many coastal and sea faring peoples, fishes provide an important source of protein and fishing plays an integral role in social, cultural and religious identity (Roberts 2007, Watson & Pauly 2013). Today, fish constitute more than 16% of the global intake of animal protein (FAO 2014). Fish products derived from wild caught fisheries and aquaculture are also the most traded of food commodities, worth more than $129 billion USD in 2012 (FAO 2014). The consumption of fish crosses a broad spectrum of cultures and societies, from subsistence living in developing countries to the high-end restaurant trade in affluent countries (Fabinyi & Liu 2014a, Roeger *et al.* 2015). Thus, humans have a long and deeply embedded history with fishing and a strong dependency on fish protein.

The world's rivers, estuaries and oceans were once perceived as a limitless resource and humans unwittingly plundered fish populations (Jackson *et al.* 2001, Pauly *et al.* 2005; Roberts 2007). However, following the industrialisation and intensification of fishing over the past century, the demise of the planet's fish populations became conspicuous (Watson and Pauly 2013, Watson *et al.* 2015). The collapse of Atlantic cod and orange roughy populations are two high profile case studies in overexploitation (Hutchings & Myers 1994; Roberts 2007). However, many smaller or less studied fisheries have suffered similar fates

(Thurstan *et al.* 2014, Young *et al.* 2014). As human populations, middle class wealth, longevity and the subsequent demand for marine resources continues to grow globally (Mora & Sale 2011, Garcia & Rosenberg 2010, Fabinyi & Liu 2014b), reports of overfishing, declining fish populations and habitat destruction are also likely to rise (Pauly *et al.* 2005, Worm *et al.* 2006, Hughes *et al.* 2013).

Although governments have often been slow to act on declining marine resources and ecosystem degradation (Sadovy *et al.* 2003, Berkes *et al.* 2006, Young *et al.* 2014), gear and catch regulations and the implementation of marine reserves have been popular response measures in recent decades (Halpern 2003, Fernandes *et al.* 2005, Gezelius & Hauck 2011). Evidence suggests that these actions have led to successful outcomes for ecosystems, fisheries and fishers (Russ *et al.* 2004, McCook *et al.* 2010) but their benefits have been the subject of much debate (Christie 2004, Helvey 2004, Sale 2013). Despite being generally supportive of regulation, recreational fishers have expressed frustration at a perceived lack of consultation, weak supporting evidence for measures and poor communication (Sutton & Tobin 2009, Li *et al.* 2010). Enforcement and compliance has also been an ongoing problem in developed and developing regions, illustrating the importance of consultation and the need for fisher support and involvement prior to implementing measures (Granek *et al.* 2008, Gezelius & Hauck 2011, Arias 2015). Conflict between fishers and regulatory authorities is one of the biggest hurdles faced during the establishment of fisheries regulation and marine reserves, and disputes are becoming increasingly politicised (McClenachan 2013, Hughes *et al.* 2016). Therefore, it is important for scientists, managers and governments to possess a thorough understanding of the motivations, behaviour and perceptions of fishers (Fedler & Ditton 1994). Such insights would provide valuable guidance for measured approaches to the implementation of regulation. This knowledge may also help authorities form strategies that harness stronger support from fishing communities and lead to improved outcomes.

An extensive body of research has examined the motivations of fishers in the developed world (Fedler & Ditton 1994, Ormsby 2004, Frijlink & Lyle 2010). These studies primarily focus on recreational fishers and reveal that the motivations for fishing are diverse (Fedler & Ditton 1994). However, little research to date has directly compared the motivations of recreational fishers and subsistence fishers from an ethnographic perspective to examine the motivations for fishing in the absence of necessity. There are also comparatively few studies exploring the role of masculinity in fishing or the perceived personal, societal and economic benefits of the activity. While recreational fishing is defined as fishing for aquatic animals that do not constitute the individual's primary resource to meet basic nutritional needs (FAO 2012), subsistence fishing is the act of fishing primarily to feed the family and relatives of an individual (Smith 2005). Likewise, artisanal fishing typically involves small-scale fisheries for subsistence and/or local markets (Smith 2005). Both subsistence and artisanal fishing are generally perceived as necessary for survival or livelihood. In a world where rising wealth may increase the prevalence of recreational fishing (Granek *et al.* 2008, FAO 2012), it is important to explore the underlying motivations that facilitate shifts in fisher mindset. Greater insight across these economic and social boundaries may help to understand and anticipate future changes in fisher behaviour and fishing pressures.

This study provides a cross-cultural examination of the motivations of fishers. It explores the similarities and differences between subsistence and artisanal fishers in the Solomon Islands (a developing country) and recreational fishers in Australia (a developed country) to provide an understanding of why fishers fish and why they continue to fish in the absence of necessity. The research also investigates recreational fisher perceptions of the benefits of fishing. As pressures on global marine populations grow, calls for conservation measures and conflict with fishers also increase. This work offers insight into the

motivations, behaviour and perceptions of fishers that can help to guide appropriate engagement measures, encourage collaborative conservation efforts and lead to effective outcomes for ecosystems and people.

6.2 Methods

An ethnographic approach was employed to conduct a cross-cultural comparison of the motivations of fishers in the Solomon Islands and Australia (Fig. 6.1). Study sites in the Solomon Islands were located within Langalanga Lagoon on the western coast of Malaita and on the small islands of Kwai and Ngongosila on the eastern coast of Malaita. In Australia, research was conducted along the eastern coast between Sydney and Townsville. In both countries semi-structured interviews were conducted and a snowball technique was used to identify a total of 53 interviewees. Experienced male fishers (minimum five years experience) between 20 and 80 years of age and with no medium- or large-scale commercial fishing interests were identified for interviews. The 28 interviewees in the Solomon Islands were subsistence or small-scale artisanal fishers who employed a variety of fishing techniques. In Australia, the 25 interviewees were exclusively recreational fishers (15 spearfishers and 10 line fishers). Interviews were conducted in a relaxed and familiar environment to maximise comfort and typically lasted between one and two hours. A set of questions was asked in a semi-structured manner to permit flexibility for the different personalities of interviewees and to provide scope for triangulation to harness greater confidence in responses. Fourteen interviews in Australia were conducted over the phone due to logistical limitations and the availability of interviewees.

The importance of semi-structured interviews and triangulation

Semi-structured interviews were essential to gain accurate insight into the motivations of fishers, particularly in the Solomon Islands. Due to potential misinterpretation of questions or hypothetical scenarios, unforeseen confounding factors and differences in personalities, a questionnaire or survey approach could potentially extract misleading responses (see Bernard 2006). The flexibility of semi-structured interviews and triangulation encourages reflective and measured responses rather than impulsive or 'strategic' answers. This less structured approach also permits time for interviewees to relax and reflect on their answers and potentially allows for insights that may not have been captured by a questionnaire approach.

For example, when one fisher in the Solomon Islands was questioned whether he would still continue to fish in the event he had secured an alternative income, he initially responded that he wouldn't. However, further questioning and triangulation revealed that he previously worked as a teacher and frequently fished during this employment period. He then elaborated that he had fished in his spare time because he enjoyed it and preferred to catch fish rather than buy them. Thus, with further questioning and triangulation the interviewee had provided a powerful example of his willingness to fish despite having an alternative source of income. This was in stark contrast to his initial response.

Another example emerged through a question about the largest fish interviewees had ever caught. A pattern began to emerge at one particular study site with multiple interviewees answering that the largest fish they had ever caught was either very recently or in the past few years. The high reported capture rate for 'large' fish in recent years was surprising and initially considered as a potential display of machismo. However, with further enquiry and triangulation, it emerged that the specified 'largest fish' were all of one species that was regularly caught at similarly large sizes. so that distinguishing these 'biggest' fish between

years was both impossible and illogical. Thus, the initial response did not provide a complete and accurate perspective and would have delivered a misleading result. These two examples clearly illustrate the value of employing semi-structured interviews and triangulation for some research applications.

The motivations, behaviour and perceptions of fishers

Interviews commenced with general background questions about the type of fishing conducted, the fish targeted, and the equipment used. All fishers were then asked to identify the reasons why they fished and were given time to elaborate and openly discuss their thoughts. In response to the high prevalence of subsistence and artisanal fishing in the Solomon Islands these fishers were presented with a hypothetical question to further explore their motivations for fishing. It was suggested that if there were an alternative source of income that was more profitable (i.e. another career/work option) would they continue to fish? They were then asked to discuss and qualify their answers. Responses were categorised and tallied the by study region in a common framework to contrast the motivations by developed and developing countries. To investigate aspects of masculinity and ego in fishing, fishers were asked how they felt when they returned with a good catch, whether they or other fishers shared knowledge of their success, and whether there was competition among fishers. The behaviour of men engaged in fishing was also observed over approximately 10 h in total (Fig. 6.2). In Australia, fishers were also directly asked for their perceptions on the personal, societal, environmental and economic benefits of recreational fishing to gain further insight into mechanisms or factors that may inspire motivations to fish. Once again, fishers were engaged in an open discussion and the benefits that they identified were noted.

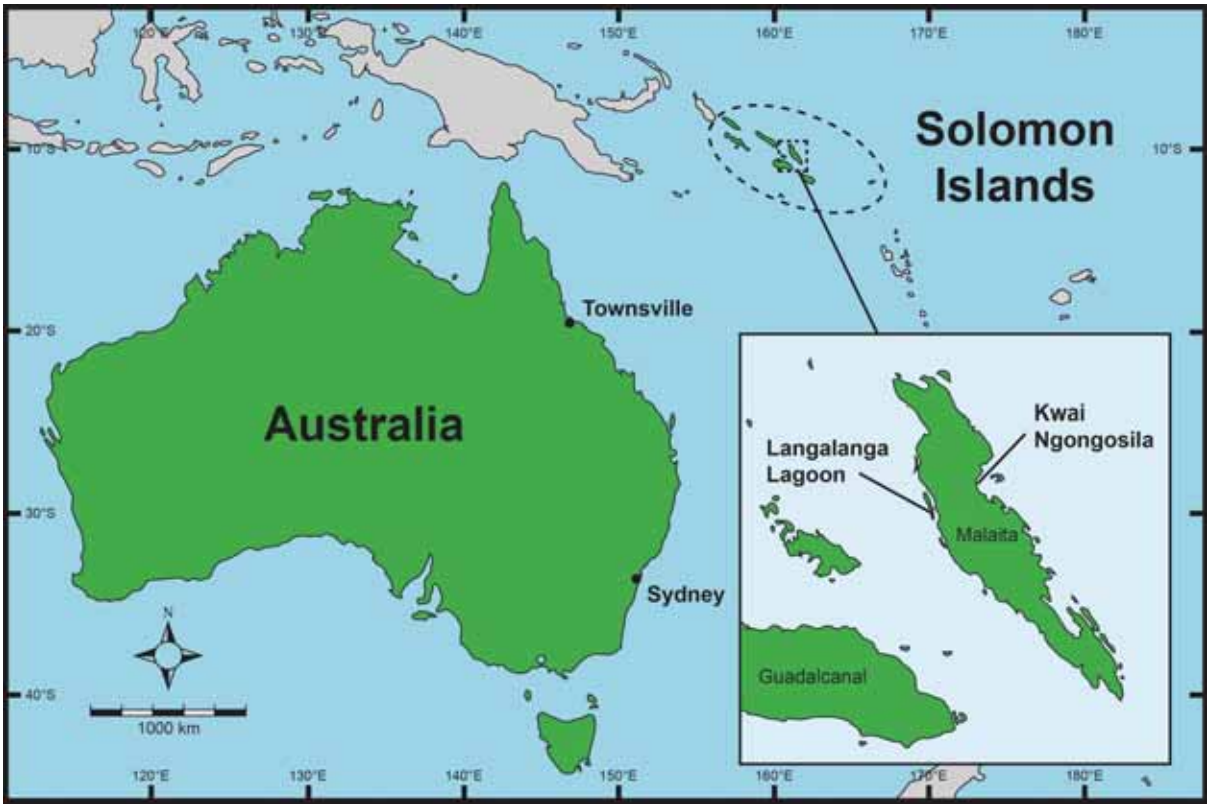

Figure 6.1 Map of the study sites in Australia and the Solomon Islands. Interviews were conducted between Townsville and Sydney on the east coast of Australia, at Langalanga Lagoon on the west coast of Malaita and on the islands of Kwai and Ngongosila on the east coast of Malaita.

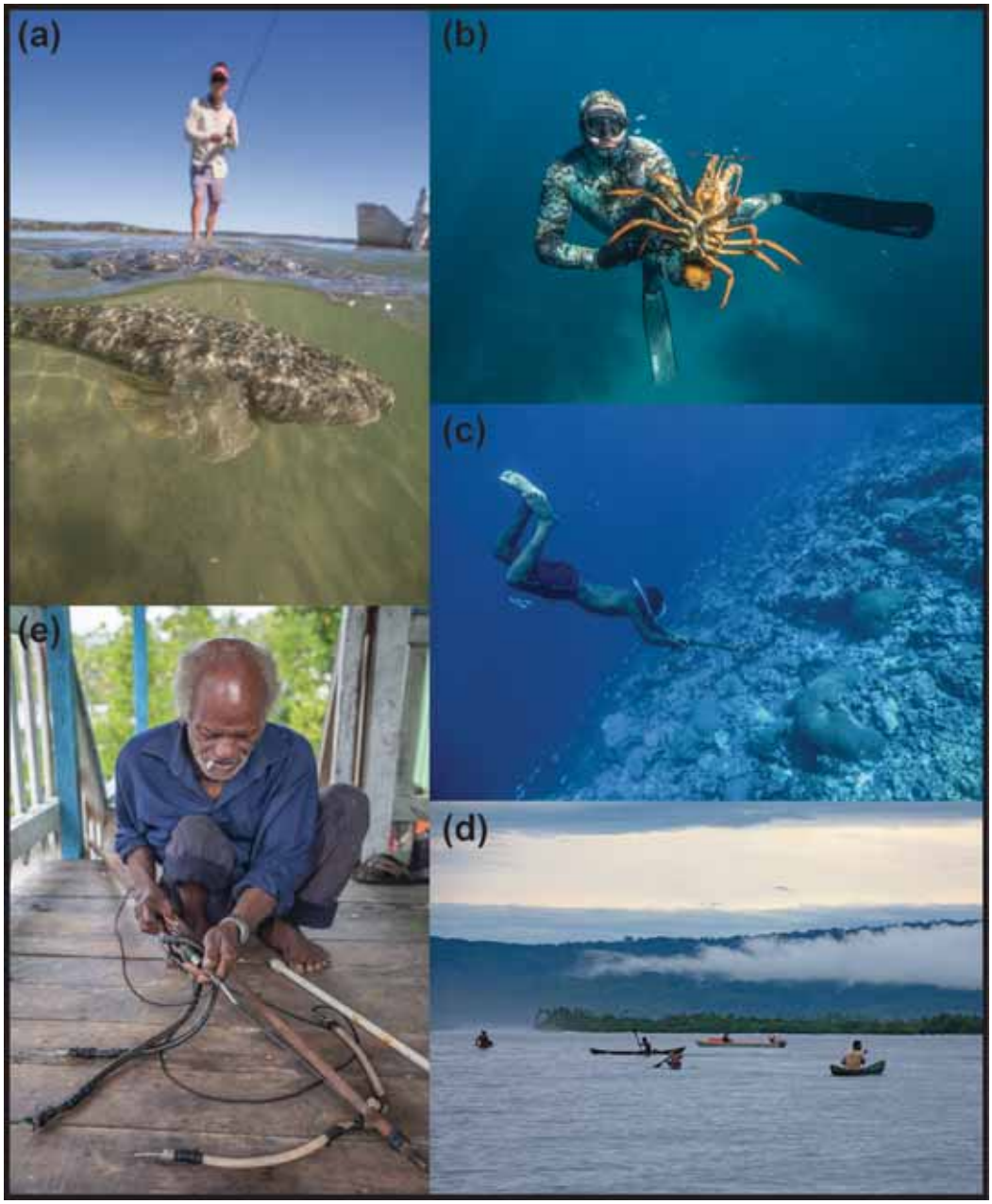

Figure 6.2 Images depicting the activities of recreational fishers in Australia and subsistence and artisanal fishers in the Pacific. (a) A typical recreational line fisher in Australia. (b) A contemporary spearfisher harvesting a lobster. (c) A spearfisher diving on a coral reef in the Pacific. (d) Fishermen in canoes and small boats at a fish aggregation device (FAD) in the Solomon Islands. (e) A spearfisher at Langalanga Lagoon displays his home crafted speargun.

6.3 Results

The natural environment

The environment, nature and scenery emerged as the most frequently identified motivation (96% of recreational fishers) for fishing in Australia (Fig. 6.3). Interviewees described a love of the environment, outdoor pursuits and the experience of being immersed in nature as one of the main reasons for undertaking fishing activities. Spearfishers, in particular, described the beauty of the underwater world and the intrigue of directly observing the behaviour of fish and marine life. Fishers also discussed their amazement at the variety of sights and experiences they encountered and emphasised how fishing provides a platform for these unique interactions. These unexpected natural events were identified by 44% of fishers as another important motivation. In the Solomon Islands, 61% of fishers identified the environment, nature and scenery as an important motivation (Fig. 6.3) and described their interest in observing the behaviour of fish and marine life, and interacting with the natural environment.

Food and income

Fishing for food was identified as a motivation by 80% of recreational fishers interviewed in Australia (Fig. 6.3). Although this emerged as the second most identified motivation (alongside escapism/relaxation), 14 of the recreational fishers clearly articulated that food was a secondary motivation. Only two Australian interviewees identified food as the primary motivation. One of these individuals fished for economic reasons to supplement his income and provide food for his family. Nevertheless, although fishers in Australia did not stipulate economic (income) reasons as a fishing motivation, some suggested that catching their own fresh fish did save them from paying expensive prices at fish markets and stopped them from

supporting commercial fishing. Another individual explained that when he returned with fish, it justified the expense of his outing to his spouse. In contrast, one interviewee expressed that he enjoyed fishing but did not like to eat seafood. Thus, food clearly had no role in his motivation to fish.

At both study sites in the Solomon Islands, marine fishes provided the primary source of animal protein and one of the main sources of income. Thus, it is not surprising that food (100% of fishers) and economic (income) motivations (93% of fishers) emerged as the two most important motivations for fishing in these subsistence and artisanal fishing communities (Fig. 6.3). These primary motivations were also reinforced through the observed willingness of fishers in the Langalanga region to shift to the most productive fishing methods. In this region, 87% of interviewees expressed an affinity for coral reef spearfishing, but most had been forced to embrace tilly light, net or strike line methods that target much more abundant small pelagic fishes (also see Roeger *et al.* 2016). Fishers explained that spearfishing was previously a common fishing activity in Langalanga, but as reefs deteriorated and reef fish disappeared, spearfishers had to embrace more productive fishing methods. At Langalanga 60% of fishers interviewed stated that there had been a decline in the abundance and size of reef fishes due to destructive dynamite fishing and high fishing pressure on coral reefs.

> "Dynamite is making fish smaller. There are lower numbers of fish because of pressure and dynamite." (Langalanga, Solomon Islands fisher)

Interestingly, at Kwai-Ngongosila where fishing pressure was comparatively lower, a high prevalence of spearfishing was mostly explained in terms of its higher productivity. Fishers specifically chose to spearfish because it provided the biggest catches of the most

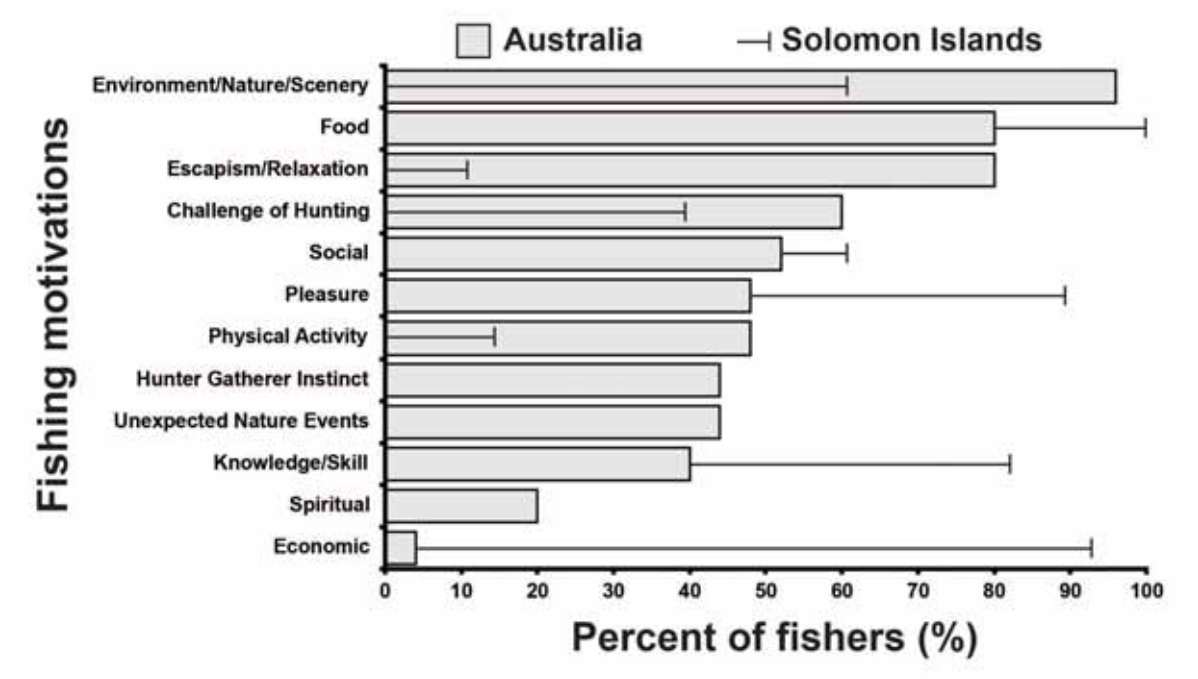

Figure 6.3 The motivations for fishing and the percentage of fishers in Australia (bars) and the Solomon Islands (lines) who identified each category during interviews.

highly sought reef fishes. These scenarios clearly illustrate the central importance of food and income motivations in the Solomon Islands.

Pleasure, escapism and relaxation

All fishers described their fishing experiences fondly and recounted tales with smiles, laughing and profound enjoyment. Fishers in Australia described how fishing provided an escape from the pressures and stresses of modern society, work and personal difficulties. They also explained that the activity allowed them to clear their minds and refresh.

> "Life today is so busy and there is constant background noise. Fishing is an escape back to basic existence that improves mental health and clears the mind." (Australian fisher)

In Australia, 48% of fishers explicitly identified pleasure as a motivation to fish (Fig. 6.3). However, it is likely that many of these fishers expressed pleasure through other motivations such as escapism and relaxation (80% of fishers), physical activity (48% of fishers) or spiritual aspects (20% of fishers). Pleasure is inherently linked to the satisfaction gained through a variety of motivations, yet it was important to include this broader category for interviewees who did not clearly articulate specific facets of pleasure. This was most apparent in the Solomon Islands, where fishing for pleasure was identified by 89% of fishers but some of the more specific categories such as escapism and relaxation (11% of fishers) or physical activity (14% of fishers) were not well represented (Fig. 6.3).

When fishermen in the Solomon Islands were presented the hypothetical scenario in which they had secured an alternative income, all indicated that they would continue to fish whenever possible because of their personal interest and enjoyment of fishing. Two

spearfishers did state that they would opt for less arduous fishing techniques such as line fishing, or avoid the cold conditions of night diving. Seven fishers also shared personal experiences that directly illustrated their willingness to continue fishing even when alternative employment had been secured. One interviewee worked as a teacher in the past and had fished in his spare time. Another had worked long hours away from home for a private organisation, but looked forward to holiday breaks and speared fish as soon as he returned home. Two other fishers in the Solomon Islands stated that they were financially comfortable and did not need to fish for food or income. However, they chose to fish because of their passion for fishing.

> "We have financial support and resources but we choose to go fishing because we love it – it's a hobby." (Solomon Islands fisher)

Knowledge, skill and the challenge

Fishers in Australia also identified the importance of knowledge development and demonstration of skill (40% of fishers) and the challenge of hunting and deceiving prey (60% of fishers) as important motivations to fish (Fig. 6.3). Similarly, fishers in the Solomon Islands placed great emphasis on knowledge and skill (82% of fishers) and the challenge of hunting (39% of fishers) (Fig. 6.3). The possession and demonstration of knowledge and skill not only provided greater potential for better catches, but also garnered respect and admiration from other fishers and the broader community. In fact, the community held such regard and confidence in the abilities of some spearfishers in the Solomon Islands that they were often paid in advance of an event to hunt a specific requested fish or animal.

Social capital

In both Australia (52% of fishers) and the Solomon Islands (61% of fishers) fishers identified the social aspects of fishing as important motivations (Fig. 6.3). Australian fishers often emphasised the importance of bonding and building relationships with friends and other anglers while undertaking fishing activities. They believed that fishing facilitated strong relationships and encouraged social cohesion through which all social and cultural groups could interact on a level playing field. They also explained that fishing activities provided a valuable opportunity for quality family time.

> "Fishing allows me to spend quality time with the family and I can share knowledge with my son." (Australian fisher)

> "Fishing provides social benefits to the community through camaraderie, fishing clubs and the sharing of a common interest. It also contributes to social cohesion as it crosses social boundaries and encourages unification." (Australian fisher)

In the Solomon Islands, fishers explained that men often went on fishing outings in groups and these occasions provided a platform for friendship, but also discussions on community issues. At Langalanga, fishers described a case where the village women were frustrated with a lack of support with the supervision of their children. The senior village men engaged in a discussion during a fishing outing and developed an idea to establish a community kindergarten. They subsequently returned to the village and implemented their solution.

Instinct, masculinity and ego

Some fishers in Australia (44%) described an instinctual hunter-gatherer motivation to fish (Fig. 6.3). They explained that regardless of whether or not they were successful in catching fish, recreational fishing satisfied an innate urge to assume the role of provider.

> "There is a primal hunter-gatherer instinct for men to feel like they are providing for the family. This is a natural thing and the more we disconnect from this in modern life, the more frustration and stress in society." (Australian fisher)

This hunter-gatherer motivation was not articulated in the Solomon Islands probably because the instinct is satisfied on a regular basis. In our sample areas of the Solomon Islands male fishers primarily assumed the provider role in regards to the hunting of animal protein.

According to senior fishers in both countries, demonstration of masculinity and ego was most prevalent in younger male fishers. Interviewees suggested that some of the younger men were eager to earn respect through large and impressive catches and had a tendency to take risks and fish excessively.

> "The young guys are competitive and are trying to prove themselves and earn respect. They are full of ego and testosterone and are focused on big fish and risky diving." (Australian fisher)

Five of the senior fishers in Australia explained that they had behaved similarly in their younger years, but became more relaxed, less competitive and increasingly discriminating in the species, size and number of fish they target as they aged. These senior recreational fishers

also described their conscious effort to act as stewards and adopt a positive and influential role in the development of younger fishers.

> "The older guys realise how much they do not know and tend to be more sensible, relaxed and focused on quality fish. The older guys also act as stewards for the younger boys." (Australian fisher)

In Kwai and Ngongosila five of the younger spearfishers claimed that those who chose not to spearfish lacked the skills and knowledge or were scared of the water. They also believed that women were more attracted to spearfishers because of the money they earn and that the community had greater respect for them because of their diving skills. Although there may be elements of truth to these claims, the men appeared to be reinforcing their masculinity through these statements. The young men also expressed a motto that they frequently recite ("die, die, live, live"), to emphasise their lack of concern for the risks or dangers involved in spearfishing and their intention to spearfish until the day they die. This expression appeared to be a striking display of machismo.

Our direct observations of groups of fishers engaged in fishing at Langalanga also suggested that the activity provided a bonding environment for the men (Fig. 6.2d). Between 10 and 20 male fishers in canoes and small boats were observed line-fishing at a Fish Aggregating Device (FAD). Fishers would occasionally break from fishing for a chat or to share betel nut and tobacco. Banter and teasing was also frequently shouted and followed with bouts of laughter. It was also evident that the men were fishing competitively. Although the joking behaviour appeared to be in good humour and the men were clearly enjoying the interaction, they were also closely monitoring which fishers were catching fish. They would then jockey and compete to position themselves where the fish were biting. This provided

further insight into the male bonding atmosphere that fishing activities may facilitate in developing countries.

Boasting and excessive displays of ego appeared to be frowned upon in both cultures, but interviewees described more subtle ways in which fishers could convey their triumphs to the community. In Langalanga, men were typically jovial and sang loudly as they returned to the village to demonstrate a good catch, tuna fishermen raised two blue flags on their boats to indicate success and small pelagic fishermen kept their lamps on all the way back to the village at night to convey that their canoes were filled with fish. In contrast, those with a poor catch turned their lamps off to avoid attention. In Australia, interviewees identified the frequent use of social media to boast of successful catches and garner broad admiration. Senior fishers frowned upon such behaviour and vented frustration at the manner in which younger fishers recklessly bragged and displayed poor fishing etiquette to the world.

> "Ego is a massive issue with the younger guys showing off and trying to prove themselves. The better divers are quiet achievers and do not post their photos on Facebook." (Australian fisher)

Recreational fisher perceptions on the benefits of fishing

Recreational fishers in Australia identified a range of personal, societal, environmental and economic factors that they perceived to be important benefits of fishing (Table 6.1). The personal benefits included physical fitness and exercise, benefits to mental health through escapism, stress release and relaxation, the health properties of seafood, the social interactions and bonding with friends and family and the ability to be outdoors and satisfy their hunter-gatherer instinct. Fishers also described modern society as an insular environment where communal life had long been forgotten. They reasoned that some

individuals achieved a sense of community through religious groups, sports or other activities, but that many fishers satisfied this need through fishing trips with friends and family, fishing clubs, or competitions.

> "People are missing out on quality community time. The modern world has become insular and isolated and is now so different to the community/village life of the past. Fishing brings people out of the bubble and back in contact with the natural world. Humans need to be part of the environment." (Australian fisher)

Recreational fishing was also perceived to provide mental and physical health benefits to the broader community, foster community cohesion, build social capital, and provide an accessible pursuit for all walks of life. It was said to promote healthy outdoor activity for individuals, families and children rather than sedentary or anti-social activities (i.e. computer gaming or gambling).

> "Fishing is great for young and old. It provides a reason for people to get outdoors rather than playing computer games or pokies." (Australian fisher)

Four senior fishers explained that fishing provided young men, in particular, with an outlet to burn energy and vent frustration. It was suggested that if they didn't have this avenue of release, especially in small coastal towns, that this angst would manifest in the community in undesirable ways.

> “Fishing is an outlet for young men to deal with aggression and male issues. If you take away this outlet, the frustration will be vented into the community in another way, shape or form.” (Australian fisher)

> “The young guys are ratbags. Spearfishing provides discipline and teaches the young men to control emotion.” (Australian fisher)

Fishers in Australia also express concern for the growing disconnect from the realities of nature in modern society. They felt that fishing activities provided a healthy grounding and a respect for the process of harvesting protein. They noted that the process of fishing teaches children to appreciate the origins of food in a society where the hunting and gathering process is highly sanitised.

> “Fishing gets kids outdoors enjoying nature. It teaches them an appreciation and respect for where food comes from.” (Australian fisher)

In addition, fishers believed that fishing fostered a respect for the environment and a love of nature. They reasoned that when humans value something highly, they tend to want to protect it. Thus, fishing encouraged a desire to protect fish populations and ecosystems. Recreational fishers also pointed out that harvesting their own fish reduced dependence and demand for commercially caught fish, which they perceived as damaging.

> “Fishing provides environmental benefits because we like to protect things that are dear to us. Experiencing nature fosters respect for the natural environment and a desire to protect it.” (Australian fisher)

Table 6.1 The benefits of recreational fishing from the perspectives of fishers.

Category	Benefits of recreational fishing
Personal	Physical fitness - exercise
	Mental health – escape and stress release
	Healthy food supplement
	Social interaction - friendships
	Family time and bonding
	Relaxation
	Satisfies hunter-gatherer instinct
Societal	Enhances community wellbeing – mental and physical health
	Community cohesion - crosses social divides
	Relationship building
	Avenue for adolescents to vent frustration
	Teaches discipline and life skills
	Encourages individuals, families and children outdoors
	Accessible for all walks of life
Environmental	Fosters respect for the environment
	Encourages a desire to protect nature
	Self-harvest reduces dependence on commercial fishing
	Teaches children to appreciate nature
	Provides perspective and appreciation of food
Economic	Fishing tourism
	Economic boost for many coastal and regional towns
	Fishing tackle, equipment and bait sales
	Vehicle sales (boats, motors, trailers and 4WDs)
	Fuel sales
	Accommodation and flights
	Food, alcohol, and ice sales
	Restaurant and pub patronage
	Camping equipment sales
	Employment

Recreational fishers perceived the economic benefits of recreational fishing to be enormous (Table 6.1). Coastal and regional towns were identified as being particularly dependent on fishing tourism and fishers felt that the economic flow-on effects to the economy through fishing were often underestimated. Fishing tackle, bait, boats, motors, 4WDs, fuel, accommodation, flights, food, alcohol, ice, and camping equipment sales were identified as important economic benefits of fishing.

6.4 Discussion

Revisiting common perceptions

The imperative to acquire food and income from fishing was immediately apparent in the Solomon Islands and clearly demonstrated through the behaviour of fishers. Spearfishing primarily targets coral reef fish in the Solomon Islands, which are often desired for both market and table (Brewer *et al.* 2012). Thus, the small number of specialist spearfishers in Langalanga is likely reflective of depleted reef fish populations relative to the more productive tuna and small-pelagic fisheries (Albert *et al.* 2015, Roeger *et al.* 2016). The coral reefs of Langalanga are exposed to relatively high fishing pressure due to the adjacent high human population density (SPC 2008, Foale *et al.* 2011), the proximity of a substantial urban market and a history of dynamite fishing in the region (Roeger *et al.* 2016).

In contrast, Kwai and Ngongosila fishers considered spearfishing to be the most productive method, potentially reflecting healthier nearby reef systems and lower population and market pressures. These observations clearly illustrate the essential role that fishing plays in providing protein and income for these communities and supports common perceptions on the motivations for fishing in the developing world (Albert *et al.* 2015). However, when presented with the hypothetical scenario in which they had secured an alternative source of

income, all of the fishers stated their eagerness to continue to engage in fishing. These fishers supported their position by citing a host of underlying personal, cultural and societal motivations that parallel those of recreational fishers in the developed world. This suggests that even in the absence of necessity (food and income) many fishers would likely continue to fish in these regions. It has been suggested that data on fishing intentions should be viewed with caution (Fedler & Ditton 1994). However, the present study found direct evidence of fishers with alternative income sources continuing to fish. In particular, the two fishers in the Solomon Islands who expressed that their financial circumstances did not necessitate fishing, chose to fish because of their interest and enjoyment of fishing. Our findings suggest that motivations for fishing in developing countries are more complex than the prevailing stereotypes of subsistence and artisanal fishers (Granek *et al.* 2008, FAO 2012).

In Australia, the stereotypical recreational fishing motivations such as pleasure, escapism or relaxation were prevalent (Fig. 6.3). Many reports and regional studies have concluded that the primary motivations of recreational fishers do not necessarily involve the catching or eating aspects of fishing (Knopf *et al.* 1973, Fedler & Ditton 1994, Arlinghaus 2006). However, fishing for food also emerged as an important, if secondary, motivation for recreational fishers. This observation lends some support to a case study that found the retention of fish was important to anglers (Matlock *et al.* 1988). However, the outrage from anglers in response to a proposed prohibition on the retention of fish in that particular study may simply reflect resentment of top down governance or inadequately justified restrictions on liberty (Jentoft *et al.* 1998, Grafton 2005, Gezelius & Hauck 2011), rather than a definitive desire to retain fish.

Masculinity and the instinct to fish

Interestingly, masculinity is rarely captured in fishing motivation surveys. However, an ethnographic approach permits observation and insight into potential mechanisms that operate subconsciously or in a less conspicuous manner. Exhibitions of machismo, camaraderie and male bonding were evident in our interviews and observations in Australia and the Solomon Islands. Young men are well recognised to exhibit impetuous or aggressive behaviour in an attempt to demonstrate their masculinity, establish their position in society and gain the respect and admiration of their peers (Arnett 1992). Fabinyi (2007) observed similar displays of masculinity in the Calamianes Islands and identified young male fishers to be primarily responsible for illegal fishing. He also observed young men speak of their fishing experiences in terms of their personal strength, bravery, pride and skill. Their high-risk, high-gain attitude also demonstrated their financial capacity to potential partners. Thus, motivations for fishing may also be associated with an ideology of masculinity that is more apparent in young men attempting to establish their status in society.

The act of catching fish has also been described as an expression and measure of male success, a means to gain prestige and a mechanism to act out aggression and competitive behaviour (Dumont 1992). Thus, the importance of fishing activities as an outlet for youth to vent frustration and angst should be considered. Notably, the aspirations of senior fishers in Australia to act as stewards and role models for younger men may offer an opportunity for management authorities to provide educational and logistical support to facilitate such knowledge transfers. Education and advice that is delivered through respected peers is much more likely to be adhered to or supported.

Recreational fishers also described an innate urge to express their primal hunter-gatherer instincts. There are a variety of historical (generational knowledge transfer), cultural, social and instinctual factors that motivate people to hunt and gather (Fedler & Ditton 1994,

Borthwick 2012). In fact, fishing for pleasure, relaxation and challenge can be traced as far back as 300 B.C. (Fedler & Ditton 1994). It is also likely that men, in particular, are hard-wired to hunt and express their role as a provider and support their families and communities (Nicholson 1998). Hunting and gathering has been integral to the survival and evolution of humans for 200,000 years and is also a potential underlying reason why fishers feel a sense of entitlement to fish and often resist regulatory measures that are perceived to be excessive or restrictive (Jentoft *et al.* 1998, Grafton 2005). Ultimately, humans have fished since the dawn of time and this desire to fish is likely to continue into the future.

Environmental values and the growing disconnect with nature and community

Experiencing the environment and nature was the most identified motivation for fishing in Australia (Fig. 6.3). This observation aligns with previous studies that have noted the high value that fishers place on the environment during fishing activities (Fedler & Ditton 1994). Combined with the perceived environmental benefits of fishing these observations suggest a heightened awareness of nature and the environment among fishers (Table 6.1). Although recreational fishing has been linked to declines in fish populations (McPhee *et al.* 2002, Cooke & Cowx 2004), many recreational fisher values align closely with that of conservationists (Granek *et al.* 2008). Most case studies where recreational fishers have been implicated in fisheries declines have occurred in an atmosphere devoid of adequate ecological or fisheries knowledge. However, when new information has emerged, fishers have been shown to embrace regulation and even encourage it (Young *et al.* 2014). It is a recognised phenomenon that when humans value something, they want to protect it (Schultz *et al.* 2005, Nisbet *et al.* 2011). Thus, in a recreational fishing environment that is devoid of excess demographic or market pressures, knowledge and awareness of potential threats to fisheries may encourage recreational fishers to advocate for conservation measures (Sherwin

2013). These desires to protect habitats and ensure the proliferation of fish populations should be embraced and harnessed.

The concern of a growing nature-culture divide expressed among Australian fishers may also have merit. It is well recognised that modern society's increasing disconnect from nature has detrimental effects on human happiness and health (Nisbet *et al.* 2011). The supply of food (meats and crops) in highly processed forms and in packaging that removes any notion of its origins illustrates this disconnect from nature (Turner & Henryks 2012). Indeed, many children in urban societies have problems identifying the origins of produce (Hillman & Buckley 2011). Television programs, glossy travel magazines and other forms of media often present a stylised or idealistic image of nature, devoid of the harsh realities of existence (Foale & Macintyre 2005). Modern societies have become more insular, consumer oriented and appear to have less appreciation and understanding of natural processes (Nisbet *et al.* 2011).

Fishermen also valued the social interactions and social cohesion that fishing activities supported but expressed concern that modern society was increasingly disconnected from a sense of community. Such social interactions are well known to build social capital and provide benefits to the health, governance and functioning of communities (Grafton 2005, Burls 2007). This sense of community may also partly explain the powerful and cohesive political influence of the recreational fishing sector (McClenachan 2013).

Top down governance and the implications for conservation and management

Top down governance may be effective and necessary for some fisheries. However, in many cases it has exacerbated the demise of fish populations through conflict, delays and compliance issues (Jentoft *et al.* 1998, Grafton 2005). In the developing world, big international nongovernmental organisations (BINGOs) have repeatedly employed a top

down approach to impose western conservation agendas that do not align with local values or fail to consider the underlying needs, motivations and perceived rights of the community (Foale and Macintyre 2005, Rodríguez *et al.* 2007, Brockington *et al.* 2008, Fidelman *et al.* 2012). While perhaps good intentioned from a conservation perspective, this underscores the potential for such measures to result in failure (Gezelius & Hauck 2011). Solutions to fisheries issues must integrate extremely diverse natural, socioeconomic, and cultural systems and harness strong local organisations to build from the bottom up and create a sense of ownership among fishers and the community (Jentoft *et al.* 1998, Rodríguez *et al.* 2007). Our research reveals that fishers in the Solomon Islands fish for several other reasons besides food and income. Many of these personal, social and cultural motivations to fish are ingrained and even in the absence of necessity some fishers will choose to fish. Thus, in some cases, management or conservation approaches that seek to prevent access to an activity that people enjoy, even if it is not economically vital, are likely to encounter resistance (Hilson & Banchirigah 2009, Pomeroy 2013).

Conflict and opposition to the implementation of regulatory measures and marine protected areas has also been an ongoing issue in recreational fisheries (McClenachan 2013, Voyer *et al.* 2014). In some cases recreational fishers have requested an unrealistic level of scientific evidence of fishery degradation and employed scepticism to delay action (McClenachan 2013). In particular, fishers are opposed to government measures that are poorly justified or perceived to be politically motivated (Jentoft *et al.* 1998). However, other research shows that fishers can be open and supportive of regulatory measures when they are well evidenced, explained and communicated (Sutton & Tobin 2009). In fact recreational fishers have even raised conservation concerns, joined forces with conservation organisations and lobbied governments for regulatory action (Sherwin 2013, Young *et al.* 2014). Well-established conflict resolution mechanisms may also help to facilitate successful fisheries

outcomes (Arias Schreiber & Halliday 2013). Nevertheless, fishers often feel that consultation on regulatory matters is inadequate (Sutton & Tobin 2009), their knowledge is undervalued (Voyer *et al.* 2014) or that they are insufficiently informed to contribute meaningfully to discussions (Li *et al.* 2010).

Top down policies have in many cases exacerbated social and ecological problems across the globe (Jentoft *et al.* 1998, Grafton 2005, Rodríguez *et al.* 2007). Government interventions in Indigenous communities are a stark example of how bureaucratic measures often fail to recognise underlying social issues (Maddison 2008). Unfortunately, heavy-handed top down management often leads to increasingly frustrated, marginalised and dysfunctional communities (Fidelman *et al.* 2012). The reality for governments, management and conservation organisations, is that they cannot dictate political agendas or convictions to the people. The key is to effectively communicate with the broader fishing community and to clearly articulate fishery concerns and the science behind potential regulatory measures to generate support (Foale 2013). It may be necessary to connect with fishing communities at a grass roots level in order to fully comprehend their needs and motivations and to implement a more appropriate and context-sensitive approach (Granek *et al.* 2008). This will minimise conflict and provide the best possible environment for successful outcomes.

6.5 Conclusions

The desire to engage in fishing crosses cultural and social boundaries and is driven by a deep connection with nature and a host of underlying cultural and social motivations. Although this study is limited to two case studies and is not representative of all recreational and subsistence fisheries in the developed and developing world, our results reveal that the desire to fish can often transcend necessity, even among highly resource-dependent populations. In

this study, fishing was perceived to enhance social cohesion, promote respect for nature and provide health and economic benefits to society. In fact, many of the environmental-oriented values of recreational fishers align closely with those of conservationists, providing a clear opportunity for regulatory authorities to embrace a consensus approach. These results suggest that fishing activities may facilitate a range of fundamental benefits to individuals and societies and that fishers may act as valuable advocates for marine conservation if their values and motivations are harnessed appropriately. Knowledge on the life history of marine species and understanding of the behaviour and motivations of fishers remain central to successful fisheries management. This knowledge can facilitate broad-based support for management that will ensure the persistence of marine populations for the benefit of ecosystems and future generations of fishers.

Chapter 7: Concluding discussion

The potential for recreational fishing participation and impacts to grow on a global scale, emphasises the importance of understanding the historical trends, ecological impacts and the socio-cultural dynamics that characterise the recreational sector. This knowledge could offer valuable insights into fisher behaviour and provide guidance for appropriate management strategies. This thesis has highlighted that recreational spearfishing can impact vulnerable fish populations yet it also reveals that fishers can be proactive in response to observed declines and advocate for regulatory measures (Young et al. 2014, Chapter 2). This thesis also reveals that recreational fisheries are not fixed or stagnant systems. Rather, they are subject to dynamic shifts in catch trends and fisher behaviour and thus require careful monitoring (Young et al. 2015, Chapter 3). Historical shifts in spearfishing catch in Australia have led to an increase in the targeting of coral reef and pelagic fish and a rise in fishing excursions to exotic locations such as the Coral Sea (Young et al. 2016a, Chapter 4). Technological advances, particularly satellite navigation and sonar developments, have facilitated these shifts further afield and dramatically increased the efficiency of fishers (Chapter 5). Although their capacity to target fish has markedly increased, fishers typically engage in fishing for a host of personal and social reasons, some of which transcend cultural boundaries. However, a strong connection to the environment, food, pleasure and the benefits of building social capital and cohesion appear to be strong motivating factors regardless of country or developmental status (Young et al. 2016b, Chapter 6).

Recreational fishing in a global context and the scope for future research

Although this body of work primarily examined recreational spearfishing in Australia, similar historical, ecological and social dynamics likely persist within recreational fisheries across the globe. In particular, given the inherent links between boating, satellite navigation, sonar technologies, and fishing, it seems highly probable that such technologies would have played a key role in the development of recreational fisheries worldwide. Recreational spear and line fishing are extremely popular activities in developed countries (Cooke & Cowx 2004, Coll *et al.* 2004, Morales-Nin *et al.* 2005, Lloret *et al.* 2008). However, global participation in recreational fisheries is likely to expand into regions with a growing population of affluent or middle class people (FAO 2012). Thus, the impacts of recreational fishing and importance of recreational fisheries research are likely to grow (McPhee *et al.* 2002, Morales-Nin *et al.* 2005). This presents a potentially interesting field of research on emerging recreational fisheries.

The development of this thesis has also highlighted related fields that show potential for future research. The use of berley by recreational spearfishers to attract pelagic fish species involves the prior capture and killing of lesser-valued fish species. It would be useful to examine this process in more detail to quantify the extent to which spearfishers engage in this practice and to identify the fish species and volumes harvested. Additionally, in the process of spearfishing a substantial proportion of speared fish either escape (survival unknown) or are preyed upon by sharks. Thus, the harvesting of bait fish or burley species and the depredation and loss of fish during capture are topics relevant to both recreational spear and line fisheries and would be valuable to pursue in future research.

The future of recreational fisheries

The future of recreational fisheries depends largely on the ability of fishers, scientists and governments to establish a sustainable and sensible balance between harvesting and conservation. Cooperation and compromise are the only possible mechanisms to achieve a win-win scenario for all stakeholders and marine ecosystems. Recreational fishers are likely to benefit from recognising their collective impacts on marine populations, acknowledging technology-induced creep in fishing efficiencies, and remaining open to reasonably justified regulatory measures. Governments, regulatory authorities, and scientists will benefit from increasing recognition of the importance of fisher knowledge, and are likely to achieve more effective outcomes by incorporating the values, perceptions and motivations of fishermen into management approaches. The history of fisher resistance to top-down authority, suggests a grass-roots approach that embraces fisher knowledge and values may nurture mutual respect among stakeholders and harness stronger support for regulatory measures. In particular, the evidence for recreational fishers recognising impacts, advocating protection measures and expressing strong environmental values should be embraced and nurtured by regulatory bodies. I hope that this thesis will provide additional impetus to the growing recognition of a common interest on protecting and propagating fish populations. Together we may find a practical, sustainable solution to the world's fishery problems.

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Appendices

APPENDIX 2.1

Chronology of Australian spearfishing publications

Table S2.1 Chronology of Australian skindiving/spearfishing publications. Title sequence A–C were published by the Australian Underwater Skindivers and Fishermen's Association (USFA). Title sequence D–I were published by Mountain, Ocean and Travel Publications. At commencement of the second sequence the editor notes that the new magazine was created to replace the USFA publications that had ceased production.

Sequence	*Years*	*Title*
A	1952–53	*Spearfishing News*
B	1953–1961	*Australian Skin Diving and Spearfishing Digest*
C	1961–1970	*Australian Skindivers Magazine*
D	1970–1974	*Skindiving in Australia*
E	1975–1979	*Skindiving in Australia and New Zealand*
F	1980–1986	*Skindiving in Australia and the South Pacific*
G	1987–1993	*Sportdiving in Australia and the South Pacific/Sportdiving*
H	1993–1997	*Australian Free Diving and Spearfishing News*
I	1998–2011	*International Freediving and Spearfishing News*

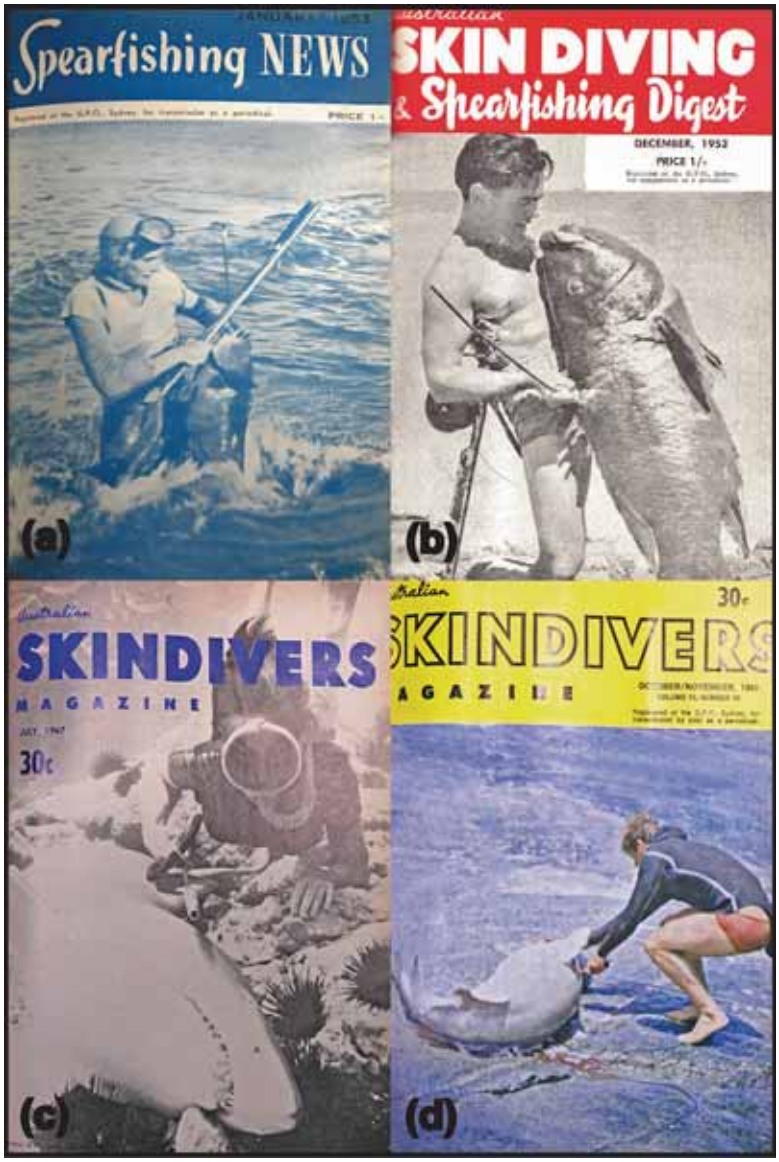

Figure S2.1 Magazine covers highlighting the importance of eastern blue groper (*Achoerodus viridis*) and grey nurse shark (*Carcharias taurus*) as target species for spearfishers during the 1950s and 1960s. (*a*) Blue groper on the cover of the January 1953 issue of *Spearfishing News*. (*b*) Blue groper on the cover of the December 1953 issue of *Skin Diving and Spearfishing Digest*. (*c*) Grey nurse shark on the cover of the July 1967 issue of *Australian Skindivers Magazine*. (*d*) Grey nurse shark on the cover of the October 1969 issue of *Australian Skindivers Magazine*.

APPENDIX 2.2

Declines in target fish species: an insight into the perspectives of spearfishers

The demise of blue groper from the perspective of spearfishers

Recreational spearfishers also expressed increasing concern for declining eastern blue groper populations commencing from the first spearfishing journal we assessed in 1952 (Fig. 1 in main text; Table S2). In May 1952, Keith Vagg, a prominent spearfisher, magazine contributor and later associate editor of *Spearfishing News*, made a plea to readers that spearfishers only take enough blue groper for their needs and to allow the other fish to breed. He also suggested imposing a bag limit as a means of self-regulation, and reminded spearfishers that the primary objective of the Underwater Skindivers and Fishermen's Association (USFA) was the 'protection and propagation of fish' (Table S2).

Concern for blue groper populations continued and, by 1958, the scarcity of blue groper had alarmed numerous spearfishing bodies. These groups, under the initiative of Edward du Cros and Ted Louis (both prominent spearfishers, magazine contributors and USFA members), took their concerns to the government and requested a bag limit on the capture of blue groper. A bag limit of two groper was subsequently imposed. Four years later, in 1962, decline in blue groper numbers was still troubling spearfishers. A meeting of the Amateur Fishermen's Advisory Council (AFAC) discussed the problem of spearfishers killing adult blue groper, while line fishers removed juveniles. Ted Louis suggested imposing a one fish bag limit on all fishers. Warnings from spearfishers continued to emerge and in 1965 Edward du Cros reflected on the loss of eastern blue groper and notes that the case should be a learning experience. The USFA of New South Wales, with the recommendation of AFAC, then submitted a request to the government asking for complete prohibition on the

capture of blue groper. As of 17 January 1969, it was an offence for a person to have blue groper in their possession in New South Wales (NSW). This legislation for protection was enacted 17 years after the first concerns for blue groper populations were raised by the spearfishing community.

Table S2.2 Published comments/views by prominent spearfishers depicting their concern for eastern blue groper (*Achoerodus viridis*) populations from 1952 until their protection in 1969.

Year	*Publication/Issue*	*Author*	*Comments/Quotes*
1952	*Spearfishing News* (May 1952)	Keith Vagg	Keith highlights to members of the Underwater Skindivers and Fishermen's Association (USFA) that the first objective of the USFA is the protection and propagation of fish. He pleads that spearfishers take only enough blue groper for their needs and leave the others to breed. He suggests imposing a bag limit as a means of self-regulation '…the Association's first object is 'The protection and propagation of fish'. If we don't heed this object, the USFA will be 'Jack' in a very short time' 'I'm merely pleading that we take only enough for our needs and leave the others to get married and raise big happy families of big blue groper' 'If we are going to continue to spear groper, we shall have to forget the quoted golden rules and the 'If I don't spear it, some other B…..d will' kind of thinking, by imposing a bag limit on ourselves, and remembering that the first object of the Association to which you belong is: The Protection and Propagation of Fish'
1953	*Skindiving and Spearfishing Digest* (October 1953)	Keith Vagg (Associate Editor)	Keith Vagg discusses Rod McNeil's plea on behalf of blue groper in relation to their slow growth rates 'Rod is a conservationist and it was pleasing to read his plea on behalf of the blue groper in the September issue, in which he quotes Gilbert Whitley as estimating the age of a 30 pound blue to be about 30 years'
1958	*Australian Skindivers Magazine* (Jan/Feb 1963)	Ted Louis (USFA Secretary)	Underwater groups realize the scarcity of blue groper and, initiated by Edward Du Cros and Ted Louis, suggest to the Chief Secretaries Department that a bag limit be imposed '…the largest groper taken by line during the year was a nine pounder and that generally groper were very scarce indeed. The underwater groups have realised this fact for some time and suggested to the Chief Secretary's Department some four years ago that a bag limit be placed on this fish' A limit of two groper was subsequently enacted
1962	*Australian Skindivers Magazine* (Jan/Feb 1963)	Ted Louis (USFA Secretary)	A meeting of the Amateur Fishermen's Advisory Council (AFAC) further discusses the scarcity of blue groper. Ted Louis explains that blue groper are hard to target for line fishers because they swim into caves and snag them, while spearfishers use this behaviour to their advantage. Spearfishers target large fish, however, anglers tend to take juvenile groper. Ted suggests a one fish bag limit for all anglers 'This habitat is his downfall when pursued by spearfishermen, as he is simply speared and killed in his cave and presents no problem at all' 'It is not, of course, the spearmen only who are depleting groper stocks, as we often see anglers on the rocks with six or seven tiny brown groper' 'In my early days of spearfishing I went along with the general idea that puny man could not possibly upset a natural state of affairs such as fish life-cycles. I have had to change my ideas radically, as by observation I have seen it happen under my nose in this case'
1962	*Australian Skindivers Magazine* (Jan/Feb 1963)	Ted Louis (USFA Secretary)	Ted Louis explains that in the past groper were plentiful and sea urchins were less common. However, groper numbers have declined and sea urchins increased by as much as 300–400% 'During this five years past, there was no doubt in my mind that the groper has decreased in numbers and the sea-urchin increased as can be seen on any underwater dive, as the colonies have extended as much as 300 and 400%'

1965	*Australian Skindivers Magazine* (March 1965)	Ben Cropp	Ben has noticed a tremendous reduction in the fish population around such famous reefs as Nine Mile, Flinders and Long Reef. Where the spearfishers once met hordes of fish, there is now a vast emptiness. Ben notes that blue groper and cod have really suffered "In the past year I have noticed a tremendous reduction in the fish population around such famous reefs at Nine Mile, Flinders, Long Reef etc. Where the spearman once (only two years ago) met hordes of fish, he is greeted now by a vast emptiness. The blue groper and cod have really suffered' 'Our sons (and even ourselves in a few years) are not going to see the fish we have all been fortunate in hunting over the past years.' 'This fish shortage is due to several things which have rapidly increased over the past years; mainly the sudden increase of spearfishermen since the Sea Hunt TV era, the increased commercialism amongst spearmen, and the use of SCUBA for spearfishing.'
1965	*Australian Skindivers Magazine* (May, July 1965)	Edward Du Cros	Edward Du Cros proposes skindivers shift away from spearfishing to wreck diving, underwater photography and research work. He reflects on the loss of blue groper and notes that it should be a learning experience 'to avoid a decline or a debacle—for the future of our sport... a move, on the largest possible scale, to make the 'big things' in skindiving finding and exploring wrecks, underwater photography, and research work, tagging, etc.—with sharks. The proposal is to see whether a great effort to shift the emphasis away from spearfishing and to these three elements in skindiving would succeed.' 'I agree with George Davies that the blue groper episode in fishing history is symbolic of our folly.'
1969	*Australian Skindivers Magazine* (April/May 1969)	George Davies	Legislation submitted from the USFA of NSW to prohibit the capture of Blue Groper was recommended by the NSW AFAC to the Chief Secretary 'On January 17 the Chief Secretary, Mr Willis, acting on the recommendation of the NSW Amateur Fishermen's Advisory Council, advised that a complete prohibition on the capture of Blue Groper had been introduced in New South Wales.' 'This legislation, which had been submitted originally from the USFA of NSW, would take effect from the previously mentioned date' 'All skindivers are advised that it is now an offence to have a blue or brown groper in their possession.' As of the 17 January 1969, it was an offence to have a blue or brown groper in possession
1969	*Australian Skindivers Magazine* (July/August 1969)	John Gillies (Editor)	Recommended by the AFAC and the USFA, a ban on scuba fishing is introduced on the 27 June 1969 'The State Government has banned the use of self-contained underwater breathing apparatus – Scuba gear – for spearfishing.' 'the regulations had been recommended by the NSW Amateur Fishermen's Advisory Council, and had been endorsed by the Underwater Skindivers' and Fishermen's Association.'

The demise of grey nurse sharks from the perspective of spearfishers

In the early 1960s, shark hunting was promoted in magazines, books and films (Table S3). However, in the January 1965 issue of *Australian Skindivers Magazine*, contributor George Davies highlighted that, contrary to public perception, grey nurse sharks were not dangerous and that their populations were at risk of extinction. He criticized shark hunting films for encouraging the slaughter, and noted that wherever grey nurse populations were discovered, spearfishers promptly decimated their numbers. He also pointed out that the general public loved spearfishers for removing the threat of sharks.

In the May 1965 issue of *Australian Skindivers Magazine*, prominent spearfisher and filmmaker Ben Cropp noted that the killing of grey nurse sharks was quickly wiping out the species. He voiced regret that he helped to instigate the craze for killing sharks through his articles, books and films, and acknowledged the need for conservation. Cropp also noted that neither the general public nor the fisheries department of New South Wales would be interested in the conservation of grey nurse sharks (Table S3). In 1970, aware of the contribution of spearfishing to the decline in grey nurse populations, *Skindiving in Australia* magazine supported a ban on skindivers killing grey nurse sharks. The magazine also made the decision to stop publishing reports on their killing (Fig. 3 in main text). Warnings from the spearfishing community about the demise of grey nurse shark populations and the misconceptions surrounding sharks continued until a prohibition on taking grey nurse sharks was announced in November 1984 (19 years after the first concerns were raised by spearfishers).

Table S2.3 A chronology of important developments and published comments by spearfishers concerning grey nurse shark (*Carcharias taurus*) populations from 1959 until their protection in 1984.

Year	*Publication/Issue*	*Author*	*Summary/Quotes*
1962			Ron Taylor and Ben Cropp's film *Shark Hunters* is released
1963	*Australian Skindivers Magazine* (April/May 1963)	Ted Louis	Ted discusses the development of powerheads and experimenting with their use on grey nurse sharks 'We have recently been trying out a new weapon for shark destruction. It is a .303 calibre breech, which fits to the head of a handspear and a 1.5lb jolt sets it off. The idea is to load it like an ordinary handspear and hit a shark with it, the impact fires it and a projectile hits the shark where it will do most good.' 'The idea is not new, as several spearos are using a 12-gauge cartridge for a similar purpose. It all adds up to one thing and that is in a short space of time the spearman will have evolved a method of destroying a shark in an emergency and the weapon will be available to all for a very nominal cost.' 'Also needed are plenty of sharks to experiment on, and one of the most prolific places I know is Jervis Bay'
1964	*Australian Skindivers Magazine* (July/August 1969)	John Gillies (Editor)	Ben Cropp's book *Shark Hunters* is released. It details everything about shark hunting with spears and powerheads. It is re-released in 1969 'Ben Cropp, one of Australia's foremost authors on skindiving and allied subjects, has released his popular book, 'Shark Hunters'.' 'The author covers virtually every aspect of shark hunting, spearing the extra large fish, and while doing so traces his early experiences and attempts before the advent of the ultimate weapon, 'Shotgun for Sharks'.'
1965	*Australian Skindivers Magazine* (Various Issues)	Advertisements	Several Ron Taylor and Ben Cropp films about hunting sharks are released. Titles include *Slaughter at Saumarez, Shark Fighters, Revenge of a Shark Victim and Shark Safari*
1965	*Australian Skindivers Magazine* (January Issue)	George Davies (AUF Secretary)	Contrary to public perception, George highlights that grey nurse sharks aren't dangerous and that their populations are at risk of extinction. He criticizes shark hunting films for encouraging the slaughter and notes that wherever grey nurse populations are discovered, they are promptly decimated. He also points out that the general public love spearfishers removing the (perceived) threat of sharks 'Ron Taylor and Dave Rowlings received widespread publicity when they killed two 8ft grey nurses with spine shots and proved the much hated shark was at least vulnerable. This seemed to be the signal for a mass crusade against this so-called man-eating fast shark. Great schools were entirely exterminated in their secluded gutters. Yes, I was there bashing away at these 'man eaters' doing some great public service and soaking up a share of the glory from a public that wouldn't know the difference between a bream and a basking shark.' 'When harassed the nurse is even more docile that the 'wobby' and will avoid her tormentor' 'With the advent of the 'Big Boom' or 'Smokey Pokey', the lethal power of which seemed to lend courage to scores of skindivers who previously were uncertain of the long-toothed nurse, the slaughter of grey nurses rapidly increased and with a combination of aqualungs and explosive heads was beyond the calling of the sport. The general public loved it, the waters were being cleared of sharks, soon the menace of death on our beaches would be practically eliminated.' 'The shark-hunting spearmen were heroes. This was good publicity but nevertheless a sound case of false pretences.'

			'Recently I had the pleasure of viewing a recent underwater production by Ben Cropp. The presentation was perfect, the narration really good. Every detail was exceptional including the first thrust of the explosive head and the luckless 'nurse' spiralling to her doom. A procession of thrusts later I was nauseated. The general public, and these are the persons we have to please most, would perhaps be delighted. I had one feeling of revulsion for an orgy of senseless killing. My sympathy lies with the 'nurses'. There was not an ounce of sport in their systematic destruction.' 'It has reached a stage now where the location of a newly found school of 'nurses' has to be kept secret or the school quickly ceases to exist.' 'Let's not kid ourselves, the grey nurse could fast follow the path of the great white shark into the realms of the extinct.'
1965	*Australian Skindivers Magazine* (January Issue)	Buggy Beaver	This club report mentions the influence Ron Taylor and Ben Cropp's shark hunting films are having on spearfishers 'Robbie shot his first real shark, a 4 foot grey nurse, but after seeing Ben's new film Robbie was back in the water, but only resulted in one 5 foot nurse.'
1965	*Australian Skindivers Magazine* (May Issue)	Ben Cropp	Ben reflects on the criticism by George Davies in the January issue. He agrees that grey nurse sharks are being wiped out and expresses regret that he helped to instigate the shark killing craze 'I agree with you wholeheartedly that the senseless killing of these sharks is quickly wiping out this species. I know I helped instigate this craze for killing sharks and led such killings many times.' 'I am looking to other forms of spectacular scenes with the grey nurse—without having to kill them. My only worry is finding a tame school which will co-operate—or finding a school of grey nurse at all.' 'Neither the general public nor the Fisheries Department are going to be interested in the conservation of grey nurse.'
1975			The movie *Jaws* is released in Australia at the start of summer
1975	*Skindiving in Australia & New Zealand* (Vol. 5, No. 4)	John Harding	John discusses the misconception of sharks within the community and the media sensationalism that has coincided with the release of the movie *Jaws* 'In that era shark attacks were occurring at an average of one or two each year, sufficient to keep the media interested in perpetuating the great shark myth of Australia.' 'It is this false portrayal of shark behaviour which annoys and upsets the dedicated attempts by many individuals professionally involved with the ocean. Entertainment in films is essential, but many people believe what their eyes see, and in the case of *Jaws*, it will be a major set-back for marine wildlife experts and many others associated with the sea.' 'Originally I had intended to write on how the shark menace had almost faded away on the east coast, as compared with the menace which apparently existed forty and fifty years ago. However newspapers are in business to sell more papers. Being accurate in an intelligent persons mind is certainly not essential.' '*The Daily Telegraph* published my original text almost word for word on the first two days of the 'Shark – A series which could save your life' serial. However on the third day 90% of the text, credited as mine, was written by an unknown staff reporter. It was the most misleading and inaccurate heap of rubbish about sharks I've seen in years.'
1977	*Skindiving in Australia & New Zealand* (Vol. 7, No. 2)	John Harding	John discusses powerheads and how they were originally intended for defence, yet were mostly used to attack sharks 'Explosive powerheads are designed to protect divers from the remote possibility of a shark attack. Most powerheads have been used by skindivers to attack sharks. There are very few cases where a powerhead has been used to save the diver from the rushes of an 'attaching' shark. Unfortunately the truth is that powerheads

			themselves are far more dangerous than most sharks.' 'The commercial manufacture began in Australia in 1962.'
1984	*Skindiving in Australia & the South Pacific* (Vol. 15, No. 3, 1985)	Barry Andrewartha (Editor)	The NSW Department of Agriculture, with the support of the NSW Amateur Fishermen's Advisory Council and the NSW Australian Underwater Federation, places a ban on the capture of grey nurse sharks. Skindiving magazine notes that it has supported a ban on divers killing grey nurse sharks since 1970 'The ban, gazetted under the Fisheries and Oyster Farms Act, 1935, will protect the declining populations of grey nurse' 'Fishermen thought they were doing the community a favour by eradicating these sharks. But the grey nurse is not known to pose any threat to human life' '*Skindiving* Magazine has supported the ban on divers killing grey nurse sharks for the past 15 years and congratulates Dr Peter Ayres and his department for supporting this ban.' The prohibition of taking grey nurse sharks is announced in November 1984.

APPENDIX 3.1

The decline in coastal fish populations and the rise of the 'conservation era'.

Table S3.1 Published commentary on spearfishing trends, declines in fish populations, declines in spearfishing participation and the emergence of the conservation era.

Year	Issue	Author	Commentary and Quotes	Topic
1969	Australian Skindivers Magazine, January	Spencer Wharton	"The spearman of yesterday is discarding his gun and now captures his fish on film. Conservation is a popular topic of discussion, with proposals of bans on the taking of particular species of fish, to complete marine flora and fauna sanctuaries. Each summer many sets of basic diving equipment are sold to men, women and children eager to see the underwater world for themselves. Modern design and manufacturing techniques have resulted in cheap, reliable scuba equipment, enabling divers to considerably increase their time underwater."	Conservation era
1971	Skindiving in Australia, Volume 2, Number 1	Peter Kemp	"Nowadays most spearfishermen realise the futility of killing these giant fish as they are not considered suitable for eating and usually after a lot of hard work the fish is wasted. In Queensland the spearfishing association is becoming concerned with the disappearance of the groper"	Fish decline
1971	Skindiving in Australia, Volume 2, Number 1	Peter Kemp	"Flinders Reef is three or four miles north of the Cape and is awash all the time. There are no big reef fish here now but pelagic fish are often seen especially Spanish mackerel."	Fish decline
1971	Skindiving in Australia, Volume 2, Number 2	Barry Andrewartha	"With the conservation theme being promoted daily by press, radio, T.V., magazines, films, etc., it is little wonder that we all are becoming more and more conservation minded, perhaps more than some of us realise! This in itself is a good thing, as long as we take a realistic look! Some so-called conservationists would have us as vegetarians not stepping on ants or killing flies - What we must reach is a	Conservation era

			practical level. The actions we as skindivers take will be only minor compared to the continued damage being done by industrial and agricultural pollution, mining and mineral research, professional fisherman and even the everyday angler. But we too must do our share towards providing a golden future for our marine world. Steps we must take immediately is promote spearfishermen to take only what they can eat and most important of all the A.U.F. and it's state associations must remove all so-called "rubbish" fish from their competition score sheets. The continued killing of these thousands of fish, year after year is as unexcusable waste that can't be pardoned. An uneducated member of the public seeing these fish being "disposed of" at the end of each competition must have many questionable thoughts on the ethics of these competitions in such a conservation minded society! Through our magazine, books, films etc. we have the chance to show the Australian public what a wonderful and unique world we have "beneath Australian seas".	
1973	Skindiving in Australia, Volume 3, Number 2	Clarrie Lawler	"Lately, we hear more and more of divers and ex-spearfishermen becoming bored with just diving or chasing the fast disappearing fish and "wanting to do something". The "something" they usually envisage is helping science or exploration in some dramatic way."	Conservation era Fish decline
1973	Skindiving in Australia, Volume 3, Number 3	Edward W. Shipsey	"A great many underwater hunters are exchanging their spearguns for cameras, capturing on film instead of stainless steel. Is it because we are becoming more conservation minded, or is it perhaps because the number of fish species available is rapidly declining? At the moment anemones, corals, sponges and nudibranchs are still there to give us some beautiful pictures, but what will we be able to photograph in twenty, or fifteen, or even ten years time? Silt covered rocks don't move, but they are not very photogenic either."	Conservation era Fish decline
1973	Skindiving in Australia, Volume 3, Number 4	George Davies	"I then advised that Australia was vitally concerned with the present system of World Spearfishing Championships as unrestricted competitions and in view of the increasing opposition throughout the world to competitions, particularly from skindivers and skindiving organisations, it seriously recommended that new ideas had to be implemented as a conservation measure. I	Conservation era

			outlined the Australian method of selective hunting as opposed to unrestricted spearfishing and requested the support of all member nations in adopting restrictive measures in their own countries and in World Spearfishing Championships."	
1977	Skindiving in Australia & New Zealand, Volume 7, Number 1	Alan Badger	“My enthusiasm comes from the new competition which was included at the Australian Skindiving Convention Cairns, that being the Photographic Comp – but this one with a difference. Run almost as a spearfishing type competition where competitors start and finish at a given time and are not permitted to use breathing apparatus. The emphasis or scoring is based on recognisable species rather than photographic skill or technique.”	Conservation era
1977	Skindiving in Australia & New Zealand, Volume 7, Number 1	Dale Chapman	"This was the first time the event had been included and to see champion spearos like Allan Badger, Ralph Whalley, Bob Hart and Ethel Everett exchange their guns for cameras, has got to be a vote for conservation."	Conservation era
1977	Skindiving in Australia & New Zealand, Volume 7, Number 3	Marin Advertisement	"In the interests of Conservation DON'T shoot a fish unless you intend to eat it."	Conservation era
1977	Skindiving in Australia & New Zealand, Volume 7, Number 4	Ross Isaacs	"Divers have found many of the large reef fish and have speared some areas out. Until this area is declared a marine park a great deal of the wonderments of the reef and an important part of the ecosystem may not return. Philosophies are gradually changing and instead of spear gun triggers, divers are now pressing a shutter release to shoot their catch, preserved for all time in the emulsion of the film and still alive, for the next person who dives to enjoy."	Conservation era Fish decline
1980	Skindiving in Australia & New Zealand, Volume 9, Number 6	Barry Andrewartha	"Major importers of diving equipment report a 50% fall in the sales of spearguns in the last financial year! - maybe another sign of the times?"	Conservation era
1980	Skindiving in Australia & New Zealand, Volume 9, Number 6	Editor	“On the 18th March the Inaugural Victorian Film Fishing Championships were held at Heards Bay. Film fishing competitions involve the skin diver taking up to 20 photos using standard snorkel diving equipment.”	Conservation era
1989	Sportdiving in	John Sarich	“Myself being a very keen spearfisherman, I	Conservation era

	Australia & the South Pacific, October		have enjoyed the sport for over 10 years, and recently I have been trying to track down a spearfishing club that has competitions, and I have had no success, until a scuba shop that stocks your magazine suggested I wrote to you.”	
1991	Sportdiving in Australia and the South Pacific, October	Barry Andrewartha	"From 1966 through 1974 we returned every year to enjoy the beauty, the serenity and the great diving this region offered. After a gap of 18 years I returned to Seal Rocks, this time without my speargun. Accompanying me on this journey of re-discovery was my 14-year-old son Jesse, who as a qualified scuba diver was looking forward to his first dives in northern New South Wales. While there are three top-quality dive operators in the Forster-Tuncurry area, for nostalgic reasons we dived with my old spearfishing buddy's "little brother", Denis Kemp. Over a 4-day period we dived reefs off Forster/Tuncurry area and the Seal Rocks, Edith Breaker reef areas off Sugarloaf Point area. Sea conditions were great but owing to prior heavy rain in the area, visibility was down. While the diving was still brilliant, the large cod and other reef fish weren't as good as I remember. The big schools of pelagics; Kingfish, Mullaway, Tailor and Trevally were also fewer, although these fish are affected by currents and water temperatures there may have been other reasons for their absence. I'm sure the reef fish populations decrease was due to the damage we did and all those who followed us.”	Fish decline
1994	Australian Freediving and Spearfishing News, No. 4 Spring	Robert Torelli	“It would appear that our publication is indeed becoming quite widespread and well received. Furthermore, it would seem that it has acted as a bit of a stimulant and encouraged the formation of another 3 more active Free Diving Clubs in the east coast of Australia. The Blue Water hunting scene within Australia has undoubtedly been helped along the way with the photographs and articles in recent issues by the American Blue Water Boys. Spearos from all states are rigging up with their big “wopper stoppers” to selectively breath hold and hunt game fish with mixed results. Hopefully these spearos will show us their skills next April in Australia’s first ever Invitational International Blue Water meet at Coffs Harbour NSW. In October I’m off with the Australian Spearfishing Team to Peru to compete in the World Spearfishing Championships after 20-years of non-	Re-emergence of spearfishing Pelagic spearfishing

			representation by Australia.”	
1994	Australian Freediving and Spearfishing News, Number 4	Kelvin Aitken	"Blue water spearfishing is the ultimate apnea hunting discipline. Working deep reefs or open ocean for pelagic species is a demanding sport. Quite often the bottom is not visible, the prey is elusive and the conditions biased against success. Species such as Spanish, tuna and kingfish are swift and cautious requiring a disciplined body and mind to succeed. The berley does not just bring in baitfish to attract the pelagics or spread an appetising aroma for the open water nomads, it also summons the top predators such as whalers and tiger sharks. For the spearo the effort is considerable but the rewards can be great."	Pelagic spearfishing
1994	Australian Freediving and Spearfishing News, Number 4	Adam Smith and Ian Puckeridge	“Sometimes they (coral trout) are one of the easiest fish to spear as they lie virtually motionless beneath a plate coral or beside a bommie or come cruising in to investigate a diver.”	Coral reef spearfishing
1995	Australian Freediving and Spearfishing News, Number 6	Advertisement	"The ecologically safe way to fish" "For centuries man has been able to spearfish for his own needs without harmful effects on the environment. Selective spearing of fish is the most environmentally SAFE method of gathering food from the sea and will ensure the continued health of the worlds oceans.”	Re-emergence of spearfishing
1995	Australian Freediving and Spearfishing News, Number 6	Tom Collins	"the lack of decent Coral Trout was obvious. We were still spearing them up to 5 lbs, and couldn't help but notice that their numbers, compared to 5-10 years ago had decreased considerably. It is our opinion that the major reason for this drop in numbers is due to the professional fishing boats which continually work these reefs with up to 8 'Doreys' (aluminium dingies). I've seen them out on the reef going from bomey to bomey catching every trout off each!"	Coral reef spearfishing Fish decline
1995	Australian Freediving and Spearfishing News, Number 6	Tom Collins	"I am very pleased that there is starting to be more publications on spearfishing as it has been shunned for too long"	Re-emergence of spearfishing
1997	Australian Freediving and Spearfishing News, Number	Tom Collins	"Again we noticed a distinct lack of trout up in the shallow water due to the pro's."	Coral reef fish decline

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1997	Australian Freediving and Spearfishing News, Number 12	John Harding	"Fish life on the Great Barrier Reef is disappearing at a rapid rate. Fuelled by skyrocketing values if sold alive for export to Asia, some fish are selling at AUS $180 per kilo at fish markets and more than double this in restaurants. Coral trout are now almost a rare species. Scientists find it difficult to believe how common this species was 35 years ago."	Coral reef fish decline
1997	Australian Freediving and Spearfishing News, Number 14	Damien Mullall	"The next day saw us hopping around from reef to reef getting trout, mackerel, wrasse, humpheaded parrot fish and anything else that moved." "We didn't have much luck with the tuna but again the freezers were filled with reef fish."	Coral reef spearfishing
1997	Australian Freediving and Spearfishing News, Number 14	Terry Maas (USA)	"A generation ago, spearfishers and everyone else viewed the ocean's resources as limitless." "From the mid '60s through the '80s the sport of spearfishing entered what I call its 'dark ages'." "In spite of the bad publicity, spearfishing is regaining popularity. The majority of spearfishers have always been responsible sportsmen. Under the intense pressure from anti-spearfishers, and through our own increased appreciation for the fragile limits of the ocean environment, we have made changes. Divers take only what they can eat. Our quarry has shifted to abundant species which grow rapidly, and away from slow-growing, vulnerable and sedentary species. Most of us limit our hunting to freediving. Spearfishing contests are no longer free-for-all shoot-'em-ups. Targeted species and their numbers are tightly regulated and contest limits are generally well below local game laws. We rotate venues to minimise our impact on any given location."	Conservation era International perspective Re-emergence of spearfishing Spearfishing trends
1999	International Freediving and Spearfishing News, Number 19	Barry Andrewartha	"I believe that as responsible citizens we have an obligation not to spear home-ranging reef fish at popular scuba diving locations. With hundreds and hundreds and hundreds of miles of coastline, islands and reefs we should avoid confrontation with scuba divers. Unfortunately spearfishing competitions bring large groups of spearos together for starts and weigh-ins and create a bad impression at scuba diving locations - it's just asking for confrontation. The facts are most divers spearfish species during spearfishing competitions that they would never spear on a day of recreation spearing, regardless of whether they are good eating	Spearfishing ethics

			or not. If we are all honest with ourselves that regardless of pollution, other forms of fishing, etc. many of the barren reefs of today that once had lots of fish life on them, our contribution to their demise is a major part of the problem. Spearfishing a fish or two for sport and a meal is fine, spearing a wide variety of fish, many just for points on a score sheet is questionable in this day and age. As you are aware, CMAS, the World Diving Association this year disassociated themselves from spearfishing competition for the first time since their inception... a sign of the times maybe!	
1999	International Freediving and Spearfishing News, Number 19	Brett Illingworth	"Thirty-two signed on. Twenty-seven weighed in. An encouraging sign was the fact that a large proportion of the competitors were first timers. These first timers will hopefully form the foundation for the continuing resurrection of Victorian competition spearfishing."	Re-emergence of spearfishing
2001	International Freediving and Spearfishing News, Number 24	Steve Barsky	"Dear Barry, In the past few years, freediving and spearfishing has seen a tremendous revival in the United States. Today's freediving spearfisherman is more conservation minded and savvy than ever before."	Re-emergence of spearfishing International perspective
2001	International Freediving and Spearfishing News, Number 24	Mark Searl	"How the times have changed. With the introduction of bluewater videos and magazines.... New equipment etc... In the last 10 years or so the amount of marlin captured has increased. Even 210% Ted Lougher managed to land one in an Aliman Shield comp this year... " "...in my opinion only, with the introduction of tag and release by game fishermen and the slow change of attitude by the average spearfishermen these days, divers are starting to target more pelagic fish, marlin, tuna, dolphin fish etc. The mowies, leatherjackets, rock cockies etc. may start to get some sort of reprieve and the protected species of groper and black cod are starting to return in numbers and with the introduction of bag limits on most species, I think the sport of 'underwater fishing' may have a future after all."	Pelagic spearfishing
2001	International Freediving and Spearfishing News, Number 27	Barry Andrewartha	"During the late 1980s and early 1990s spearfishing as a sport was a 'dirty word' and had no future and no credibility in the foreseeable future. In 1952 there was no such thing as a dive shop. With the advent of dive shops in the 60s and 70s it was as if by mutual agreement that sports stores	Conservation era

			would not sell spearfishing gear. Scuba went on to become a multi-million dollar industry and spearfishing faded into obscurity."	
2003	International Freediving and Spearfishing News, Number 32	Rob Torelli and Barry Andrewartha	Rob and Barry emphasise that the sport of spearfishing is growing and expanding rapidly with more manufacturers, importers/distributors and retailers of equipment.	Re-emergence of spearfishing
2003	International Freediving and Spearfishing News, Number 32	Adam Smith	"I would like to help lead the Australian Underwater Federation (AUF) into the 21st Century. Historically, the focus of underwater activities has been competitions and in the future we need to include a greater emphasis on recreation, education, training, research, conservation and communication. Spearfishing is a safe, regulated, selective and ecologically sustainable method of catching fresh fish."	Re-emergence of spearfishing
2003	International Freediving and Spearfishing News, Number 34	Cameron Kirkconnell	"As much as we all love to hunt the crystal clear waters of the reefs, the bluewater and pelagics are what most of us have come for."	Pelagic spearfishing Coral reef spearfishing
2005	International Freediving and Spearfishing News, Number 40	Luke Downie	"We plan our expedition so that on our way back in from the Coral sea we can shoot our quota of table species. The system was open to us for the last 4 days, so what better time to run a competition for the most amount of trout."	Coral reef spearfishing
2005	International Freediving and Spearfishing News, Number 43	William Stares	"One of the ideas I have for another piece is about the lowly parrotfish. I think certain parrotfish are under-rated as a food fish and we have picked up a couple of awesome recipes along the way that are suited perfectly to its bland white flesh."	Coral reef spearfishing
2007	International Freediving and Spearfishing News, Number 51	Barry Andrewartha	"Back in 1993 spearfishing as a recreational activity was the 'bad guys' of the marine world. Scuba divers and the professional diving arena were 100% anti-spearfishing and the nation wide lobby to ban spearfishing was extremely strong. I was then editor of Sportdiving Magazine which was launched in 1970 and was started as a spearfishing magazine. However within 18 months it had transgressed to a 100% scuba diving magazine due to lack of support from the spearing market and total support from the scuba industry."	Conservation era

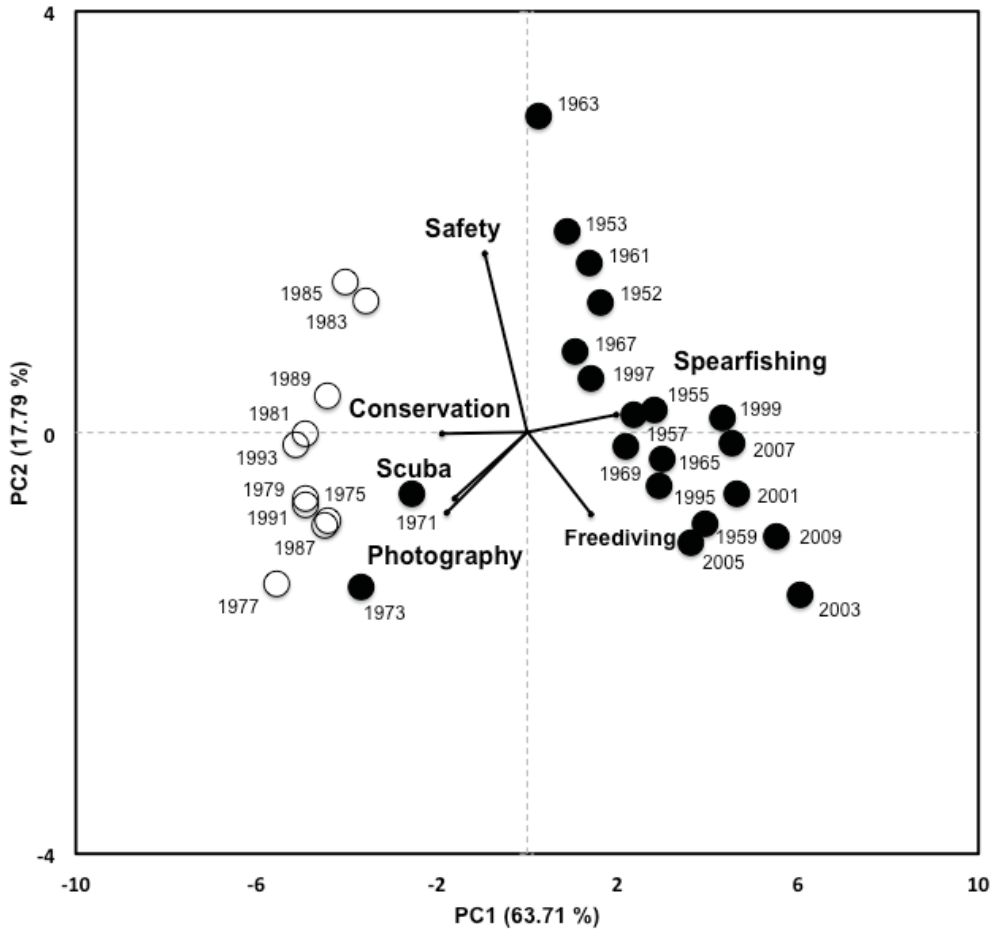

Figure S3.1 Principal component analysis on the proportion of the six main topics represented in magazines in each year. Closed symbols represent years included in analyses and open symbols represent years in which spearfishing catch data was insufficient for analyses. The years 1971-1993 are characterized by the topics ‘conservation’, ‘SCUBA’ and ‘photography’, and separate strongly from all other years along PC1 (63.71%). All other years are characterized by ‘spearfishing’. Note that 1971 and 1973 are transitional years that contained sufficient spearfishing data for analyses.

APPENDIX 3.2

Trends in spearfishing: additional insights.

Table S3.2 Excerpts from a magazine article that illustrate trends in recreational spearfishing from the perspective of spearfishers.

Downie, L. (2011) Frog Dive: spearfishing the Coral Sea. Fishing Monthly. Accessed 6th February 2014. http://www.fishingmonthly.com.au/Articles/Display/10532-Frog-Dive-Spearfishing-the-Coral-Sea **Excerpts**
"In the past 10 years the sport has come a very long way in the equipment used, the locations visited and in the species that are targeted."
"Technology also plays a big part, as it does in line fishing. Areas all of us thought were too far or treacherous to reach in the past, are now seeing line fishers and spearfishers encroaching into new frontiers."
"Just like any type of trip the weather plays the most important role and it determines when and where we can venture to."
"You can imagine how difficult it is with four blokes in a tinnie with massive amounts of equipment trying to get to the exposed sides of the reefs to encounter as many pelagic fish as possible. And we are after pelagic fish! So the wind and weather forced us to spend the first five days within the protection of the Swain Reefs system."
"Just like all fishers, we still wanted to bring home some table fish for the weeks after the trip. So spending time in the Swains provided us with that opportunity."
"Of course the favourite is coral trout, along with all the edible demersal species such as the emperor family, jobfish, Spanish mackerel, some cod species, giant trevally and generally most table fish."
"Equipment plays a major role in this sport. Each diver will be wearing a mask, snorkel, massive fins and socks, a 3mm 2 piece wetsuit, weight belt, two knives, and gloves. They also have attached to their belt a whistle and a surface marker buoy in case they are separated from their mates and the tinnie. Then their terminal gear consists of a big speargun of at least 1.3m, sometimes up to 1.6m."
"On the first drift of the first day at Frederick 1 boat witnessed over 40 wahoo, but seeing them doesn't mean that we could land them."
"Many of these species are not present on the wider reefs, but for a spearfisher, the dream to land a pelagic fish such as a sailfish, wahoo or dogtooth continues to draw them back year after year."

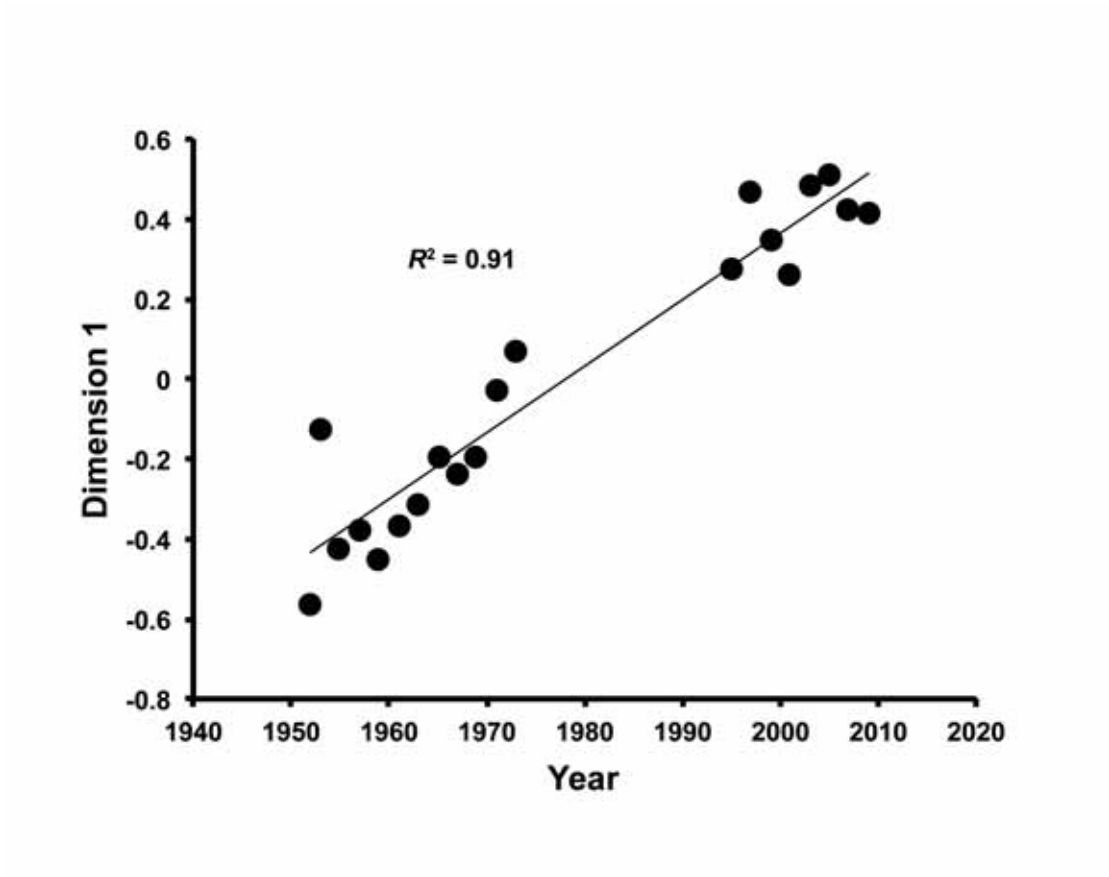

Figure S3.2 Values from dimension 1 of the multidimensional scaling analysis (Figure 4a) plotted against time. The linear regression model suggests that the spread along dimension 1 is explained by time.

APPENDIX 4.1

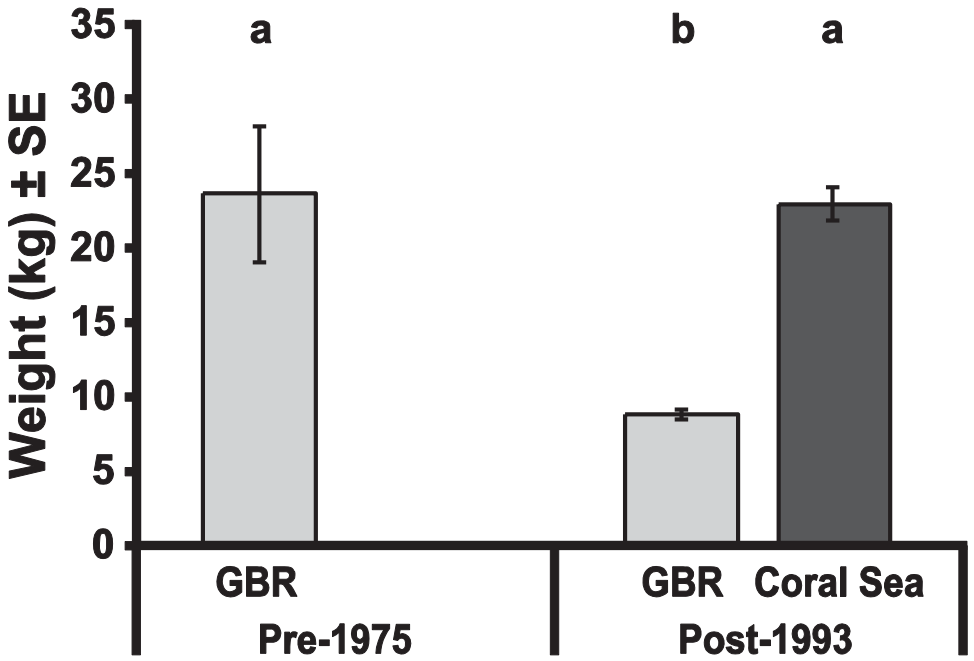

Figure S4.1 Mean weight ± SE of reported trophy fish captures on the GBR from 1965 to 1973 (pre-1975), and on both the GBR and in the Coral Sea from 1995 to 2009 (post-1993). Homogeneous subsets are indicated by letters.

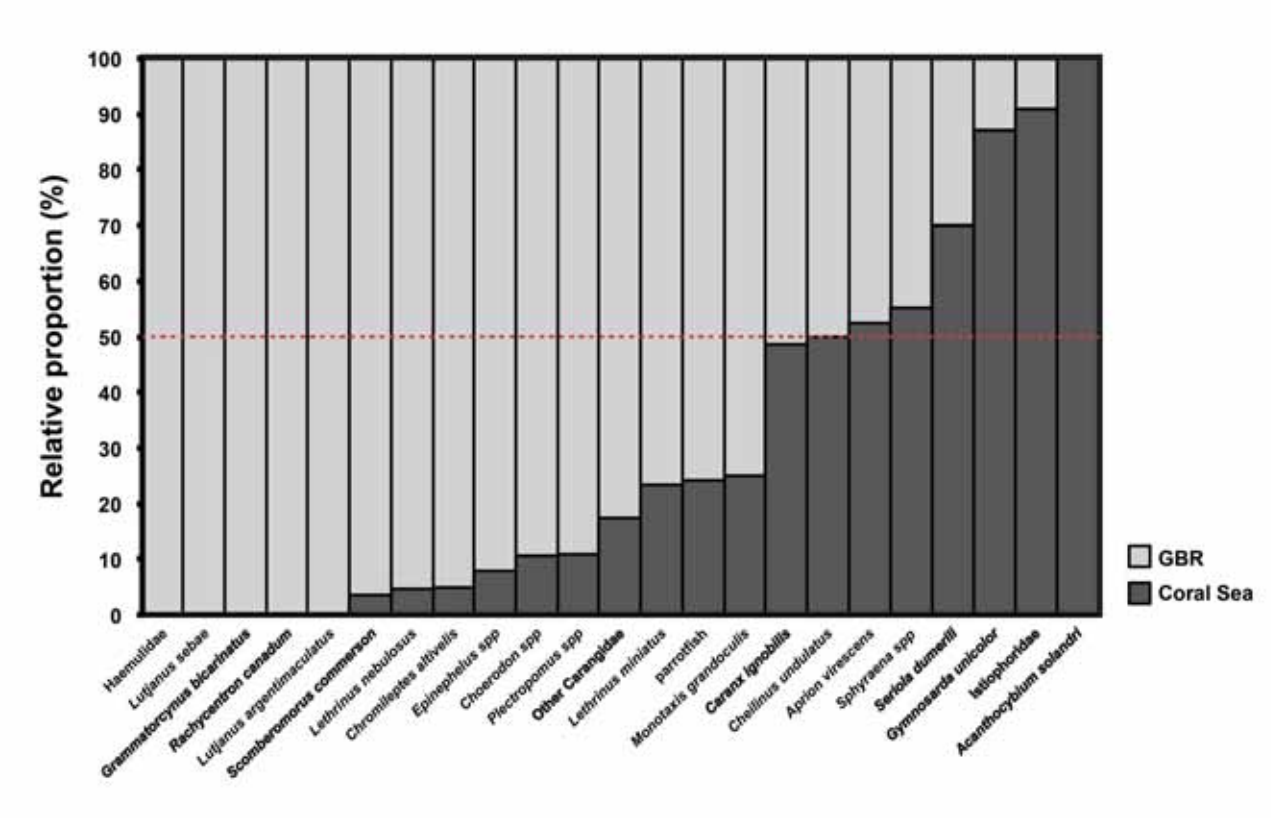

Figure S4.2 The relative proportions of the 23 most commonly reported fish species by spearfishers on the Great Barrier Reef (GBR) and the Coral Sea. Pelagic and semi-pelagic species are indicated in bold type.

Figure S4.3 Images depicting trophy reef and pelagic species. (*a*) Maori wrasse (*Cheilinus undulatus*) weighing 72 kg chased into a cave and speared on Hayman Island (Gannet Cay) GBR in 1965. (*b*) Queensland groper (*Epinephelus lanceolatus*) weighing 159 kg speared at South Keppel Island GBR in 1969. (*c*) Dogtooth tuna (*Gymnosarda unicolor*) weighing 81 kg speared at Kenn Reef in the Coral Sea in 2005. (*d*) Wahoo (*Acanthocybium solandri*) weighing 50 kg speared in the Coral Sea in 2007. Images (*c*) and (*d*) courtesy of Barry Andrewartha at *International Freediving and Spearfishing News*.